PLATE

Product Lifetimes And The Environment

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September 18–20, 2019
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Nils F. Nissen
Melanie Jaeger-Erben (eds.)

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How to Stimulate People to Take Care of Products? – The Development of a Toolkit for Designers

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Keywords: Product Longevity; Consumer Behaviour; Behaviour Change; Design Toolkit.

Abstract: Taking care of products is an important aspect of sustainable consumer behaviour, because it is an appropriate approach to prolong products' lifetimes. Although consumers in general agree on this and demonstrate a general motivation to take care of their products, previous research has shown that they struggle to repair, maintain or treat their products carefully in daily life. Design has the potential to increase consumers' product care activities, but more knowledge and distinct strategies are needed by designers to purposefully design for this behaviour. We used three different approaches – a workshop with design students, an analysis of already existing products and services that have implemented aspects of product care, and an ideation session – to create eight strategies and 24 sub-strategies that can stimulate product care through design. These eight strategies are *informing, enabling, social connections, appropriation, control, awareness, antecedents & consequences,* and *reflecting*. To support designers in the implementation of these strategies, we transferred these strategies into a toolkit, which can be used in the product development process of different kinds of products. This paper describes the development of the product care strategies as well as the Product Care Toolkit.

Introduction

Keeping products in use for a longer period of time is an important step towards the Circular Economy (Ellen MacArthur Foundation, 2013). One possibility to extend products' lifetimes is to take care of them. Product care is defined as any practice performed by consumers that prolongs a product's lifetime, such as repair activities, maintenance, adaptation of an existing product according to consumers' needs (such as modifying the size of clothing) and executing measures that aim to prevent product damage (Ackermann, Mugge, & Schoormans, 2018). Product care can be conducted by both the consumer or a service provided. Nevertheless, in both cases, product care is initiated by the consumer, so he/she plays a crucial role. Research has shown that consumers do not lack the general motivation to take care of their everyday products, but still struggle to do so (Ackermann, 2018). More knowledge is needed on how design can contribute to the desired change in product care behaviour. This paper addresses this gap by (1) developing and researching a wide array of design concepts and ideas that in some way stimulate product care, (2) categorising them into different product care design strategies, and (3) translating this knowledge into a toolkit that supports designers who wish to implement product care into their service and product design.

The Need to Stimulate Product Care

Several design approaches, such as van Nes and Cramer's (2005) Design for Repair & Maintenance principle or the Design for Ease of Repair and Maintenance principle (Bakker, den Hollander, van Hinte, & Zijlstra, 2014) propose to facilitate product care through the implementation of specific design solutions, such as the use of standard tools or the avoidance of glued joints. Although these approaches are an important angle to design for product care, they only focus on the product itself while disregarding the crucial aspect of consumer's motivation and behaviour. The latter will, however, in the end determine whether according action is taken or not, that is if the consumer takes care of his/her product in daily life.

Prior research on product care (Ackermann et al., 2018) used the behaviour model by Fogg (2009) to describe the necessary means to increase product care among consumers. Based on this model, people need motivation for behaviour to occur, but also need to feel capable to carry out these activities. Finally, triggers – small events or signals that enhance the motivation or ability at a certain point of time – are important for people to initiate activities. In general, people are motivated to take care of their products, but still struggle to integrate these activities into their daily lives (Ackermann, 2018). In order to tackle this issue and to address product care to its full potential, we believe that product care behaviours should already be considered when a product is still in the design phase. Thus, the aim of this study was to explore how product care can be stimulated via design, while by focusing on the consumers' perspective. For the practical application of designing for product care, we aim to teach designers about product care and provide them with strategies to stimulate product care through the design of the product or related services.

Method

We aimed at first developing design strategies for product care, which could then be translated into a toolkit. To identify different ways to enhance product care, three different sources of inspiration were used to ensure a broad range of ideas and concepts. The first one was a workshop with four design students and one design professional. As the strategies were meant to support designers, we found it important to include them in our process. Some days prior to the workshop, we sent an overview of seven types of product care to the students. This list was based on prior research (Ackermann et al., 2018) and included the following activities: repair, preventive measures, product revival, creating something new/different, instructed handling, mindful handling, and routine acts. With this knowledge, the students were asked to think about two products: One product that they take care of, and another product that they do not take care of. During the session that lasted around 2.5 hours, the participants presented their two products to start the discussion about product care. Three different rounds of ideation followed: In a first ideation round, they created ideas for each type of product care. In the second round, ideas to stimulate care for the products they brought with them as not being cared for, were developed. In the last round, ideas for a range of six different product categories (based on Ackermann et al., 2018), such as household appliances, consumer electronics, and furniture were collected. The workshop was wrapped up with a preliminary clustering of the 140 ideas.

Secondly, an extensive research of already existing products, services and concepts that support product care was conducted via the internet, by asking friends and colleagues and based on prior experiences. By doing so, we also gained insights from solutions that had been on the market for several years. This research led to the collection of 76 care solutions. Thirdly, an individual ideation session was conducted by one member of the research team, based on her knowledge about product care and about already existing concepts. She aimed to find ideas for the six different product categories, for the seven types of product care and for the five senses (sight, touch, hearing, smell and taste). Her ideation session resulted in another 63 ideas to stimulate product care.

This phase ended with 279 new ideas and already existing solutions to stimulate product care through design. As this number is too large for successful implementation in a design tool, it was decided to translate the solutions to more general, superordinate design directions that can be used by designers. To identify these design directions, the ideas and concepts were first clustered individually by two researchers based on correspondence between the different solutions in the way product care behaviour was encouraged. Afterwards, these researchers discussed their clusters with each other and reached consensus on the final 8 strategies and 24 sub-strategies.

Results: Design Strategies for Product Care

Eight strategies with 24 sub-strategies were identified as possible ways to stimulate product care (see Table 1).

strategy	sub-strategies
informing	static info
	interactive info
	physical information
enabling	providing flexibility
	providing necessary means
	providing a service
social connections	social connections as a result of product care
	social connections as facilitators for product care
	shared ownership

appropriation	personalization
	ever-changeable products
	creative change
control	product takes initiative
	product handles product care itself
	unconscious takeover
	forcing product care
awareness	push messages
	product changes in appearance
	product changes in functionality or performance
antecedents & consequences	anticipating effects
	after-effects
reflecting	meaningful memories
	showing traces
	experience of the product care activity

Table 1. Strategies and sub-strategies.

Informing is related to different kinds of information. Besides already well-known means, such as written manuals and instructions, this strategy can also be implemented through interactive means, such as online tutorials, workshops for consumers etc., that can be offered as a service by the producer. The overall aim of this strategy is to heighten consumers' knowledge on product care to facilitate the care activities.

Enabling facilitates product care activities in a more practical way by offering the right tools together with the product at purchase. Another part of this strategy is to enhance the flexibility for repair and maintenance by designing the product in a way that standard tools can be used. The establishment of a network of service providers is also a way to enable product care.

Social connections describes the facilitation of product care through social connections. Specific communities can support consumers in their care activities, such as repair cafés or shared private garages to work on cars. Social connections can also be seen as the result of product care activities when interactions are created through product care. Shared ownership, which means that a product is used by several consumers, is also part of this strategy, because the users can feel obligated to take care of the product so that they do not experience social rejection.

Appropriation describes the adaptation and/or personalization of a product according to the consumer's needs. This can be achieved by modular, ever-changeable products that allow the replacement of certain parts when an upgrade is desired. Appropriation also describes a product design that encourages the consumer to change the product in a creative way, such as upcycling and do-it-yourself activities. As a consequence of these creative activities, the consumer will feel more attached to this product and thus will take care of it.

Control can also stimulate product care and can be applied with different intensities: This strategy ranges from products that start the initiative for product care themselves. Some examples are a product that automatically opens when it needs cleaning or a product that refuses to work if it is not being cared of. In other cases, the product encourages the consumer to take care of it regularly, so it can be seen as an unconscious take-over of control, as product care becomes a habit. Another possibility is the use of materials that to a certain degree take care of themselves, such as self-healing materials.

Awareness is especially relevant for products that consumers often forget to take care of. Simple reminders, such as an alarm on the smartphone or an e-mail by the service provider, can make the consumer aware of the need to take care of his/her product. Furthermore, the product's appearance might change, such as a surface that looks unappealing when it is not being cared for. Also, a decrease in the product's functionality can raise the awareness.

Antecedents and consequences of product care – but also of non-care – can be communicated to the consumer. For example, the advantages of a well-maintained bicycle, such as less effort while cycling, can motivate the consumer to conduct these care activities. When a product is especially shiny or well working after product care, it might also motivate the consumer for future care activities.

Reflecting refers to meaningful memories and traces that are created through the interaction with the product in general and lead to a higher motivation to take care of it. An example might be a skateboard with scratches, which can be seen as traces of usage. This valuable memory can also be created through the care activity itself. For example, painting a wooden piece of furniture can generate a unique value for the consumer, because he/she remembers that activity in a positive way. Another corresponding aspect of reflecting is the gamification approach: It connects the care activity with fun and pride, which can stimulate product care activities in the future.

The Product Care Kit

These results were then transferred to the Product Care Kit (Figure 1). The aim of this toolkit is to teach designers about product care and provide inspiration on how to design for it.
The toolkit is designed as a card-set and helps designers to understand the many aspects that can be relevant when designing for product care. Therefore, it consists of cards describing the seven different types of product care activities and eight cards which explain the different design strategies and their substrategies. For easy recognition, there is also a cartoon figure on each of the cards. The process of working with the Product Care Kit is flexible, so there are no strict rules or processes to be followed and not all cards have to be used each time. Instead, the cards are meant as triggers for providing inspiration, starting discussions and trying out different angles for the design solution. To facilitate that process, the toolkit also provides persona cards and product cards which can help to implement product care based on a specific scenario. In addition, cards with already existing examples of products that implement product care strategies are provided. The cards are magnetic, which makes it possible to use them on whiteboards and easily hold brainstorm sessions around them. They present questions which trigger the designer to think about how to target product care with their design. The outcomes of sessions with the Product Care Kit can range from conceptual product ideas or a visual map of the context to deepen discussions and generate new insights and knowledge about product care.

Figure 1. The Product Care Kit.

Discussion

The workshop, the research and the ideation session enabled us to develop eight design strategies with 24 sub-strategies to stimulate product care. One aspect that was discussed during the clustering session was that product care should be considered continuously during the design process, because it is a relevant issue to consider in different design phases, such as the choice of materials, service design etc. A general awareness about the relevance of product care is needed to bring product care into design processes. This awareness could be created by implementing product care knowledge into design education, or by training designers through workshops.
The comparison of our design strategies with already existing models and tools provides some theoretical background for our results. Specifically, it is relevant to compare our results to Fogg's model for behaviour change, which describes the importance of ability, motivation and triggers. Ability can be found in the *enabling* as well as in the *informing* strategy, both facilitating product care for the consumer. Young (2017) showed that the missing knowledge and equipment needed for product care are the strongest barriers to maintenance activities, so there is a huge potential concerning this issue. Also, *social connections* as a facilitator for product care is related to this aspect. These strategies can also be linked to Design for Ease and Repair (Bakker et al., 2014). Motivation, but also triggers, is covered by the design strategy *antecedents and consequences*, because positive and negative expectations about the outcome of taking care or not taking care of products can stimulate consumers. Further aspects that increase motivation are *appropriation* and *reflecting*, because they create a connection between consumer and

product that can stimulate product care (see also Mugge et al., 2005; Scott & Weaver, 2014). People's need to feel socially integrated, which is an intrinsic source of motivation, can explain the strategy *social connections* as a result of product care. *Control* and *awareness* are – depending on their sub-strategies – either sources of motivation or triggers that enhance the motivation at a certain point of time and thus lead to an immediate reaction by the consumer. Concluding, all design strategies seem to break Fogg's general model of behaviour change down to more manageable and concrete approaches to stimulate product care. These strategies support designers to use the insights into product care during their product development processes.

In contrast to already existing approaches to support repair and maintenance, our strategies take the consumers' perspective into account by stimulating their motivation and perceived ability. However, we do not yet know how consumers will respond to these strategies and if they would accept products and services with these strategies implemented. Consequently, in future research, we will interview consumers to uncover how they evaluate these strategies to understand under which conditions the implementation of these strategies would be accepted. Future research should also explore if the implementation of these strategies will increase product care in consumers' daily lives in the long-term. So far, the toolkit itself has been part of a small pilot study with design students, who judged it as easy to understand and work with. In addition, the toolkit will be tested in depth with designers and design students, during a workshop at the PLATE conference 2019.

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Circularity in Business: A Framework for Assessing the Circularity Potential of Small and Medium Enterprises (SMEs) and its Relation to Product Lifetime Extension

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Keywords: Circular Business; Product Lifetime Extension; Theory of Change; Framework; SMEs.

Abstract: This study explored the potential outcomes of circular business activities, of small medium enterprises that are operating in London, United Kingdom and examined how they relate to product lifetime extension. The data sample consisted of 89 start-up companies, trading for 1–4 years and either at seed or growth stage. The analysis was based on the 'Theory of Change' framework and a logic model was created to illustrate the causal links between circular business activities, circular outputs and outcomes. The results of the study demonstrated that several outcomes can be attributed to circular business activities beyond product lifetime extension, including (i) material, (ii) space and (iii) packaging lifetime extension but also reduction and elimination of lifetimes. In addition, results suggested that predominantly those outcomes are linked to circular business strategies that tend to focus on resource recovery and resource efficiency, while there are fewer examples demonstrating business innovation through circular design, circular revenue models and clean resources strategies. The results also suggested that the main outputs of circular business activities are (a) prevention, (b) reusability and (c) recyclability.

Introduction

This study demonstrates that circularity of resources in a business could lead to different outcomes other than extension of a product's lifetime (e.g. material lifetime extension). In addition, the paper introduces a Circularity Framework for businesses and highlights the elements of the circular activities of a business that are more likely to contribute to different lifetime extension outcomes (i.e. product, material, space) on the basis of data collected during the first two years (2017–2018) of the Advance London business support programme for small and medium enterprises (SMEs) in London.

Methodology

The methodology used to cluster and analyse the business data was based on the 'Theory of Change' (TOC) framework (Anderson A, 2005) that defines long-term goals (i.e. outcomes: product lifetime extension) and then maps backward to identify necessary preconditions (i.e. inputs: business activities). A logic model (Coffman J., 1999) has been used to illustrate, in a simplified way, the hypothesis or 'theory of change' that circular business activities could be connected/lead to a product's lifetime extension or other types of outcomes. It should be noted that the ultimate long-term goals (impacts) of 'product lifetime extension' – a net positive environmental impact related to waste diverted from landfill and the avoided CO_2 emissions – are beyond the scope of this study and hence haven't been quantified.

The research sample comprised of 89 SMEs that were supported to either grow their circular business (product or service based) or implement circularity initiatives, across five focus areas including food, textiles, built environment, plastics and electronics as defined in London's Circular Economy Route Map (LWARB, 2017).

Outcomes

For the purposes of this study, the lifetime of a product is defined as the cycle that begins with the product's introduction into the market, continues with the product's growth as it captures the attention of the target audience (Sampson Q, 2019) and ends with the disposal of the product by its user/owner. However, this study highlighted that business circularity activities could lead not only to the extension of a product's lifetime but also to other outcomes related to material, packaging and space lifetime (Figure 1). Evidence was also collected to demonstrate that the expected positive material outcome could be related to the reduction of a lifetime (e.g. bio-based materials substituting fossil-based materials) or the elimination of a lifetime (i.e. reusable packaging), or the maximisation of a product's use (i.e. reuse of product's that their owners do not want to dispose). Therefore, the definition of the anticipated circularity outcome – the extension of the product lifetime – was extended to include:

- *Material lifetime extension*, referring to the potential conversion of a material (extracted from a non-functional product) to a new product.
- *Packaging lifetime extension*, referring to the extension of the lifetime of the packaging (primary or other) used to complement a product but not necessarily the product's lifetime.
- *Space lifetime extension* referring to the activities converting an idle or 'wasted' space (e.g. rooftops) to a product/service.
- *The reduction of a product's/material's /packaging's lifetime*, connected to business activities that tend to substitute technical for bio-based materials (e.g. offering a biodegradable alternative to traditionally polymer-based solutions such as alginate based versus Polyethylene terephthalate (PET) based packaging).
- *The elimination of a material's or packaging's lifetime* altogether, referring to activities that lead to the prevention of the existence of that material or packaging (i.e. single use packaging), avoiding the material or packaging to be needed for use in the first place (i.e. through packaging-free solutions).
- *The maximisation of the use of a product* during its lifetime, without extending its lifetime. The outcome is relevant to idle assets that their owners still make use of but not constantly, allowing for an increased use of their asset during its existing lifetime by another user.

All outcomes defined above, have a positive material footprint – raw material use is prevented – through the extension of the lifetime of products/packaging/materials /spaces and waste is diverted from landfill or incineration. However, further research needs to be conducted on the wider environmental impact of the business activities deployed in achieving lifetime extension. It should be noted that the term 'resources' used below, will refer from now on to all of the following product /packaging/material/space.

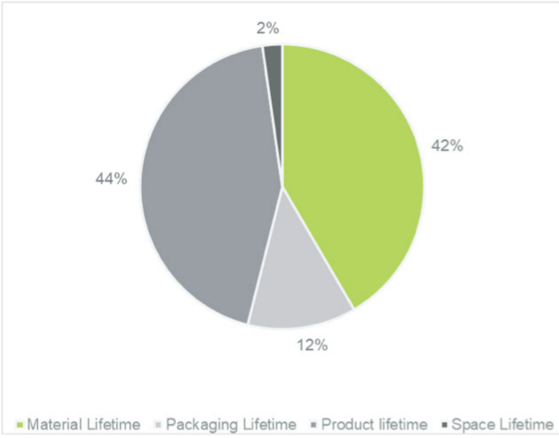

Figure 1. Extended focus areas of lifetime extension activities assessed in the study.

Outputs

Three main outputs –the direct results of circular business activities – on the resources were identified and included: recyclability, re-usability and prevention. The recyclability aspect refers to the material recycling as defined in the European standard EN 13430 and EN 16848 (European Commission, 2004) and results in the mechanical or chemical conversion of a resources for a different purpose (e.g. from chicken feathers to thermo-packaging, from food waste to building materials) and it covers both technical and biological cycles, as defined by the Ellen McArthur Foundation in 2013. The re-usability aspect refers to the use of the resources for the same purpose (e.g. from cup to cup) and the prevention output to the avoidance of using a resources (e.g. packaging-free groceries).

Circularity Business Activities

The outputs above resulted from a wide range of circular business activities on the input resources. The occurrence of those business activities within the business sample of the study is showed in Table 1.

Circularity Business Activity	**(%)**
Material conversion	26 %
Redistribution	8 %
Renewable inputs	8 %
Modularity	7 %
Packaging reuse	7 %
Product as a service	6 %
Refurbishment	6 %
Material monitoring & tracking	4 %
Sales of used/refurbished products	4 %
Customer education	3 %
Recycled inputs	3 %
Behaviour monitoring	2 %
Material repurposing	2 %
Reuse	2 %
Second hand purchasing & sale of refurbished products	2 %
Take-back scheme	2 %
Asset rental	1 %
Data monitoring & Tracking	1 %
Expandable design	1 %
Recyclable inputs	1 %
Sharing platform	1 %
Space repurposing	1 %

Table 1. Circularity Activities deployed by SMEs in London © LWARB, 2019.

Inputs
The businesses assessed during this study either handled products/others made of technical materials (67%) or biological materials (33%).

Circularity Strategies
This study recognises a 'circular' business as one that keeps natural resources (both resources required as inputs and resource outputs produced from its operations) in circulation for as long as possible, that defines its strategic objectives in line with these principles and/or generates revenue through multiple sales cycles of the same products. As such, the 'circular' businesses assessed in this study have deployed any or more of the following strategies:

At an operational level
- Clean resources (inputs): Ensured that all inputs into a new product/service are from renewable and toxic free sources.
- Resource Efficiency (process): Created, packaged, distributed and sold products or services through the most resource efficient processes, ultimately aiming at reducing energy, water and material use.
- Resource Recovery (outputs): Captured all resources that are no longer needed so they can be used again either in the business's value chain or others.

At a strategic level
- Circular Design: Designed products or services in a way that allows them to be used multiple times, easily adapted, repaired or remanufactured; and when they are no longer needed, they can be easily dismantled to allow the recovered materials to be used again.

At a financial level
- Circular Revenue Model: Generated revenue through keeping products in use for as long as possible at the highest value possible.

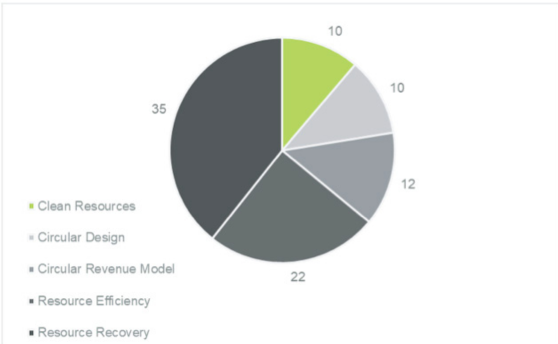

Figure 2. Number of businesses deploying different circularity strategies, © LWARB, 2019.

Results
The study showed that from the four possible outcomes – extension, reduction, elimination or maximisation of resources lifetime, 82% of small and medium businesses, included in the study, are focusing on extending resources

lifetimes (Table 2), of which the majority is most likely to focus on material lifetime extension (47%), on product lifetime extension (45%) and to a lesser extent on packaging (5%) or space (3%). This reinforces the need for the sector to attribute outcomes to circular activities that are not only related to product lifetime extension and distinguish between different outcomes that include materials, space and packaging.

Outcome on Lifetime	% of total businesses	Focus Area	% within the outcome category
Eliminate	9%	Material lifetime	38%
		Packaging lifetime	63%
Extend	82%	Material lifetime	47%
		Packaging lifetime	5%
		Product lifetime	45%
		Space lifetime	3%
Maximise	2%	Use of product	100%
Reduce	7%	Packaging lifetime	33%
		Product lifetime	67%

Table 2. Key outcomes attributed to circular business activities © LWARB, 2019.

The assessment of the various business activities for both types of inputs – biological and technical – resulted in the following observations.

On product lifetimes: The majority of businesses (82%) with outcomes at a product-level would extend a product's lifetime through achieving reusability of the product (e.g. Rype Office, Reyooz, Too Good to Go). There are also businesses that contribute, with their product, to the extension of the lifetime of another product(s). This activity has been demonstrated by Mimica, who through freshness indicators for all types of perishable products aims to maximize their lifetime and by Jiva Materials, who through Soluboard®, a recyclable Printed Circuit Board (PCB) laminate, extends the lifeftime of all products usually attached to a PCB (i.e. microchips).

Some of the businesses (Twipes, Adaptavate, Green Oil) who are managing products with biological inputs, by achieving recyclability of the product, they have demonstrated that they reduce the product's lifetime, allowing for the product to biodegrade at a faster pace or in a more efficient way, resulting in a positive material impact.

On material lifetimes: Traditionally a material's lifetime is extended through a recycling process, which is confirmed by 76% of the businesses of the study who are aiming to extend material lifetimes. However, 22% of businesses with outcomes at a material-level (Eiravato, Customem, Rehandle), aim in predominantly extending material lifetimes by enabling the reusability of those materials, through refurbishment activities, material monitoring and tracking or through the use of renewable inputs in the making of the material.

On packaging and space lifetimes: Businesses contributing to outcomes on packaging or space (13/89), are fostering prevention (46%), reusability (38%) and recyclability (15%) that is achieved through reuse of the packaging/space (54%), through renewable inputs (15%), product as a service or take-back schemes and circular activities (31%).

Figure 3, illustrates the logic model of all the circular activities described above, their expected outputs and respective outcomes.

The study also examined differences in the logic model between businesses with biological and technical inputs. As figures 4 and 5 suggest, there are significant differences both in terms of circularity strategies and activities deployed by the businesses to deal with biological and technological inputs but also in terms of final outcomes.

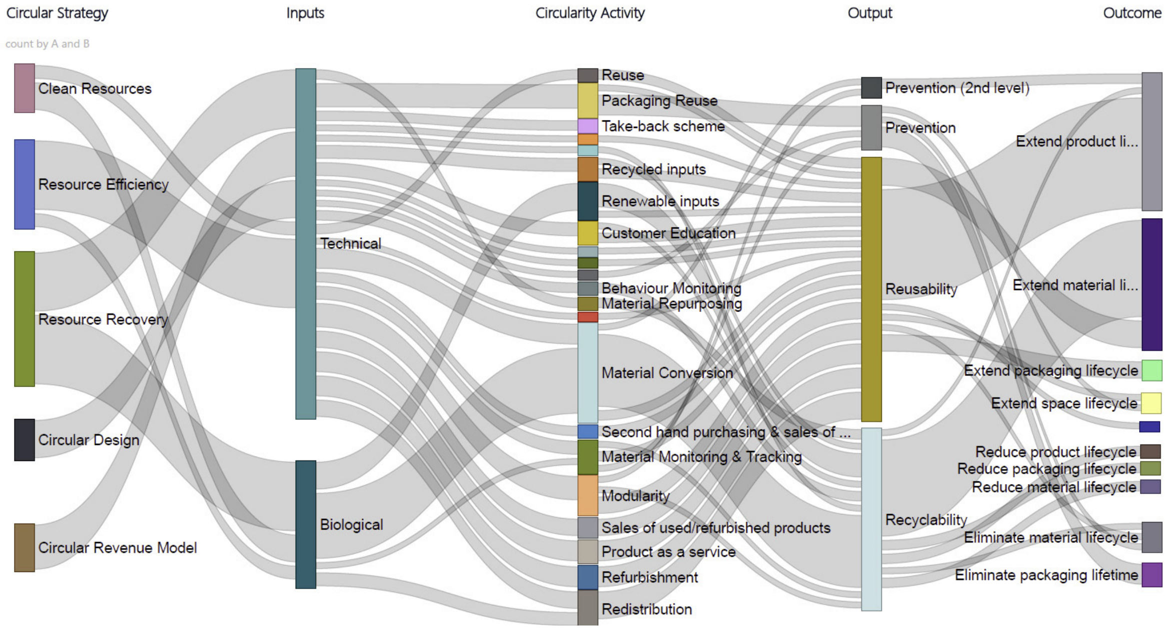

Figure 3. Logic Model of Circular Business Activities © LWARB, 2019.

The predominant 'theory of change' for businesses handling biological inputs starts from a resource recovery business strategy that, through material conversion, a waste stream will be recycled to a new material, resulting in the extension of the lifetime of that material. In comparison, a business using technical inputs is most likely to deploy a resource efficiency strategy that through modularity or material conversion or reuse or refurbishment, products will be reused, resulting in the extension of their lifetime. The results also suggest that businesses with biological inputs have not deployed any circularity strategies in circular design, circular revenue models or clean resources.

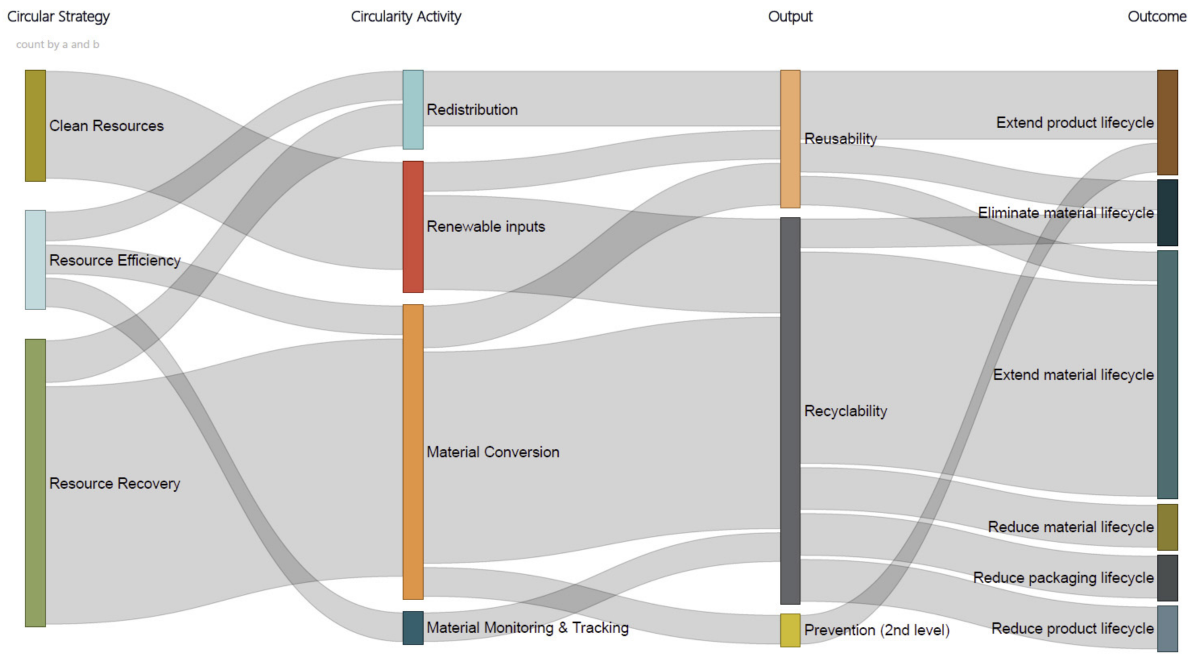

Figure 4. Logic Model of circular business activities with biological Inputs © LWARB, 2019.

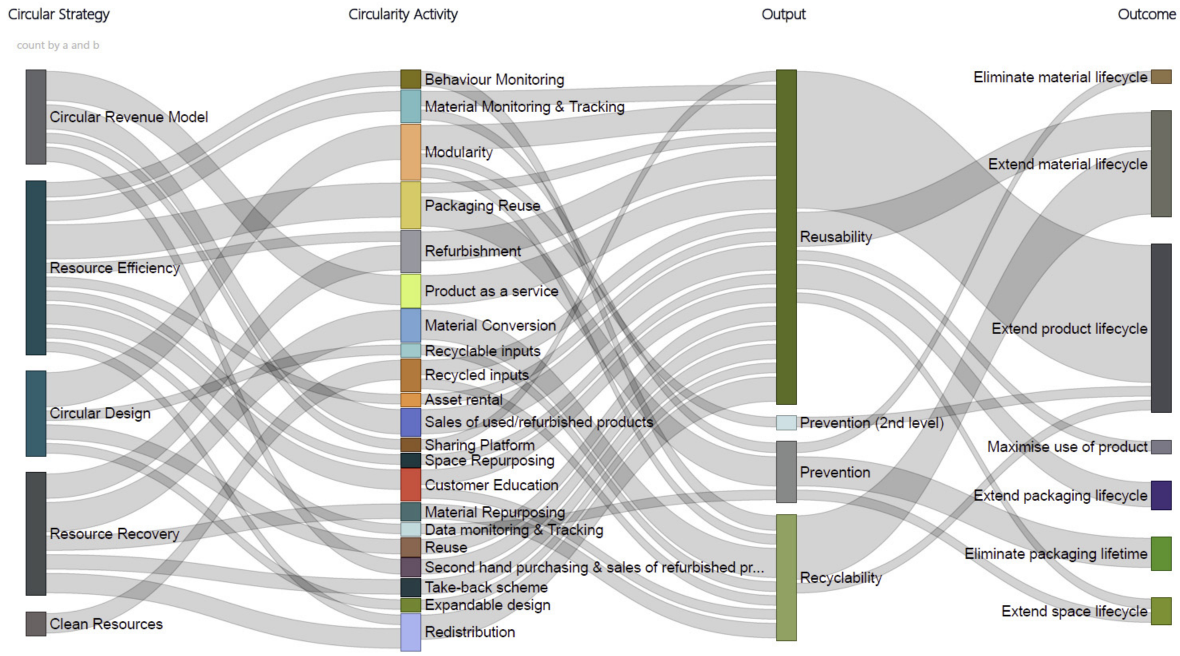

Figure 5. Logic Model of circular business activities with techical Inputs © LWARB, 2019.

Conclusions

Circular business activities can contribute to outcomes beyond product lifetime extension, including material, space and packaging lifetime extension, reduction or elimination. Businesses in London have demonstrated that circularity activities can also result in maximisation of a product's use within its current lifetime. This paper highlighted that those outcomes should all be considered as equally valuable as a product life extension outcome when aiming to illustrate and/or assess the impact of circular economy in a business context. Further research should be conducted in order to quantify specific material impacts and business benefits coupled with those outcomes.

Based on the sample of 89 small and medium businesses supported through the Advance London programme, the main outcome achieved from circular business activities in London, is predominantly extension of product and material lifetimes. The notion of converting waste streams to new products and therefore expanding the product or material lifetime is the most frequently encountered type of circular business. Both from a design perspective/available technology as well as a business readiness perspective, entrepreneurs are more likely to identify a waste stream and launch a business that will tackle it.

However, some entrepreneurs have focused their business activities on eliminating or reducing lifetimes of packaging and materials. Fewer entrepreneurs are venturing into extending the product/material lifetime by redesigning the product or by offering products in the form of a service.

The study has also validated that certain circularity strategies – circular revenue models and circular design – are applicable to technological inputs and it is yet to be explored whether there is a possibility for businesses handling biological inputs to deploy those strategies as well.

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PLATE
Product Lifetimes And The Environment

Smart Products as Enabler for Circular Business Models: the Case of B2B Textile Washing Services

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Keywords: Service Business Models; Rental; Internet of Things; Circular Economy; Smart Textiles.

Abstract: Service business models have the potential to improve the product life cycle due to their emphasis on maximising value over time. Emphasising access to products over ownership may encourage firms to keep their products at their highest value during their entire lifetime and reuse materials after end of life. Against this background, service business models may allow a restorative and regenerative system to thrive and thereby contribute to a circular economy. Moreover, investing in technologies like smart products and the Internet of Things could facilitate the optimisation of closed-loop business processes and services, enabling the provision of access. However, extant literature has acknowledged an absence of empirical evidence of this emergent phenomenon. This paper explores how the industry uses smart products to optimise service business models in the context of the circular economy. We present an in-depth case study in which we analyse a textile rental firm in the business-to-business domain. The firm has operated a rental business model for several decades and has recently become a front-runner in using textiles tagged with Radio Frequency Identification (RFID) chips. Implementing smart textiles has allowed the firm to improve the transparency of the product life cycle (e.g. product location and condition). This information has enabled a more accurate internal analysis of the reuse loop, losses, and the product quality-longevity nexus. The firm has also used lifetime information to raise customer awareness (e.g. product misuse and theft) and improve product procurement decisions.

Introduction

The Industrial Revolution paved the way for a new mindset towards the product lifetime. Products became disposable and were quickly discarded. This change in mentality stimulated a throwaway economy and has generated severe problems of environmental pollution (Lieder & Rashid, 2016). In a linear economy, most products are lost to landfills, incinerated, or end up in downcycling schemes (e.g. House of Commons, 2019; Sanders et al., 2019).

In order to replace the prevalent linear economy, scholars, practitioners, and policymakers have increasingly embraced the concept of the *Circular Economy* (CE) (EMF, 2015; Kirchherr, Reike, & Hekkert, 2017; Murray, Skene, & Haynes, 2017). In a CE, products are kept at their highest value during their entire lifetime and materials are reused after end of life, allowing for a restorative and regenerative system to thrive (Stahel, 2016). For instance, a circular textile industry would create safe materials, scale-up service business models (SBMs), increase product longevity and utilisation, and improve recycling, among other transformations (EMF, 2017).

The use of technology holds great potential to operationalise the CE. Smart products connected through the Internet of Things (IoT) could facilitate closed-loop business processes and services, enabling firms to streamline the provision of access to their products (EMF, 2016). Moreover, technologies could enable longer lifetimes through product traceability and data sharing across the supply chain. For example, firms may tag textiles with Radio Frequency Identification (RFID) chips to improve quality testing and coordination with suppliers, fostering product longevity (Cooper et al., 2017). However, there is a lack of empirical evidence of how the vision of a CE enabled by smart products can become a reality (Alcayaga, Wiener, & Hansen, 2019; Nobre & Tavares, 2017; Pagoropoulos, Pigosso, & McAloone, 2017). Therefore, the purpose of this article is to explore how practitioners are adopting smart products to optimise SBMs in the context of the CE.

With this objective in mind, we address the following overarching research question: *How do smart products enable circular service business models?* This question is operationalised using the following sub-questions: *a) How do smart products enable the reuse of fast-cycling goods?*, *b) How can smart products enable product longevity through maintenance and repair?*, and *c) How can real-time life cycle data inform better product procurement and related design?*

Literature Review

Circular Economy

The CE is understood as a cyclical closed-loop system (Murray et al., 2017) and has been proposed as an approach to replace our current take-make-dispose system of production and consumption (EMF, 2013). The CE could be a solution for firms to engage in environmental protection and reduce the negative impacts of business operations (Ghisellini, Cialani, & Ulgiati, 2016). Specifically, improving product longevity could considerably reduce waste and increase the positive environmental impacts of the firm (Tietze & Hansen, 2016).

Blomsma and Brennan (2017) have framed the CE as an umbrella concept (Hirsch & Levin, 1999) that groups several circular strategies, i.e. maintenance, repair, reuse, upgrade, remanufacturing, and recycling, among others. The adoption of circular strategies could transform the economy and lead to more sustainable practices and outcomes. In particular, reusing products could offer savings in the energy and materials otherwise required for the production of new goods (Cooper & Gutowski, 2017). For example, textile reuse in the healthcare industry has reported significant cost savings, reductions of waste, and a minimisation of the health consequences that residents near landfills and waste incinerators may experience (Zins, 2011).

Service business models

It has been generally understood that improving the product life cycle requires product-service systems (Tukker, 2004, 2015), and, relatedly, new SBMs (Hansen, Grosse-Dunkler, & Reichwald, 2009). In this respect, SBMs may allow firms to focus on maximising value over long periods of time. By internalising the costs of risks and waste, firms may integrate resilience, sufficiency, and redundancy into their practices (Stahel, 2010). Also, minimising costs of disposal drives life cycle management at end of life, fostering recycling (Stahel, 2016).

Furthermore, SBMs offer firms a strategic position of proximity to their customers. This position allows firms to influence the way products are used and circulated (Heyes, Sharmina, Mendoza, Gallego-Schmid, & Azapagic, 2018). It also motivates firms to seek process and practice alignment between their suppliers and customers towards a circular infrastructure (Pedersen & Clausen, 2018).

Smart Products and the IoT as Enablers

Continuing the advancement towards a CE, smart products and the IoT could facilitate this transition. Smart products can be considered as physical products amplified with distinctive physical and digital smart enablers, i.e. hardware and software components (cf. Noll, Zisler, Neuburger, Eberspächer, & Dowling, 2016). Smart products are opening unprecedented opportunities for value creation (Porter & Heppelmann, 2014). These opportunities relate to the use of digital technologies to increase resource efficiency, extend the product lifetime, and recover materials (EMF, 2016). Digital technologies enhance product design using life cycle data. They also support the optimisation of the use phase through product monitoring and tracking and facilitate the provision of maintenance and recycling (Bressanelli, Adrodegari, Perona, & Saccani, 2018). Moreover, life cycle data could offer a better account of product condition before reuse, a reduction of process failures and losses, and improved output quality, among other benefits (Alcayaga et al., 2019). For instance, textiles and clothing powered by RFID tags and related readers could communicate their location remotely, enabling tracking and streamlining sorting, logistics, and analytics (Hansen & Gillert, 2008, p. 249). Business analytics tools could generate insights into efficiency improvements or lifetime extension (EMF, 2017). Thus, smart products and the IoT can be utilised to develop feedback-rich systems throughout the entire product life cycle, accelerating the scaling up of a CE (EMF, 2016).

In addition, firms having SBMs could leverage smart products to optimise their circular value proposition (Alcayaga & Hansen, 2017). For example, RFID-tagged crates allow optimal control and higher speed of circulation in a closed-loop system (Leblanc, 2011). Additionally, a digital identity for textiles could connect the entire fashion value chain, facilitating the identification of products and materials for reuse, repair, or recycling (EON, 2019a, EON, 2019b).

Method

This paper presents an in-depth case study (Yin, 2018) in which we analyse Wozabal Miettex GmbH (in the following simply referred to as Wozabal), a firm that rents out and washes professional textiles. We chose a case study approach because of the uniqueness of the case that characterises an emergent and contemporary phenomenon (Eisenhardt & Graebner, 2007; Yin, 2018).

We selected Wozabal because they have operated a rental business model for several decades and have recently become a front-runner in using RFID-tagged textiles. We triangulated data from semi-structured and ethnographic interviews at various hierarchical levels, observations at site visits and industry events, and data from internal reports.

Introducing Wozabal

Wozabal has facilities in several locations across Europe. The firm serves a range of industries, including healthcare, hospitality, manufacturing, pharmaceutical, and semiconductor industries. Wozabal services cover three product types: *flat textiles* (e.g. towels, bedsheets, and napkins), *surgical textiles* (e.g. surgical gowns, drapes, and towels), and *uniforms* (e.g. trousers, shirts, and other garments). Textiles are equipped with ultra-high frequency (UHF) tags, high frequency (HF) tags, or barcodes. The main difference between UHF and HF technologies lies in their reading capabilities. Textiles powered with UHF tags are read in batches, whereas textiles with HF tags are read individually. Moreover, UHF tags can be read from longer distances than HF tags can. Wozabal also equips textiles owned by specific persons (i.e. patients) with tags so that they seamlessly circulate throughout the reuse loop.

This paper focuses on a laundry line at a location dedicated to the healthcare industry. The top management of Wozabal selected hospitals and nursing homes for this location to allow for productivity improvements. When compared to other customers, like hotels, hospitals and nursing homes are more concerned about cleanliness than the appearance of textiles. This understanding of quality allows for faster but more intensive washing cycles, generating negative consequences for the fabrics and shorter product lifetimes.

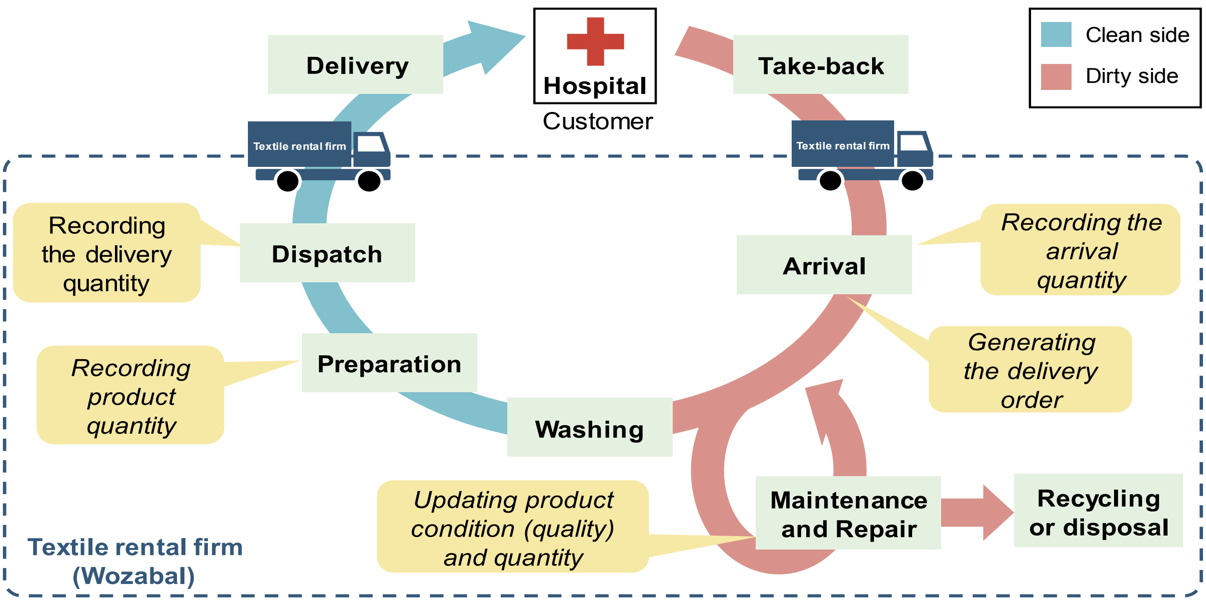

Figure 1. Reuse loop.

The facilities at the location are distributed into two buildings and can process around 60-70 tonnes of textiles per day. The laundry line under study is located in one of the buildings and processes UHF-tagged flat textiles rented only to hospitals. Activities in the selected building are highly automated, whereas tasks in the other building are executed rather manually; this differentiation allows us to understand the impacts of smart products combined with automated systems on circularity and SBMs. Besides the automation level, both buildings differ in customer types, product types, and the IT infrastructure installed.

Preliminary Findings

Smart Reuse of Fast-Cycling Goods

Smart rental textiles circulate in a closed-loop system between Wozabal and its customers. As seen in *Figure 1,* the reuse loop starts with the take-back of dirty laundry that is collected by employees of Wozabal. Then, the laundry cycle takes a predefined number of days to wash, prepare, and dispatch clean textiles. Finally, clean laundry is delivered to the customer to replenish its working stations. This delivery closes the reuse loop.

Textiles circulate several times per week between Wozabal and its customers in an overlapping manner, i.e. while some textiles are in the laundry cycle, others are at customer sites or in transit. Both the duration of the laundry cycle and the number of deliveries (and take-backs) per week are agreed upon with the customer in advance. For example, a laundry cycle may last four days, and the firm could do three deliveries per week (*Table 1*). Furthermore, flat textiles can circulate freely among customers. For instance, a towel could be used a few weeks at customer A, then at customer B, and then at customer A or C.

Take-back	Delivery	Cycling time
Tuesday	Saturday	4 days
Thursday	Tuesday	4 days
Saturday	Thursday	4 days

Table 1. Laundry cycle of a single customer.

In order to ensure a continuous replenishment of the textile stock at customer sites, Wozabal offers several alternatives for the order and delivery process. Firstly, UHF tags, with their batch-enabled reading capabilities, allow a process driven by the *current stock*. The number of textiles to be delivered is the difference between the required stock and the current stock at customer sites. The required stock per working station is agreed upon in the contract. Changes to the current stock are made at Wozabal in an Enterprise-Resource-Planning (ERP) system when the laundry arrives and when it is dispatched. Secondly, Wozabal and its customers can agree on the delivery of a fixed number of textiles at each delivery day. Finally, customers may make additional requests via electronic orders or use a web portal to order clean textiles on-demand.

A mixed order and delivery process drives the laundry line under study. It combines the current stock approach with other alternatives previously described.

The overlapping nature of the reuse loop requires Wozabal to identify the current stock as soon as possible. For this reason, flat textiles are read one time directly after arrival. This reading point enables the generation and faster processing of the upcoming delivery. Then, flat textiles are sorted automatically along the laundry line. As seen in *Table 2*, many reading points have been installed to ensure a highly accurate reading rate. Reading in batches may generate some discrepancies and several reading points may correct them.

Rental textiles are assets, and a long-lasting textile lifetime is crucial for this business model. However, one of the main challenges for Wozabal involves losses (and higher costs) because of lost textiles. An approach to evaluate losses is the *speed of circulation*. The firm classifies textiles in four categories according to the speed of circulation (fast, slow, very slow, and not circulating or lost). A highly accurate identification of textiles based on multiple reading points along the laundry line enables this categorisation. Textiles circulating between Wozabal and its customers within seven days are identified as fast circulating textiles. When textiles are not read within 90 days, they are considered lost. Lost textiles are either disposed of at customer sites or stolen by customers' employees or final customers (e.g. patients). For several product types (e.g. towels), more than 50% of the textiles reach the not circulating category within one year, i.e. they have not returned to Wozabal 90 days after the delivery within a specific year.

Laundry line	Dirty side: Arrival (collection, inspection & pre-sorting)	Washing (washing, disinfection & drying)	Clean side: Preparation (sorting, ironing & finishing)	Clean side: Dispatch
Flat textiles with UHF tags	2 reading points		4 reading points	1 reading point

Table 2. Laundry line of flat textiles for hospitals.

A shorter than expected product lifetime due to severe dirt and damages is a second (but minor) source of losses. Wozabal participates in public procurement tenders to obtain contracts for textile rental services. The expected lifetime of the textiles and the price per washed textile unit are set in the contract. However, some textiles may reach the end of their lifetime before the agreed one, increasing costs. Textiles may be extremely dirty, even for an industrial laundry line, or may be damaged due to intensive usage, continual washing, or laundry line jams. Wozabal discards all these textiles because it is not possible to clean or repair them.

The use of RFID-tagged textiles has allowed Wozabal to generate accurate information about losses. The firm has used this information to raise awareness among its customers and perform better cost control.

Maintenance and Repair

Customers send textiles back in special bags because they need a repair or have stains. These bags do not enter the laundry line and are sent to the repair crew, a dedicated team at Wozabal that manually analyses these textiles and decides on a repair, another washing cycle, or disposal. After the team has performed the required repairs, they book the flat textiles into the ERP system allowing for full traceability of repair activities in the product life cycle. Then, textiles are sent to the dirty side for washing and re-enter the reuse loop (Figure 1).

Recycling

Currently, flat textiles, surgical textiles, and uniforms at the end of their lifetime are collected in large waste containers and then sold in the market for the highest economic value (or least cost). Most flat textiles that have reached the end of their lifetime are downcycled into cleaning towels by an external firm. However, severely damaged or dirty textiles are utilised as inputs in waste-to-energy plants, for which Wozabal pays a fee. Further recycling opportunities have been investigated, but have not been implemented so far.

Feedback into Procurement (and Product Design)

The data from the product life cycle allows the company to analyse product quality over time. This data is then used to inform the next procurement cycle, for instance, by changing product specifications or switching to alternative products or suppliers. Ultimately, it can be expected that this also has an (indirect) impact on product (circular) design at the suppliers' development teams.

Conclusion

Before implementing RFID tags, the fast-cycling nature of rental textiles and their large quantity (several tonnes per day) made it practically impossible for Wozabal to perform a daily inventory of arrivals. In this sense, the implementation of smart textiles has allowed Wozabal to acquire more accurate information on the condition and location of its textiles. This information has enabled an analysis of circulation, losses, and quality of specific product lines. For these reasons, the most remarkable benefit for Wozabal of using RFID-tagged textiles within the reuse loop is the gain in transparency. This enhancement of data analysis and transparency enables a circular SBM.

Furthermore, the use of smart textiles has allowed the implementation of value chain measures that may improve circularity. The firm has used product lifetime data to raise customer awareness due to losses of rental textiles. Reducing losses at customer sites could bring cost savings for both parties. In addition, an analysis of product quality could improve product procurement decisions and enable proactive supplier management. These changes could allow the development of better relationships along the value chain, and consequently, an overall improvement of the SBM.

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Information Requirements to Enable the Repair or Upgrade of Products: EU Policy Tools and Other Voluntary Labels for Computers

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Keywords: Computers; Information; Label; Policy; Repair; Upgrade.

Abstract: Extending the lifetime of products can mitigate, from a life cycle perspective, their environmental and social impacts. One of the options to extend their lifetime is repairing and/or upgrading the product, when possible. A key measure in support of this objective is the availability of relevant information to users and professionals to enable repair/upgrade of products.
Requirements on the provision of repair information have been introduced by different policy tools and labels for a variety of products and services on the market. In the case of computers, minimum requirements have to be fulfilled to enter in the EU market according to the Commission Regulation (EU) No 617/2013, while more ambitious requirements are associated to voluntary tools such as the EU Ecolabel and the EU Green Public Procurement (GPP) for Computers, as well as to other labels such as Blue Angel (the German Ecolabel), TCO Certified and EPEAT. Provision of repair information is also included in the Scoring System on Reparability developed by the Joint Research Centre.
The aim of this work is to review these initiatives to present a classification and comparison of existing information requirements for computers in terms of: i) repair aspects covered, ii) availability of the information to various target groups, and iii) communication vehicles. The analysis focuses on sub-categories of computers that are relevant in terms of market share such as laptops, desktop computers, all-in-one computers and tablets.
The results of the analysis can offer a useful basis for the improvement and harmonization of information requirements on computers, potentially facilitating their implementation by manufacturers and allowing more sustainable purchase decisions of consumers and public administrations.

Introduction

Significant contributions to the environmental impacts along the life cycle of computers are related to the manufacturing of the device itself and sub-assemblies such as motherboards, hard drives, batteries and display units (EC 2016a). The supply chain of computers and other ICT products can be also associated with conflict and human rights impacts (Köhler et al. 2013). Facilitating repair, reuse and upgrade of computers can contribute to extend their lifetime and reduce the impacts associated to resource extraction, production and end of life (Cordella et al. 2019a).
EU consumers currently lack information on reparability (Cerulli-Harms et al. 2018). Providing more information to consumers at the point of the sale about the durability and reparability of products can be an effective measure to shift demand towards products with better environmental credentials and make repair easier (Cerulli-Harms et al. 2018).
At EU level, policy measures supporting repair of products could also provide turnover gains and create jobs in the repair sector, which is largely composed of SMEs and social enterprises located in the EU (Deloitte 2016).
Product policy tools such as the Ecodesign Directive (EC 2009), the EU Ecolabel (EC 2010) and the EU Green Public Procurement (GPP) (EC 2008b) can include requirements on reparability and supply of information.
It should be noted that, at the moment of preparing this work, the current Ecodesign regulation for computers (EC 2013) and GPP criteria for computers (EC 2016a) are under revision, with the possibility to introduce new requirements for the provision of repair information.
Moreover, new tools to inform about the ability to repair and upgrade products are under policy

discussion, such as a scoring system to rate the ability to repair and upgrade products. In that context, product-specific criteria have been defined for laptops (Cordella et al. 2019b).

Voluntary Type I ecolabels (ISO 2018) such as TCO Certified (TCO Certified 2018a, b, c, d), EU Ecolabel (EC 2016b) and Blue Angel (Blue Angel 2017), as well as rating system such as EPEAT (IEEE 2018), also include requirements on the provision of repair information. These labels can be also used in support of the formulation and verification of GPP criteria to include in public tenders or to implement sustainable procurement strategies in organizations.

This work provides a classification and analysis of repair/upgrade information requirements set for computers in EU relevant policy initiatives and voluntary programmes. These are finally compared to crosscheck the coherence and level of harmonization between different approaches with the final aim to promote their implementation by manufacturers and allow consumers and public administrations to make better purchase decisions.

Scope and methodology

The scope of this analysis has been restricted to repair/upgrade operations, defined according to Cordella et al. (2019a) as:

• Repair: the process of returning a faulty product, or a part of a product, to a condition where it can fulfil its intended use;

• Upgrade: the process of enhancing the functionality, performance, capacity or aesthetics of a products or a part of a product.

In terms of technologies, this study covers the following sub-categories of computers (EC 2013):

• Notebooks: a computer designed specifically for portability and to be operated for extended periods of time either with or without a direct connection to an AC power source;

• Desktop computers: a computer where the main unit is intended to be located in a permanent location and is not designed for portability and which is designed for use with an external display and external peripherals such as a keyboard and mouse;

• Integrated desktop computers: a computer in which the computer and the display function as a single unit, which receives its AC power through a single cable;

• Tablets: a product which is a type of notebook computer that includes both an attached touch-sensitive display and an attached physical keyboard.

Information requirements are analysed for the following EU product policy tools: Ecodesign (EC 2013), EU GPP (EC 2016a), EU Ecolabel (EC 2016b). Requirements from other international voluntary labels are also analysed. Among the labels, only those recently developed or updated (i.e. after 2016) have been taken into consideration. These are: TCO Certified, Blue Angel and EPEAT. The scoring system developed by JRC (Cordella et al. 2019b), also referred to as Repair Scoring System, has been moreover considered. More details of the analysed initiatives and related background information are listed in Table 1.

Type	Policy/initiative	Rev.	Application
EU policy tools	Eco-design (EC, 2013)	2013	Mandatory application at EU level
	EU GPP (EC 2016a)	2016	Voluntary inclusion of criteria in public tenders.
	EU Ecolabel (EC 2016b)	2016	Voluntary type I ecolabel
Labels	TCO (TCO 2018 a,b,c,d)	2018	Voluntary type I label ecolabel (mainly oriented to sustainable procurement in organizations)
	Blue Angel (Blue Angel 2017)	2017	Voluntary type I ecolabel
	EPEAT (IEEE 2018)	2019	Environmental rating system and label (mainly oriented to sustainable procurement in organizations)
Others	Repair Scoring System (Cordella et al 2019b)	2019	Under discussion. Product specific methodology developed for laptops.

Table 1. Details of the Initiatives analysed and their applicability.

The presence of key words as "repair", "information", "instructions", "access", has been crosschecked in the corresponding reference documents in order to identify requirements specifically requesting provision of information / instructions to facilitate the repair process. The level of market uptake has been also verified through the consultation of the product registries and considered in the discussion of the results. The repair information has been grouped based on topics covered. Associated target groups (e.g. professional repairers, users) and vehicle of communication / media required (e.g. free access website, user manual, other product documents, .external packaging) have been identified.

EU product policies on computers

The Ecodesign Regulation (EC 2013) mainly focuses on energy efficiency aspects; however this regulation already requires manufacturers to inform about the skills needed to replace batteries in notebooks. The Commission is exploring the possibility of including additional requirements such as disassembly instructions to be shared with professional repairers (Viegand Maagøe and VITO 2018). Similar requirements about the availability of repair information have been implemented in recent Ecodesign implementing measures for ICT products like servers (EC 2019a) and displays servers (EC, 2019b).

Current GPP criteria (EC 2016a) focus on the provision of disassembly and repair instructions during the service contract, as well as the information on the availability of spare parts; additionally, information on spare parts cost can be requested as awarding criteria. However, it has to be remarked that the provision of repair and spare parts information to the public administrations can be useful during the contract performance only when the public authority is actually responsible for the repair/upgrade of the equipment. It is moreover difficult to evaluate the level of implementation of GPP criteria since public authorities are free to select and adapt the criteria to integrate in their tender process.

The EU Ecolabel for computers (EC 2016b) introduces criteria on the availability of repair information such as the availability of a repair manual including clear disassembly and repair instructions and the provision of information on repair service. Nevertheless, there are no models registered under the European Ecolabel and the criteria expired in August 2019.

Voluntary labels on computers

Despite all the analysed labels have been available on the market at least in the past three years, only TCO and EPEAT have been able to reach a good level of market uptake in Europe (Table 2). Currently there are no computers registered neither under the EU Ecolabel nor under the Blue Angel.

Type of computer	Number of certified models			
	EPEAT	TCO v.8	Blue Angel	EU Ecolabel
Notebooks	135	48	0	0
Desktop Computers	90	21	0	0
Integrated Desktop Computers	42	23	0	0
Tablets	5	1	0	0

Table 2. Computer models certified in the EU under different voluntary labels (June 2019).

Identified information criteria

Based on the analysis of existing criteria, the following types of information on repair have been compiled (Table 3):

- Information on the availability of professional repair services;
- Instructions on how to identify failures;
- Instructions on data erasure;
- Information on replaceable components and skills needed;
- Information on the availability of spare parts;
- Disassembly instructions (for battery and/or other key components);
- Self-repair implication on computers warranty.

The implementation of such information differs from initiative to initiative as described in the sections below.

Availability of professional repair services

Information on the availability of professional repair services is required by EPEAT, EU Ecolabel, Repair Scoring system. This information should let the user know where to find professional services for the repair and upgrade of the computer.

Instructions on how to identify failures
It can include troubleshooting instructions, software diagnostic tools (e.g. battery health tools), troubleshooting videos or other troubleshooting guidance. The provision of instructions to identify failures is optional under EPEAT while this prescription is considered as a pass/fail criterion in the application of the Repair Scoring System to laptops.

Type of information	ECD	GPP	EL	TCO	BA	EPEAT	RSS
Availability of professional repair services			X			X	X
How to identify failures						X	X
Instructions on data erasure				X		X	X
Replaceable components and skills needed	X					X	X
Information on the availability of spare parts		X			X	X	X
Disassembly instructions		X	X	X	X	X	X
Self-repair implication on computers warranty		X					X

Note:
- ECD = Ecodesign
- GPP = EU Green Public Procurement
- EL = EU Ecolabel
- TCO = TCO Certified
- BA = Blue Angel
- EPEAT = EPEAT
- RSS = Repair Scoring System

Table 3. Information requirements included in different initiatives for computers.

Instruction on data erasure
By providing software that wipes the storage of the device, the computers owners can more safely send out products for repair (TCO 2018a, b, c, d). TCO requires that manufacturers, in case data erasure software is not preinstalled on the product, provide the link to download the software on their webpage. EPEAT includes this requirement as optional. According to the Repair Scoring System, the data erasure software has to be provided (either pre-installed or as web-link), and complemented by information for installation.

Information on replaceable components and skills needed
According to the current Ecodesign Regulation for computers, manufacturers have to disclose whether the battery (notebook) cannot be easily replaced by users themselves. This information has to be made available on a free-access website and on the external packaging of the notebook computer. EPEAT explicitly requires a statement from manufacturers about the possibility to replace batteries; the other ecolabels require other components to be replaceable as well (see Table 3). Despite the initiatives analysed require a design of replaceable components (see Table 3) there is no obligation to disclose this information, except from battery for EPEAT. A repair scoring system label could address this aspect.

Information on available spare parts
Transparent information and procedures on how to obtain spare parts are required by Blue Angel, EPEAT and Repair Scoring System. EU GPP criteria include the declaration of the spare parts that will be made available to the contracting authorities. More comprehensive information on their availability period, price, functional specifications and compatibility is awarded through the Repair Scoring System.

Disassembly instructions
EU GPP, Ecolabel and TCO require that the disassembly information for the key components should be made publicly available. EPEAT includes the availability of this information as an optional criterion, while the Repair Scoring System requires disassembly information available to professional repairers as entry level. The list of replaceable components varies depending on the initiative considered. Instructions on how to replace the battery must be publicly available according to TCO, EU Ecolabel and Blue Angel, while EPEAT require, as an alternative, providing information on how to obtain and replace the battery. The Repair Scoring System requires, in addition, that functional specifications and compatibility with other products of parts (such as batteries and external power supplies) is made available.

Information on self-repair implication on computers warranty
Some warranty clauses can affect the actual possibility of repairing the product. EU GPP criteria require confirming which parts are covered by service agreements under the warranty. A product is considered to score points under the Repair Scoring System only if

the warranty is ensured for the entire product. The Repair Scoring System also requires to inform consumers about any implications of self-repair or non-professional repair for the safety of the end-user and for the legal guarantee (and when applicable also to the commercial guarantee).

Availability of information to different target groups and communication vehicles

Depending on its level of sensitiveness, the information reported above can be accessible to different target groups. The voluntary labels analysed require, whenever an information requirement is included, to have information accessible to the generic public (i.e. all possible users). A graded approach is presented in the Repair Scoring System, where information to carry out a repair has to be made available to professionals (either authorised repair centres or qualified independent repairers) in order to enter the assessment framework (corresponding to a minimum requirement under Ecodesign); higher scores are then assigned in case relevant information is made publicly available.
Different communication vehicles can be used including external packaging, publicly accessible websites and manuals (e.g. service / repair or user manuals). This wide range of information sources and vehicles could make difficult the comparison of products, especially at the decision stage (e.g. the point of sale).

Conclusions

This research shows a spectrum of repair information and instructions required by different policy tools and voluntary labels for computers.
As "entry level" in the EU market, the Ecodesign regulation obliges manufacturers to inform consumers about the skills needed to replace a notebook battery. However, the ongoing revision of the EU regulation 617/2013 could introduce a more ambitious set of mandatory information supporting the repair of computers, as already done for related product groups (e.g. servers, displays).
Among the voluntary labels analysed it is evident that only those more oriented to business to business procurement have been able to reach a good level of market penetrations.
Type I Ecolabels (such as TCO, the Blue Angel and the EU Ecolabel) aim to award the best environmental performing products on the market that are, together with other characteristics, repairable. These ecolabels aim to ensure the reparability of key components and require providing comprehensive information available to the end-users (e.g. contacts of professional repairers, disassembly instructions, information on the availability of spare parts).
EPEAT, although characterized by a less ambitious entry level, can stimulate the market by qualifying the products according to the different level of ambitions reached (bronze/silver/gold). The best performing products meet optional criteria such as the provision of detailed disassembly instructions, diagrams and the availability of troubleshooting instructions in a publicly accessible website.
A similar approach is proposed in the Repair Scoring System, where an entry level is associated to the availability of repair information limited to professional independent repairers. A potential label based on the Repair Scoring System would have the advantages of addressing specifically reparability issues and being more complete and granular in terms of requirements. However, how to best communicate this information with consumers is still under discussion.
In this context, and in absence of further initiatives, consumers could still have some difficulties in the access to reparability information, especially in the purchase decision stage.
This work, showing examples and results achieved by voluntary labels and initiatives established in the EU market, can serve decision makers as guidance for a broader and harmonized diffusion of repair information. This could support the formulation of relevant policies and strategies allowing more sustainable purchase decisions of consumers and public administrations.

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Cigar Box Guitar Forums: Fostering Competency, Creativity and Connectedness in Communities of Practice and Performance

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Keywords: DIY; Making; Performance; Musical Instruments; Social Media.

Abstract: This paper analyses research carried out into a particular group of makers whose DIY activities are centred on the creation, dissemination and performance of home-made musical instruments in the form of cigar box guitars. As objects that are based almost exclusively on notions of recycling, reuse and upcycling, cigar box guitars extend the life of component parts that would otherwise be discarded, but also, as hand-crafted labours of love, the resulting instruments are often used for extended periods, being added to, altered and reconfigured over time as new components become available and the makers' skills improve. This community of makers more often than not carry out their making practices in isolation, meeting in person only at festivals and concerts where performance with the home-made instruments takes place. For many, this activity is their first foray into creative production of any kind, and often, they need to find solutions to problems they encounter in the making of their instruments. Because of the solitary nature of the activity, these makers make extensive use of online forums and networks to become part of a community of practice, openly sharing their knowledge and experience to help each other, and to celebrate their achievements of productive labour. It is argued that the use of social media in this way is directly linked to the extension of product lifetimes of the objects made.

History, Context and Background

Cigar box guitars (and also cigar box fiddles, canjos, banjos and ukuleles – see Figure 1) are very simply constructed objects usually created through the upcycling of discarded objects and the recycling of reclaimed materials. Originally acoustic instruments appearing around the middle of the 19th Century in America, the building of cigar box instruments was initially driven by necessity and they were made by Civil War soldiers, frontier immigrants and plantation workers and sharecroppers that had no access to professionally made instruments. They were a means of entertainment and raised morale amongst poverty-stricken, isolated groups of people, speaking to the commonly held belief that making music is far from a distraction and more an essential part of the human condition. As standards of living gradually improved and the necessity for self-built instruments fell away, the cigar box guitar came to be regarded more as a child's plaything. The cigar box guitar was a staple project of the American DIY boom of the 1950s and 1960s, often made as a bonding exercise between fathers and their children. However, in the late 1990s the cigar box guitar reappeared in the USA as a 'serious', amplified instrument – a reactionary object representing an alternative to mainstream consumption. The 'Cigar Box Guitar Revolution' encouraged people to make themselves an instrument and to get out and perform with them in public. The scene rapidly grew and now cigar box guitar festivals are held across the whole of the United States. When the American blues player 'Seasick Steve' appeared on UK television in 2006, the US cigar box guitar scene started to grow significantly in the UK.

Figure 1. Selection of 'cigar box guitars' made from cigar boxes, wine boxes, and various tins by Spatchcock and Wurzill. Photo by Author.

Through a series of in-depth interviews and observations, an earlier research study explored the creation of these instruments in the UK in an attempt to uncover the making processes involved and the motivations that drives makers to create them (Atkinson 2018). That study concluded there is, as in the USA, an element of resistance evident, which is the predominant force in the UK scene. There is a realisation that there is no real requirement to buy an instrument made in a Far East factory and unsustainably shipped to the West, or to pay huge sums of money for a factory-made guitar bearing a famous (usually American) maker's name. Perfectly good music can be produced on a far from perfect instrument. In fact, a key element for many of the UK makers was that wherever possible, the materials used should be recycled, reused, repurposed or upcycled rather than bought, despite a whole infrastructure of online suppliers of cheap parts for such instruments having appeared to support the scene in recent years (with many suppliers based in China).

Isolation, 'Flow', and the desire to connect

The original study found that one of the important issues encountered by makers was one of isolation. The vast majority of makers build guitars in workshops or sheds outside of the home, and so spend many hours alone. Many of these regularly experienced a 'flow' state, described by Mihaly Csikszentmihalyi as the point at which people are fully engaged and completely occupied while concentrating on an activity and nothing else seems to matter (Csikszentmihalyi 1990). Makers would enter their sheds or workshops early in the morning and then re-emerge to find that the whole day had slipped by. This may go some way towards explaining the makers' extensive use of social media to counteract the feelings of isolation. However, even those makers producing cigar box guitars as a cottage industry stated how important it was to them to meet people involved in the activity face to face. Whether this was through selling their instruments at festivals, or through attending or taking part in cigar box guitar performances, the fact is that the cigar box guitar more often than not becomes not only a means to an end, but an intrinsic part of the maker's lifestyle.

Netnography and the use of Social Media

An important aspect then, not fully explored in the original study, is the desire that cigar box guitar makers evidently have to feel that they belong to a community of like-minded people – being part of virtual communities connected through social media as well as physical communities of people for whom meeting and playing their home-made instruments in public is a primary concern. Netnography is 'a research methodology of ethnography adapted to the study of online communities' (Kozinets 2002). Analysing the content of internet-based activity allows insights into the drivers and motivations behind the behaviours of online communities.

The virtual communities studied here interface through well-established websites such as *Cigar Box Nation*, *Hand Made Music Clubhouse*, *The Musical Instrument Makers Forum* or *Homemade-Guitars*. Interviews revealed that the main go-to website for people joining the scene is *Cigar Box Nation*, the website set up in 1993 in the USA by Shane Speal, the founder of the 'Cigar Box Guitar Revolution' (Speal 2018: 9) that boasts almost 20,000 members. This site hosts instructional videos on making and playing, acts as a repository of downloadable plans, as an online store of parts and materials, and as a discussion forum for makers. Helpfully, the site counts the discussions that have accrued over the years under particular categories, with by far the most popular at the time of writing being 'Building Secrets, Tips, Advice, Discussion' (5,167 discussions) followed by 'Performances, How to Play, Lessons, Concerts' (2014 discussions). By comparison, all the other discussion categories, including 'For Sale: Cigar Box Guitars, other instruments, cds and related items', 'Fests and Concerts: Organizing and Promoting' and 'Other Stuff – off topic, fun stuff, whatever', number only in the hundreds.

As well as the use of websites specifically aimed at cigar box guitar makers discussed above, general websites such as *YouTube* also play a huge role in encouraging the movement through the hosting of instructional demonstration videos as well as hosting libraries of cigar box guitar performances. However, reflecting changing online practices, the majority of online activity for the movement now occurs through Social Media including

Twitter, Instagram and Facebook groups and pages including *Cigar Box Guitars*, *UK Cigar Box Guitars*, *Cigar Box Guitar Builders, Owners and Players, Cigar Box Guitar History*, and *DIY Cigar Box Guitars* among many others.

A simple 'netnographic' analysis of the different types of postings on Facebook provides an insight into the ways in which members connect with each other, promote participation and transfer knowledge on an open basis. An analysis of 50 randomly selected posts were coded and fell within five basic types. These are listed below with a few examples given of typical posts within each group.

Self-promotional posts - Making:

- Look at this cigar box guitar I've just made/ have for sale
- I've found these cigar boxes/ components I'm going to use
- Advertising cigar box guitars/ components for sale

Self-promotional posts - Playing:

- Video of me playing my latest cigar box guitar at home/ on stage
- Download my latest tracks here/ links to YouTube videos
- Advertising CD's for sale

Calls for help:

- I've got a problem making this cigar box guitar – can anyone suggest solutions?
- I want to use nails as frets – what problems am I likely to have?
- What's the best position for this particular pickup?

Instructional posts/videos:

- This is how to make a cigar box guitar/ solve a problem/ Downloadable plans
- Reviews of related equipment, tools, pedals or amplifiers
- How to play 'Spirit in the Sky' on a cigar box guitar

Promotional posts:

- Advertising Cigar box guitar-based performances / festivals/ trade shows
- Sharing 'found' posts/ videos of players, instruments etc.
- General promotion of the scene – cartoons, old photos etc.

To see if there was a pattern to the distribution of these different types of posts a sample of four Facebook groups was chosen, and the posts over a period of one month (May 2019) were analysed. The deliberately diverse groups chosen were *Cigar Box Guitars* (9,670 members); *Cigar Box Guitar Builders, Owners and Players* (3,264 members); *UK Cigar Box Guitars* (829 members) and a page (as opposed to a group) *Cigar Box Nation* [hosted by the people behind the Cigar Box Nation website] which at the time of writing had 54,365 followers.

The results (Table 1), particularly when graphed (Figure 2) show a remarkable similarity of distribution, despite the markedly different number of actual posts. When averaged out, by far the largest number of posts were self-promotional posts where people took the opportunity to display their making skills, followed by posts where people demonstrated their playing skills, which follows exactly the most popular discussions on the *Cigar Box Nation* website as mentioned above, showing a continuation of the dominance of these two topics. There is some crossover between these two types of posts, as very often, the people demonstrating their playing ability are simultaneously demonstrating the sound of an instrument that they have made. The next most common post types were more altruistic, promoting the cigar box guitar scene in general terms, advertising festivals or sharing historical photographs of cigar box guitars or related images. Next came calls for help, with less experienced members hoping for a solution from more experienced members, and finally came instructional posts, with members demonstrating how to perform certain making tasks, or providing lessons on how to play particular tunes. Some crossover between all these results occurs as the same posts were very often submitted to a number of different Facebook pages, so the entries are not unique to that page or group.

Facebook Cigar Box Guitar Pages	SP Making	SP Playing	Promotion	Call for Help	Instruction
Cigar Box Guitar	260	139	70	24	28
Cigar Box Guitar Builders Owners and Players	221	104	47	43	16
UK Cigar Box Guitars	65	26	15	8	13
Cigar Box Nation	17	13	6	0	15
Average	140.75	70.5	34.5	18.75	18

Table 1. Distribution of post types.

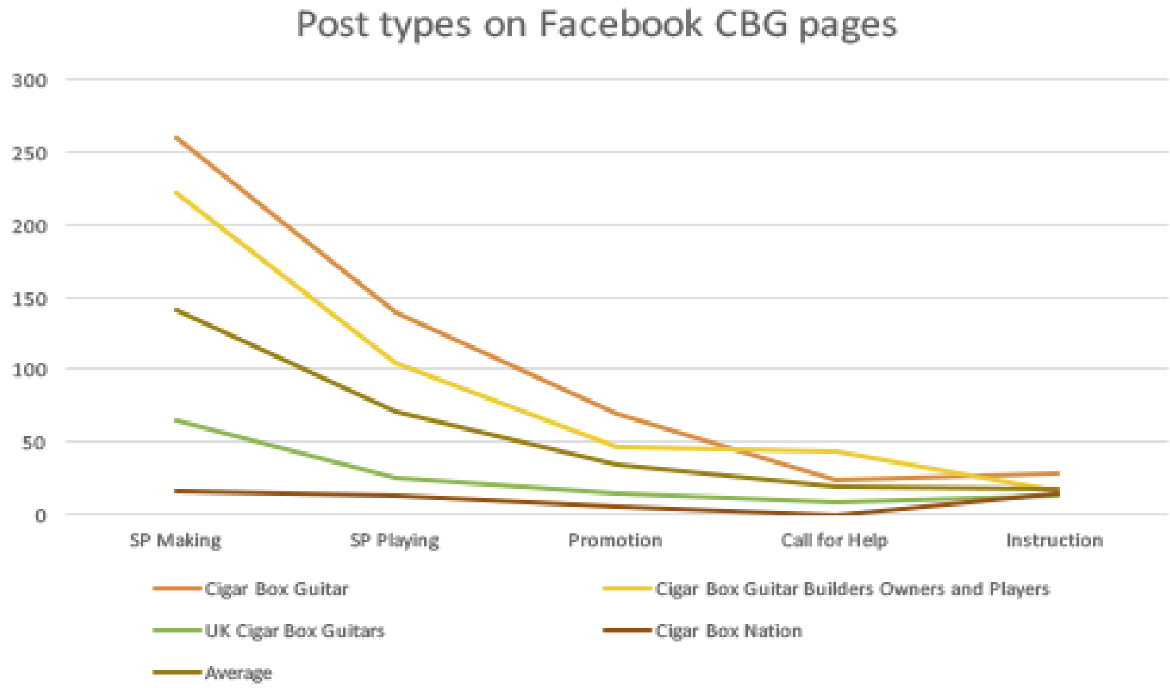

Figure 2. Distribution of post types.

Promoting Participation: Fanzines, Festival and Workshops

An element that was evident in the original study, and which has relevance to the subject of extending product lifetimes, is one of altruism among members. A number of the makers interviewed had struggled to learn how to make the instruments in the early days of the movement, and wanted to help others get involved in learning the making process. This resulted in the hosting of workshops where complete beginners could be taken through the process stage by stage, making an instrument from scratch and learning a basic tune to play in a single day. The most prolific of these has been 'Chickenbone John', one of the leading lights of the cigar box guitar scene in the UK, who has taught almost 2,000 people how to make and play an instrument.

Chickenbone John's other big contribution to promoting the cigar box guitar in the UK has been his hosting of an annual festival called 'Boxstock', usually held in Wolverhampton. This one-day event brings together makers and players from all over the country, with a number of the makers having stalls to sell finished cigar box guitars, cigar boxes and wooden neck blanks ready to use in making, specialised tools such as fret slot saws, guitar hardware such as tuners and strings, and related equipment such as amplifiers. Various demonstrations are also given on specific aspects, such as hand winding guitar pickups, and open mic slots are available through the day for people to perform on stage. The evening sees a concert of invited artists from across the country and from Europe, all performing with home-made instruments constructed from recycled parts.

Further promoting the movement, individual makers have at times progressed from making and selling cigar box guitars to producing online fanzines, such as *CBG Review*. This high-quality fanzine, launched in 2017, is assembled and edited by Ross Hewitt, an Australian now based in Switzerland, and promotes the scene as a now global phenomenon, showcasing the craftwork of makers, publishing interviews with players and reviewing gigs and festivals.

Conclusions

In conclusion, the sense of connectedness achieved through active participation in online and real life communities of practice and of performance is a hugely important part of the world of the cigar box guitar maker. The main impact of these communities on the makers is to move their practice away from being purely a Do-It-Yourself activity into one of Do-It-Together or Do-It-With-Others, even if the participation is on the level of knowledge exchange rather than hands-on construction. In doing so, increasing numbers of people are becoming involved in a creative activity (many for the first time) where they realise they have the ability to make choices and decisions about what materials to use (and reuse) and the freedom to use any found objects and upcycled parts resulting in unique products that they have an incredibly strong emotional bond with. Statements made by cigar box guitar makers during the filming of *Three Chords and the Truth*, a documentary film on the subject (Heath & Atkinson 2019), made it clear that makers saw their guitars as extensions of themselves:

“This is part of me. I mean, it’s come out of my head and out of my endeavours. It doesn’t exist anywhere else before I’ve got these little bits of scrap wood together and made it. The sound appears and you think ‘Wow! You know, that’s me. That really is me, because this doesn’t exist if I hadn’t have made it.”

Such emotional bonds are absolutely key to preventing the object being discarded at a later date. By developing such bonds, makers proactively extend the product lifetime of the component parts they select, and through constant upkeep, repair, alteration and additions to their instruments as they gain experience, they extend the product lifetime of the instruments they create.

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PLATE
Product Lifetimes And The Environment

Ten Golden Rules of Design for Sustainability

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Keywords: Design; Guidelines; Sustainability; Circular Economy; Product-Service Systems.

Abstract: This paper presents a generic set of guidelines of Design for Sustainability (DfS), targeted at product and service design students. A literature review showed that almost all generic guidelines of DfS are over a decade old and relatively outdated. Recent DfS literature tends to focus on sector, life cycle stage or industry-specific guidelines. However, for students of design, having a number of state-of-the-art DfS guidelines that give an overview of the field, was considered useful as the field is currently experiencing a period of rapid development and renewal. For design researchers the guidelines can serve as a springboard for a debate on recent developments in design for sustainability. The paper presents the 'ten golden rules of design for sustainability' based on literature and the general discourse in the field. The ten golden rules are ordered according to the product lifecycle and include a system-level perspective. The rules are: (1) design adaptive systems, (2) design for net-positive impact, (3) go bio and renewable, (4) go clean, (5) do with less, (6) ensure equity and well-being, (7) support and shape sustainable lifestyles, (8) design for long use and reuse, (9) design for endings and (10) design for recovery.

Introduction

The field of product design for sustainability (DfS) has developed and branched out over the past three decades (Ceschin and Gaziulusoy, 2016). This is good because it indicates that, as a field of research and practice, design for sustainability is developing and maturing. The downside however is that the field has diverged to a point where it becomes very difficult for design students, and even for professional designers, to fully grasp the concept of 'design for sustainability' and find starting points for its operationalization. The objective of this paper is to develop an updated set of generic guidelines of DfS. More precisely, the objective is to create support tools in the form of guidelines or rules, for the design process of product-service conceptualization and development.

The main target groups are product and service design students and design researchers. For design students, it was proposed that the rules could be helpful as a generic mnemonic and to give direction and inspiration for their projects, and for design researchers they could serve as a springboard for a debate on the latest developments in the field of design for sustainability. Given that the most recent paper on generic Design for Sustainability guidelines was written in 2006 (Luttropp and Lagerstedt, 2006), this paper is considered a timely contribution to the field.

Background

The more recent papers that aim to provide guidance for DfS tend to focus on specific fields or subsets of DfS such as energy efficiency (Bonvoisin et al, 2010), recycling (Fakhredin et al., 2014), remanufacturing (Ijomah et al., 2007), repair (Flipsen et al, 2016), emotional durability (Chapman, 2015), 3D printing (Sauerwein et al, 2018), Computer-Human Interaction or HCI (Silberman et al., 2014, Knowles et al., 2018) and software (Becker et al., 2015). There is also a sizeable literature that deals with DfS guidelines for specific sectors or product categories such as fashion (Fletcher and Tham, 2015), medical systems (Kane et al, 2018), automotive (Schöggl et al, 2017), and even vending machines (Vezzoli and Sciama, 2006).

Both generic and specific guidelines are relevant in design; they have different purposes. Being involved in teaching design students the first principles of DfS, we felt the need for an updated generic set of guidelines that reflects recent shifts in perspectives in the field of Design for Sustainability.

Method

In this paper we follow Vezzoli and Sciama's (2006) definition of guidelines as "procedures to orient a decision process towards given objectives." We use the word 'rule' as synonym of 'guideline'. After developing a set of criteria for the guidelines, recent literature on Design for Sustainability was reviewed from the fields of product and service design, HCI, urban design and systemic design, taking care to include conference proceedings and grey literature as this is where interesting academic discussions tend to unfold first.

The following set of criteria was used for the development and choice of guidelines:

1. Life cycle focus. The rules should follow the principle of life cycle design (Vezzoli and Sciama, 2006), in particular "the extension of the design horizon from product design to the systemic design of all product life cycle stages." (p.1320)
2. Applicable to product-service systems, which were defined by Tukker (2004) as 'tangible products and intangible services designed and combined so that they are jointly capable of fulfilling specific customer needs." (p. 246). The rules should be valid for tangible (product) as well as intangible (service) design.
3. Newness. The guidelines should reflect the latest developments and most important new insights in the field of DfS, drawing from a variety of sources.
4. Generic. A small number of guidelines should be selected in order to give a generic overview the field without too much detail. Each guideline should give access to a deeper layer of knowledge and insights.
5. Inspirational and aspirational. The guidelines should be ambitious and give promising directions.
6. Non-redundancy and avoidance of conceptual overlaps. Each rule should represent a clearly separated area of concern.
7. Adaptability. Designers should be able to adapt the guidelines to their own project or process.

Results

The ten golden rules are listed in figure 1, ordered according to the product lifecycle stages of production, use and recovery, with 'system' added as an overarching category.

System

On system level, two rules try to capture the essence of systemic sustainable design. The first rule reflects a break away from an eco-modernist 'command and control' stance: **design adaptive systems**. Sustainable design is systemic by nature. This is for instance reflected by the recent 'systemic design' initiative, that aims to integrate systemic thinking and human-centered design to help designers deal with highly complex problems such as posed by the United Nations Sustainable Development Goals (Jones, 2017). Rather than claiming that design can come up with definitive solutions, systemic design aims for "aspirational change" through "better-fit processes and practices" (Jones, 2017). Sustainability is not a distinct point on the horizon, instead we have to acknowledge that we are in constant flux. As Håkansson and Sengers (2014) put it: "there is no such thing as a fixed 'sustainability' where change is no longer needed. Products, services and systems need to be open for ongoing change along the way." The design of adaptive systems, open for change and adaptation over time, is fundamental to a state-of-the-art Design for Sustainability methodology.

The second rule, **design for net-positive impact** stipulates that, through the design of adaptive systems, we should aspire to create products, services and systems that have an overall positive impact on the environment and on society. Net-positive outcomes have in the past decade become a topic of academic discussion in the field of sustainable architecture and urbanism. Birkeland (2012) for instance describes net-positive outcomes as able "to expand future options, diversity and ecology." Any design intervention in a system will have both positive and negative impacts. For instance, designing water filters for use in Africa will have a positive impact on overall health. But the environmental cost of producing the filters in China and transporting them to Africa, and the impact on household finances to purchase the filters, would have to be weighed against the potential benefits. Hertwich (2005) warns us to be aware of these rebound effects, which are behavioural and systems responses to an intervention. Hertwich argues that any design intervention aimed at solving a particular problem will show co-benefits, spillover effects and negative side effects and these need to be understood in order to increase the chance of a design intervention having a net-positive impact. Essential in this process, according to

Birkeland (2012), is to move away from design approaches that encourage "choosing among alternatives" as this results in 'trade-off thinking' that allows social gains to balance out ecological losses. Instead we should aim to design "new synergistic alternatives." This requires the development of tools that assess designs on a positive scale while taking into account potential rebounds, which is an underdeveloped field. On a policy level, the EU has started to put in place a system of natural capital accounting (La Notte et al, 2017), which may, in time, inform the development of new design tools.

Figure 1. The 10 Golden Rules, see appendix for larger version.

Production

The many eco-design guidelines that are related to the production of materials and products tend to converge on one topic: reduction. Reduction of materials and energy consumption, reduction of production waste, reduction of transport, reduction of toxic and other harmful substances, etc. (for instance, van Hemel and Cramer, 2002, Luttrop and Lagerfeld, 2006). We decided these guidelines needed reframing. The climate crisis (Carrington, 2019) requires us to do more than reduce and optimize. The third rule, **go bio and renewable** addresses the urgency to keep global temperature increase below 1.5°C by a rapid and far-reaching transition towards a low-carbon economy (IPCC, 2018). This requires us to embrace alternatives for fossil-based materials and energy sources. Future polymers, for instance, will increasingly be biodegradable and bio-based (Lambert & Wagner, 2017) and designers will have to learn how to design with these, as well as with renewable energy technologies such as photovoltaics, wind and hydrogen-based systems.

The fourth rule, **go clean,** is about ensuring that the products and services we develop and the materials and processes we specify, cause no harm to human health, are non-critical (Köhler et al., 2013) and do not pose toxicity and other detrimental risks to ecosystems. The recent attention for marine microplastic pollution (for instance Haward, 2018) has put 'go clean' firmly back on the design agenda.
The fifth rule **do with less** reflects the need for designers to attain absolute reductions in (both renewable and non-renewable) materials and energy consumption and to consider sufficiency in consumption. Decoupling economic growth from its material impacts has proven not to work. Jackson (2009) proposes that we need to find new ways to define prosperity, without growth. Translated to design, sufficiency touches upon the very roots of our profession, for should we – can we - decide *not* to design?

Use

Sustainable design strives to end poverty and improve well-being through products and systems that support universal access to better nutrition, healthcare, education, information, housing, clean water and basic sanitation. This is reflected in the sixth rule, **ensure equity and wellbeing**. This rule is inspired by the United Nations Sustainable Development Goals. As it covers a wide and important area with much design activity that we cannot do justice in the limited space of this paper, we refer to the descriptions and targets of the SDGs for extensive information and data (UN, 2015). The seventh rule focuses on behaviour change through design. A field of vigorous design research interest, it asks how design can intervene in everyday life to **shape and support sustainable lifestyles** for (groups of) people and communities. A multitude of approaches and methods has sprung up. Among the modernistic approaches are for instance Design for Sustainable Behaviour (e.g. Lilley, 2009) that looks at design as a 'lever' to which an individual will respond by changing his/her behaviour. On the other end of the scale are the constructivist approaches that consider everyday practices to be socially constructed, both stable and changeable in time. This makes behaviour change a collective, social process rather than an end-point (Kuijer and Bakker, 2015) and requires design to adopt co-creation and action research as part of its toolbox (Tromp and Hekkert, 2019, Håkansson and Sengers, 2014). Rule number eight, **design for long use and reuse**, was included as a response to consumerist trends such as the increasing rate of change in the fast fashion industry (Day et al, 2015), the proliferation of plastic disposables (EC, 2019) and the long-term decrease in repairability of devices such as smartphones (ifixit, 2019). Design for long use and reuse is about creating products that last and that can be loved and cherished, maintained, repaired, reused, upgraded, adapted, personalized, refilled and repurposed for as long as possible (Bakker et al, 2014, Van den Berg, 2015).

Recovery

In an economy that should increasingly focus on becoming more circular and that should maintain high-value and high-quality material cycles (Korhonen et al., 2018) it is no longer useful to talk about 'end of life' of products, as this suggests a rather linear lifecycle from cradle to grave. Instead, we use the word recovery to highlight the strategic importance of recovering obsolete products and materials, and looping them back into the economic system (Den Hollander et al, 2017). Recovery is probably one of the least researched Design for Sustainability areas. The ninth rule, **design for endings** reflects the key role consumers have in closing resource loops (Zeeuw van der Laan, 2019, Selvefors et al., 2019). For a consumer or user, ending the engagement with products and allowing these to flow back into the economic system, is an important, but generally overlooked, part of consumption (Macleod, 2017). Design for endings aims for well-designed and respectful 'offboarding' experiences. The tenth and final rule, **design for recovery** focuses on value retention processes such as refurbishment, remanufacturing and recycling. This requires the development of design strategies that help create, preserve and recover value, which gives design for recovery a strategic edge, because value retention processes can "support growth opportunities ... by targeting and engaging new, previously untapped, market segments that are underserved by OEM new products" (IRP, 2018).

Discussion and conclusions

Having developed the set of 10 golden rules, we will evaluate these against the criteria in the method section. Regarding the first criterium, the golden rules clearly follow the principle of life cycle design, starting from a systemic view and following the three major stages in a product's life, production, use and recovery. Its applicability to product-service-systems (criterium 2) is however open to debate. The 10 rules have a bias towards tangible products. We struggled to find ways to incorporate intangible product services (including digitization) into the guidelines, and the lack of literature on this topic is a sign that more exploration is needed here. For instance, dealing with software sustainability has been addressed by Becker et al. (2015) but the resulting manifesto still needs to be translated into usable guidelines for product-service designers. With regard to criterium 3, the rules try to reflect new insights in the field of DfS. It is quite possible that aspects were overlooked, or not given the spotlight they deserve. For instance, the renewed attention for transition design (Lockton and Stuart, 2018) or for the existential crises we are facing (Fritsch, 2018) may, in time, lead to new guidelines.

The choice for 10 rules (related to criterium 4) is somewhat arbitrary, and was critiqued during discussions with colleagues (see below). Regarding criterium 5: the rules are certainly ambitious and an attempt was made to reframe them away from a reductionist approach. Criterium 6 asks for non-redundancy and avoidance of conceptual overlaps. Each rule does represent a separated area of concern. However, the two systemic rules are, by nature, broad and inclusive and operate on a higher level of abstraction. A certain overlap between the 'system' and other rules is unavoidable.

Finally, according to criterium 7 designers should be able to adapt the guidelines to their own project or process. This has not been tested in practice yet.

The evaluation of the rules against the criteria is a first internal validation. Additional internal validation will have to be done by discussing the rules with independent DfS experts, and an external validation would involve testing the rules with students in a design project. A first debate with colleagues of the Design for Sustainability research group at TU Delft led to the following critiques of the 10 Golden Rules:

- The choice for 10 rules comes across as arbitrary and unscientific. Why not 12 or 8 rules?
- Economic sustainability ('prosperity') is not taken into account.
- A meta-guideline is missing that argues that all 10 rules should be considered as interdependent, to prevent students from cherry-picking.

- There is nothing on ethics (not directly, at least) or sustainability assessment.

It follows that creating a compact set of up-to-date generic DfS guidelines is not a scientifically rigorous process. Choices need to be made, and this inevitably reflects some of the biases of the creator of the guidelines. The ten golden rules should be regarded as a discussion piece; the intention is not so much to reach consensus (which may be an elusive goal), but to spark conversation and debate. It is also important to realize that no set of guidelines is ever fixed; guidelines can and should evolve in time. We hope that the 10 Golden Rules will lead to renewed debate in the field, drawing on insights from different disciplines, and that they might offer design students some guidance and a first window into the complex but fascinating world of design for sustainability.

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Appendix

Figure 1. The 10 Golden Rules of Design for Sustainability (large version).

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Circular Fashion Archetypes – a Feasibility Study Exploring how Makerspaces Might Support Circular Innovation, within the Context of Fashion and Textiles

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Keywords: Circular Economy; Sustainability; Textiles; Fashion; Makerspaces.

Abstract: We live in a 'throwaway and replace' culture, our growing population and demand for new products has placed huge pressures on our planet's resources. Our economy is locked into a system in which everything from production to economics and the way people behave favours a linear model of production and consumption, where resources pass through from sourcing to disposal in a 'take-make-use-dispose' construct. Climate instability, volatile commodity prices, ocean dead zones, vanishing forests, stalling economic growth, expanding food insecurity and resource conflicts are all part of the resource to waste linear economics (Grayson, 2008). Any of these are surely justifiable reasons to explore a new pattern. This research presents the findings from a feasibility study exploring Redistributed Manufacture (RDM) in Maker Spaces, using these hubs to experiment with new making practices and processes for reusing local textile waste. With the aim cultivating knowledge, skills and capabilities to grow Circular Economy (CE) practices in Scotland. The exploratory method of developing 'Circular Fashion Archetypes' is discussed and applied as a practical solution to connect different stakeholders and prototype a local model for a circular supply chain. The insights drawn from this research act as a starting point for future work, reflecting on the implications of the methods applied, concluding the circular economy is the same imperative whether people are focusing on ecology, economy or just their own business. Furthermore, it will suggest that design-led approaches play a role in embedding collaborative ways of working to integrate sustainability into the business modelling process.

Introduction

This research is responding to the ecological crisis of waste in today's fashion industry and aims to question conventional approaches, in relation to garment design, production, consumption, use and re-use.

Within a linear system typically, fashion consumers are not aware of the materials or production methods used in the industrial system, nor are they aware of the range of approaches that can be used to extend garment lifetimes (Gwilt, James, 2019). At the same time the mainstream UK fashion system is generally made up of profit-driven businesses that are dependent on a seasonal cycle of producing and on selling large quantities of clothing to meet economic returns. Regardless of whether or not consumers want them, the fashion industry as a whole produce roughly 80 billion new garments annually, made from plastics or resource-intensive natural fibres like cotton (Fletcher, 2019). If we continue to use materials as we are today, we will need two planets to meet these needs (Meadows and Randers, 2012).

Further research is required to consider how we might dematerialise fashion and textile design practices and lessen our reliance on using new materials, as conventional methods of dealing with these issues have been cited as being symptoms based; they have not addressed continuous and rising consumption levels (Brooks, A., Fletcher, K., Francis, 2018). This clothing is currently designed in response to regularly changing trends that enable quick profit, often becoming obsolete as it is cheaper to buy a new piece than repair or alter an existing garment (Fletcher, 2012).

However, if we want to see changes in the consumption patterns of fashion or the attitudes among consumers we will have to design systems which includes them and takes their role in the lifecycle of clothing seriously. von Busch claims (2009) we need to create a 'declaration of dependence' between producers and consumers as the production phase is only a very small part of the garment's lifecycle.

This research aims to expand upon several principles of the Circular Economy to explore how designers might play a role in designing out waste and pollution and to identify design-led approaches which endeavour to keep garments and materials in use, which in turn might play a role in the regeneration of natural, social and business systems. Through practice-led research, this paper aim to address the following research question: How might fashion and / or textile designers tackle the issue of material obsolesce by creating Circular Fashion Archetypes to pilot new systems that nurture clothing longevity and support re-use, care and repair?

This research is aligned to a design-led business support programme titled 'Design for Business' - positioned within the V&A Dundee – a Design Museum in Scotland. Design for Business aims to broaden the current remit and focus of design by using Design Thinking methods and approaches, to enable businesses, organisations and even citizens themselves to tackle complex problems, such as the Circular Economy. This paper presents on-going practice-led research that began as a six-month feasibility study titled 'Re-Mantle and Make' (McHattie and Ballie, 2018; McHattie, L. S., & Ballie, J. 2018), funded by a larger project titled 'Future Makerspaces in Redistributed Manufacturing', a two-year research project funded by the Engineering and Physical Sciences Research Council (EPSRC). This research was conducted in partnership with Kalopsia Collective, a micro-manufacturing unit based in Edinburgh, Scotland, with additional in-kind support from several Scottish based textile manufacturers; Johnstons of Elgin, Begg and Company, MYB Textiles and the Scottish Leather Association, who participated within this research project and contributed further by gifting surplus textile waste from their factories.

This paper begins by outlining the current state of fashion, and most recent attempts to shift towards the industry focus towards circularity in an endeavour to address planetary boundaries. The following sections outline an action research approach to apply 'Circular Fashion Archetypes' as a method, with an aim of lessoning our reliance on using precious new materials.

The paper will conclude by reflecting on insights drawn from an emerging network of local, connected and engaged partners, by facilitating opportunities for them to work together as custodians for textile materials, as opposed to users. With a premise of interrogating the concept of the circular economy on a local scale, by using Makerspaces to experiment with redistributed manufacturing (RDM) methods, using high value textile waste sourced from the Scottish textile industry.

Context

Our planet provides us with an abundance of natural resources. However, with global demand rapidly outstripping supply, the fashion industry cannot continue to operate as it has in the past. As a result, various ethical and environmental issues related to fashion have been at the forefront of public consciousness and debate over the last few decades. More recently, the term 'Circular Economy' (CE) – has come to the forefront of this discussion to re-think how fashion is made, consumed and used. In a CE, the fashion industry, as the Ellen MacArthur Foundation (2017) sees it, should strive to ensure that "… clothes, fabric, and fibres are kept at their highest value during use, and re-enter the economy after use, never ending up as waste." The Make Fashion Circular initiative (2017 – present) steered from the Ellen MacArthur Foundation is bringing together leaders from across the fashion industry, including brands, cities, philanthropists, NGOs, and innovators. Its aim is to stimulate the level of collaboration and innovation necessary to create a new textiles economy, aligned with the principles of the circular economy. Its ambition is to ensure clothes are made from safe and renewable materials, new business models increase their use, and old clothes are turned into new.

This alternative model for a "new textile economy" is intended to sit alongside a linear fashion system that utilizes approaches focuses on reducing negative impacts, the circular vision for fashion is "… one that is restorative and regenerative by design and provides benefits for business, society, and the environment" (Ellen MacArthur Foundation, 2017, Stahel, W. R. 2016).

Within the UK, the RSA's Great Recovery programme has focused on the role of the design community in delivering a more circular economy. They highlight the importance of acknowledging that it is not the designer's responsibility alone to change whole supply chains and transition to a circular economy entails four fundamental building blocks – materials and product design, new business models, global reverse networks, and enabling conditions (Lewandowski, 2016). Businesses must also begin to develop design briefs around new business models that take account of provenance, longevity, impacts and end of life (Thomas, 2012). Existing business models for the circular economy have limited transferability and there is no comprehensive framework for supporting every kind of company in designing a circular business model (Lewandowski, 2016) and there are very few studies covering, how a circular business model framework should look. Most recently, the Ellen MacArthur Foundation has partnered with world leading design agency IDEO (IDEO, 2019) to develop the 'Circular Design Guide' – a toolkit to explore how design might play a strategic role in supporting circular innovation to support systemic change focusing explicitly on the fashion industry.

This research aims to learn from this ongoing work and expand upon it further to identify what sustainability strategies, innovation tools and business support is required to cultivate Circular Fashion Innovation and to re-think supply and demand on a local scale.

Methods and Approach

This research followed an Action Research methodology (Coghlan and Brannick, 2014) with methods integrated to support planning, action, observation and reflection. To build iterative approaches using the exploratory method of co-designing 'Circular Fashion Archetypes', the word archetype, is defined as an "original pattern from which copies are made".
Within this study, the premise was to build archetypes collectively, and test them to understand how they can might be used, to capture emerging insights and further refine each concept. To further explore how they might be implemented within a local circular supply chain designed to operate in a Circular Economy (CE).
With feedback loops designed into each of the research activities, to enable participants to reflect and share learning, to document insights as they emerged. These insights were capturing using a design method - 'Rose, Thorn and Bud (RTB)', and analysed using thematic analysis.

Research Activity

This feasibility study aimed to address the practicalities for repurposing textile waste within a redistributed manufacturing system (RDM) – supported by local Makerspaces. This was achieved through partnerships with Kalopisa collective and MAKLab in Glasgow who provided access to their facilities, resources and staff.

Sourcing High Value Textile Waste

The Scottish textile sector had previously expressed a growing awareness and responsiveness to circular innovation. This could be credited to the work undertaken by Zero Waste Scotland, who had provided a range of training programs and master classes (Zero Waste Scotland, 2014-18) tailored to demonstrate a wealth of different strategies such as design for modularity, collaborative consumption, zero waste design and pattern cutting and material efficiency (Wilson, 2015).

The workshop participants comprised of; design researchers, product designers, fashion designers, textile designers, Makerspace staff with expertise in digital fabrication tools, manufacturers – both managers and designers, micro manufacturers and citizens.

Workshop 1: Building Circular Concepts

The workshops were designed to facilitate collaboration by providing a platform for previously disconnected stakeholders from across the local textile economy to come together, to explore the complex and systemic issues around textile waste and to identify how they might work together in the future.

Figure 1. Mapping Circular Fashion Systems.

The workshop was framed using a design brief – to set the scene and frame a challenge around developing modular circular archetypes for a shift dress. The brief was produced in advance and supported by contextual research and reference materials. This was introduced to the participants ahead of the workshop to enable them to familiarise themselves within the issues. They were asked to adopt the mindset of 'material custodians' throughout the workshop.

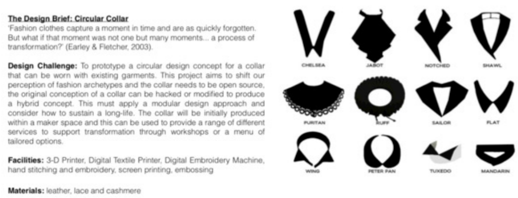

Figure 2. Circular Archetype Brief.

The workshop was supported by a design method titled 'Circular by Design' (CD) (Ballie and Woods, 2018). This resource was developed as a visual and strategic tool to map circular systems.

The method supports a holistic approach by allowing individuals to work together to explore circularity by mapping different stakeholders across their network and identifying their needs. They framed 'How Might We?' questions, this was followed by ideation, to build concept ideas for Circular Archetypes. The purpose was to challenge each individual within the group to adopt a systems thinking view, to consider end of life strategies at the beginning of the design process, and to understand the role and responsibility of each stakeholder across the supply chain. With ultimate goal of sustaining and optimising the flow of materials.

Workshop 2: Building Circular Fashion Archetypes

The second workshop was facilitated to focus on making textiles, to explore how Makerspaces facilities could be used to rework these textiles to support Re-Distributed Manufacturing (RDM) methods. The Makerspaces were used as a lab to foster an enabling culture; build local connections; nurturing individual / community capacities; and for stimulating practical application. Throughout this workshop the author / facilitator aimed to unearth everyday 'how-to' guidance to interweave circular practices for the local textile economy. Throughout this process, the participants also began to prototype the KIT within a domestic home sewing box by combining digital fabrication tools to provide an extended palette of making options that included; laser cutting, 3D Printing, digital textile printing and digital textile embroidery.

Figure 3. Re-Distributed Manufacturing Textiles.

Figure 4. Building Circular Fashion Archetypes.

The Circular Archetypes emerged around prototyping a circular system around a simple shift dress, exploring how it could evolve overtime through swapping in and out accessories that are modular, open source and zero waste. Rather than disposing of clothing once it has served a purpose, might parts be replaced or re-made locally, to enable citizens to re-assemble their garments over and over again, making them last much longer. However, a more, complex and in-depth exploration of patterns and prototypes is required, as opposed to designing and manufacturing regular ready to wear clothing (Karell, 2014).

Findings

In this research, we see how connecting different stakeholders from across the supply chain is instrumental in supporting circular practices. However, the research unearths many contradictions in the current narrative about circularity in Makerspaces. For instance, the business focus of the CE, and the required Sustainable design strategies will require intensive resource management to implement a RDM system for the local textile economy in Scotland.

To evaluate the study the research team undertook research observations during each workshop and conducted an evaluation using RTB method and analysed the data using thematic analysis. Discussion was facilitated to challenge existing perceptions and prompt conversation around circular innovation to re-think design, production and use. The following insights emerged;

Circular Supply Chains

Throughout the workshops the author/s emphasised the need for creative and participatory methods and approaches to enhance cross-disciplinary, cross-sector awareness and understanding of the need to design for a circular economy. A concern that is frequent voice about the proposition to extend the garment lifetime is that there is no economic incentive for producers to move away from manufacturing large volumes of clothing (Gwilt, James, 2019). However, this small study demonstrates how we might go beyond traditional approaches to manufacturing textiles, further research might work towards textile durability and service design, focusing on offering design solutions for upgrading, repairing or exchanging.

Circular Custodians

The design brief was written to encourage those who participated within each of the workshops to challenge themselves as designers and citizens alike, to re-think new ways of designing. With a focus on developing concepts with 'designer-user' relationships to consider the cultivation of a new approach to consumption in which the user is provided with an opportunity to learn new skills, knowledge, and is motivated to extend the life or use of their clothing. This is a new challenge for industry, business and designers, but also for consumers, who need to critically consider their own consumption practices.

The flow of Textiles within Circular Systems

The feasibility raised further questions about the willingness of businesses to collaborate with both independent designers and makerspaces in the future. Many makerspaces are not financially self-sustainable. There a gaps within circular textile systems and the role of a collector or sorter will be pertinent in the future.

Conclusion

We have to create a new consciousness towards the use of clothing and introduce new practices for using our clothing longer, maintaining it well, but also investing in a smaller wardrobe with less content. Circular Fashion Archetypes offer an alternative to buying something new, opposed to energy going into creating a new piece, reuse extends the life of these item and cuts down on their carbon footprint. Within the future, the role of the citizen interrogating their own 'fashion footprint' will be essential to understand the narrative of the CE but to in order to engage they require more support.

We also require more examples of circular fashion systems in all scales, from the local and unique to the global and mass-produced. Although the fashion industry proclaims to be innovative and new, the reality is the design, manufacturing and production and consumption processes have remained relatively unchanged since the introduction of ready to wear clothing in the late 1800s (Manlow, 2009). This research endeavoured to learn more about the drivers for cultivating resourcefulness and cherish-ability within fashion and textiles – a term coined by

Chapman (2006), but experimentation was required to identify creative methods through which these approaches could be implemented.
This study provided a different lens through which to view micro-manufacturing from a textile design perspective, with materials sourced from large scale industrial textile manufacturers who service a global fashion industry. While emergent, the Circular Fashion Archetypes provide stimuli to facilitate circular conversations to continue to discuss how we might expand upon the role, skills and capabilities of the designer in the future to equip them to operate within a circular economy.

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A Performance and Consumer-based Lifespan Evaluation for T-shirt Eco-design

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Keywords: Consumer-Oriented Quality; Normative Duration; Material Damage.

Abstract: Increasing clothing longevity is recognized as a promising lever to help in reducing apparelsector's environmental impacts. However, longevity evaluation of textile products remains complex and so tracking of longevity factors is needed. Current researches mainly focused on garment design to increase lifespan. Since, no researches involving fabric quality, raw material and technical performances were carried out in this sector, we defined a methodology to address the lack of performances-based approach to help in evaluating clothing longevity. We defined the consumer-oriented quality (COQ) score. Since it relies on both the consumer and the product knowledge it could be used as a normative duration index. Indeed it takes into account relative importance of material damage that lead to disposal, and products performances (i.e. their ability to withstand these damage). To assess COQ score's appropriateness as a lifespan index, products were truly aged through a wash and care procedure and were evaluated by a non-trained panel to determine whether or not they were still usable.

Introduction

The clothing sector is said to be responsible for 2% to 10% of private consumption's environmental impacts (Tukker et al., 2006). Design for longevity as recognized eco-design lever (ADEME, Fangeat, Chauvin, & le pôle usage et durée de vie, 2016; Cooper, 2010; De Saxce, Pesnel, & Perwuelz, 2012; Laitala & Klepp, 2011; UNEP, Bakker, & Schuit, 2017) could help in reducing such impacts. However since there is no consensual method to measure clothing longevity, identifying clothing longevity factors remains complex. Current "Design for longevity" researches mainly adopted an user-centered approach (Cooper, Hill, Kininmonth, Townsend, & Hughes, 2013; Laitala, Boks, & Klepp, 2015; Lilley, 2009; Maldini, Stappers, Gimeno-martinez, & Daanen, 2019; Niinimäki & Hassi, 2011) and revealed size and fit as a main reason for garment change. Garment's cut and shape is thus a first approach to increase lifespan. However and to the best of our knowledge, no researches involving fabric quality, raw material and technical performances were carried out in this sector. In this paper we defined a methodology to address the lack of performances-based approach to help in evaluating clothing longevity.

Methods

To help in framing this study, we first should sharpen product lifespan definition we have relied on. The French environmental agency, ADEME defined the "normative duration" as an average operating time, measured under specific test conditions (ADEME, 2016a). It is thus supposed to be measurable and objective however, since it is a cross-functional vocabulary, specific tests conditions should be specified.

Laboratory tests conditions are supposed to reflect objective use phase constraints such as material damage that lead to disposal. The consumer behavior has thus been surveyed to identify damage type and their importance in the disposal decision. More than 800 answers were collected and material damages of seven clothes categories were identified.

Calculated, relative importance of the consumer perception to deterioration, concerning T-Shirts, is deduced using multiple criteria decision-making method and fuzzy techniques, Fuzzy Analytic Hierarchy Process (Fuzzy AHP) (Chang, 1996; Saaty, 1980).

Damage type knowledge enables to set up a laboratory tests procedure to measure product's performances, i.e. their ability to withstand to deterioration. It should involve standardized tests which selection is to reflect the use phase constraints. However such performances translate specific quality of product and not an overall quality. We therefore defined a Consumer Oriented Quality score (COQ). Since it combines product and consumer knowledge, it could be used as a normative duration index.

The COQ score was computed using a complete ranking method (Brans, 1982) such as the PROMETHEE II method (Preference Ranking Organization Method for Enrichment Evaluations), to minimize a compensating effect and not to blind products' weaknesses with a high strength.

To check the COQ score appropriateness as a normative duration index, we compared it to an evaluated product lifespan. Such an evaluation resulted from an ageing procedure and a sensory survey. We restricted the ageing procedure to product care making the procedure more replicable. Washing, drying and ironing parameters were selected in accordance to consumer practices. On a regular basis sensory survey sessions involving a non-trained panel were conducted. Consumers were asked:

"Given the state of wear of the product, would you continue to wear it?"

Three answers were accepted:

- Yes, to be worn under normal conditions;
- Yes to be worn under poor conditions (gardening, cleaning, etc.);
- Nor to be worn anymore.

Based on answers distribution, an actual lifespan value was attributed to product and compared to the COQ score.

We implemented such a methodology on the T-shirt case as it is the reference product in the Product Environmental Footprint (PEF) methodological frameworks (ADEME, 2016b; European Commission, Pesnel, & Payet, 2019).

Consumer perception to deterioration

Thus 29 T-shirts were bought from national and international retailers. Three samples of each were needed: one as control product, one for testing and one for ageing.

Based on the evocated consumer survey, we first identified T-shirt's material damages that lead to disposal. The disposal frequencies of five material damages were investigated:

- Loss of colour (MD1);
- Loss of shape (MD2);
- Opened/Torn seam (MD3);
- Hole(s) (MD4);
- Pilling (MD5).

Relative importance of each material damage in the disposal decision were computed from collected behavior using Fuzzy AHP method (Chang, 1996). It finally appears that T-shirts are more likely to be disposed of for hole(s) and loss of shape issues (Benkirane, Thomassey, Koehl, & Perwuelz, 2019) (Table 1).

	MD1	MD2	MD2	MD4	MD5
Consumer perception to deterioration (%)	15	26	18	27	14

Table 1. Consumer perception to deterioration (Benkirane et al., 2019).

Consumer-oriented quality score computation

The COQ score relies on the product and consumer knowledge. Thus, we set up a laboratory tests procedure regarding material damage's nature. T-shirts abilities to withstand material damage were finally tested through ten standardized tests specifically identified to reflect the use phase constraints (Table 2).

Damage category	Test	Standard
Loss of colour	Colour fastness to domestic laundering Colour fastness to water Colour fastness to hot pressing Colour fastness to rubbing	NF EN ISO 105 - C06 NF EN ISO 105 - E01 NF EN ISO 105 - X11 NF EN ISO 105 - X12
Loss of shape	Dimensional change in washing and drying Spirality after laundering	NF EN ISO 5077 ISO 16322-3
Opened/Torn seam	Seam tensile properties (Grab method)	NF EN ISO 13935-2
Hole(s)	Bursting properties of fabrics (Pneumatic method)	NF EN ISO 13938-2
Pilling	Surface fuzzing and pilling (Pilling box) Surface fuzzing and pilling (Martindale)	NF EN ISO 12945-1 NF EN ISO 12945-2

Table 2. Conducted standardized tests.

Tests results corresponding to T-shirts performances were measured and combined to the consumer perception to deterioration using the PROMETHEE II method to get one unique score [19].

As illustrated in figure 1, each T-shirt is thus given a single score going from -1 (for lower quality) to +1 (for higher quality). Combining both product and consumer knowledge, the COQ score aims to predict product quality as it should be perceived and could be used as a normative duration index.

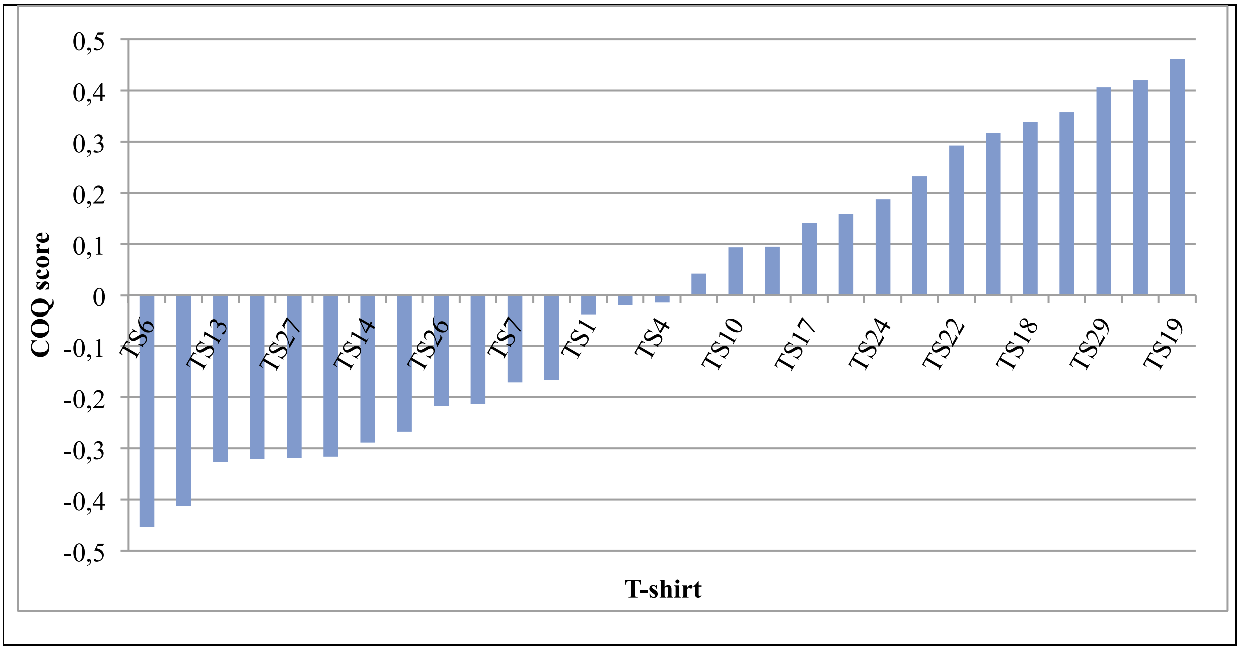

Figure 1. T-shirts' COQ score.

COQ score and panel evaluation

To check appropriateness of the COQ score as normative duration index, T-shirts lifespan were evaluated through repeated washes. According to surveyed practices, all T-shirts were thus washed to 40 °C, air dried and not ironed.

Three sensory evaluation sessions were held after 15, 30 and 50 washes respectively. Each involved about 30 people. An example of response rate after 15 washes is given in figure 2.

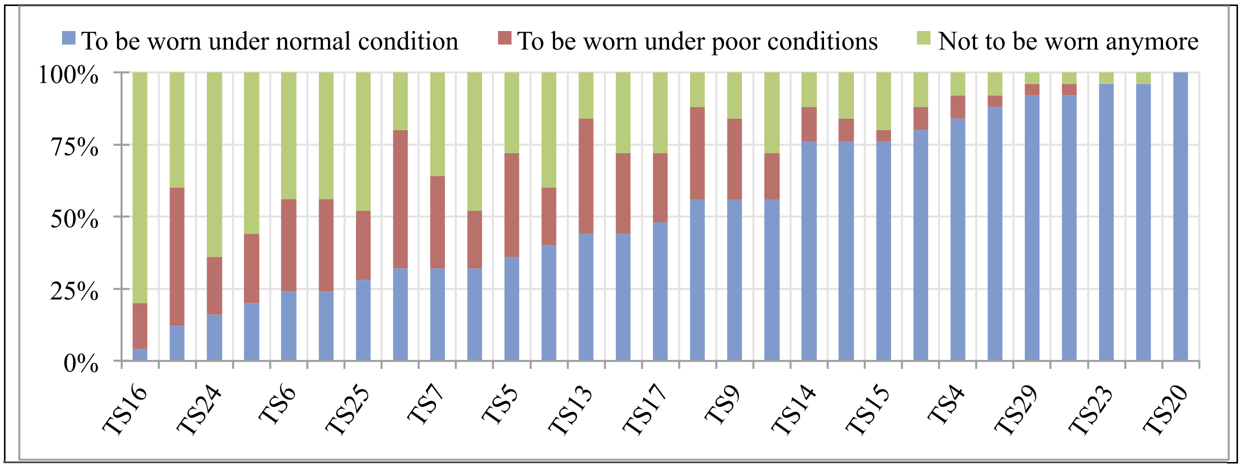

Figure 2. Panel Response rate to the question:" Given the state of wear of the product, would you continue to wear it" after 15 washes.

Cumulative wear and tear after 15 washes appears to be sufficient to affect normal conditions usability of half of the 29 T-shirts as 50% of surveyed consumers won't wear these products under normal conditions anymore.
To go further and to evaluate T-shirts lifespan, we focused on answers evolution over washes, with a particular interest in the first answer (i.e. "to be worn under normal conditions") (figure 3). For a better graphical visualization, only six T-shirts are illustrated depicting major evolutional patterns.

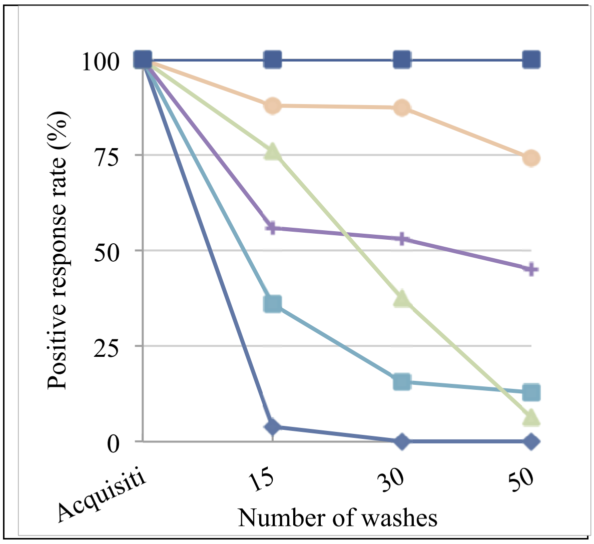

Figure 3. Panel response rate evolution over washes.

Two types of evolutional patterns were distinguished:

- A progressive response rate evolution which could be assimilated to a progressive ageing. Here represented by T-shirts TS15, TS19 and TS20.
  8 of 29 T-shirts follow such a pattern and reach a lifespan of 15 washes, 6 reach 30 washes and only 4 reach 50 washes;
- A decreasing exponential pattern, here represented by TS3, TS5 and TS16. It concerns 21 T-shirts of which only 6 reach 15 washes.

Based on these results, an evaluated lifespan was assigned to each T-shirts and compared to the COQ score (figure 4).

Finally, good correspondence is to observe between the computed COQ score and an actual lifespan for 12 T-shirts and a promising correspondence for 4 others. COQ score currently covers five material damages.

Discussion

In this paper, we discussed about a methodology proposal to compute a consumer-oriented quality score. Since its uniqueness comes from the consumer integration through its perception of material damage, we consider it could be used as a normative duration index. Our findings revealed a promising but partial correspondence between the COQ score and an evaluated lifespan.
However, computed COQ score currently covers five material damages. Based on an existing consumer survey which main advantage was number of answers, we actually restricted our study on loss of colour, loss of

shape, seam, hole(s) and pilling issues. To go deeper and to better conform to consumer we should consider more damages, including more subjective ones.

Finally, to assess the appropriateness of COQ score we conducted a product care-based ageing procedure set up to conform consumer practices: washing to 40 °C, air dry and no ironing. 3 sensory evaluations sessions followed, after 15, 30 and 50 washes respectively. This could be improved in two ways:

- First, we should refine number of sensory evaluation sessions by conducting more at the beginning as more of the T-shirts do not reach 15 washes;
- Secondly, we should also conduct a parallel wear study to check our ageing procedure validity.

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Assessing Potential Environmental Benefits of Planned Product Obsolescence Based on Individual User Behaviour by Life Cycle Assessment and Scenario Analysis

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Keywords: Planned Obsolescence; Life Cycle Assessment; Mass Personalization; Scenario Analysis; Stuttgart Models.

Abstract: In general perception, planned obsolescence of consumer products is mainly seen as a marketing strategy, boosting sales numbers to the detriment of the environment. Yet, planned obsolescence can also be used to minimize environmental impacts of product use, for example when a more energy efficient successor product becomes available and power users could minimize the overall impacts by switching to the new product. A key requirement for the mitigation of environmental impacts is the alignment of technical specifications of a product with the individual user behaviour. The Stuttgart models of Mass Personalization provide a methodological framework for the product creation and a methodological approach for the personalization process taking the individual user into account by joining the product and the user model. In this study an approach to identify the individual environmental obsolescence point is described using scenario analysis combined with Life Cycle Assessment. The environmental impacts for the life cycle of a consumer product can be assessed and in combination with the individual user behaviour and the specific triggers for obsolescence, the ideal lifetime of the products regarding the environmental impacts can be determined. For the results to lead to tangible action they need to be communicated effectively. Exemplary communication strategies for the product developer via interactive dashboards and for the end user via personalized messages are presented.

Introduction

Obsolescence is defined as the "process of becoming obsolete or outdated and no longer used" (Oxford University Press 2019) and can be triggered by numerous different reasons including technical and user-specific ones. Yet, in public discussion obsolescence is mainly referring to planned obsolescence, a revenue-driven marketing strategy to boost sales numbers by shortening technical product lifetime (Jaeger-Erben & Proske 2017) with the first known example being the arrangements between light bulb producers in the 1920s (Rivera & Lallmahomed 2016) and a current example being the revealing letter from Apple regarding their anti-repair policy (Apple Inc. 2019a). Nevertheless, from an environmental perspective obsolescence can also be beneficial, if e.g. technological advancements of new products can lead to significant energy savings from a long term and life cycle perspective (Vidalec & Meunier 2015). This potential can only be unlocked when the user changes the product or her/his own behaviour at an advantageous point of time. Prerequisite for this is that the technical specifications are optimized in a way that they match the product lifetime utilized by the individual user. Thus, to harness the potential of reducing environmental impacts, product developers need in-depth information about the individual user behaviour to synchronize technical product lifetime with the product lifetime utilized by the targeted customer group. On the other hand, customers can be supported with accessible and understandable results for their own usage. The study presents an approach on how to create and visualize information on the determining point of obsolescence by scenario analysis Life Cycle Assessment (LCA) within the Stuttgart models of Mass Personalization.

Assessing obsolescence with LCA for Mass Personalization

According to Longmuss and Poppe (2017) there are three dimensions of obsolescence. The first dimension distinguishes according to its reasons between absolute and relative obsolescence, where absolute refers to the ultimate technical obsolescence and relative refers to the user specific obsolescence based on individual preferences. Especially the absolute obsolescence can be induced by a range of different reasons (e.g. functional or evolutionary obsolescence (Vidalec & Meunier 2015)). The second dimension is based on the time of obsolescence and distinguishes between premature and delayed obsolescence. The third dimension is spread between intended and unintended obsolescence. The three dimensions are summarised in Figure 1.

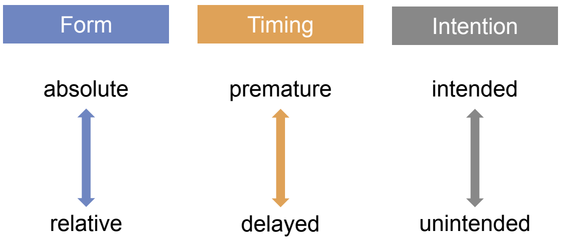

Figure 1. The dimensions of obsolescence according to Longmuss and Poppe (2017).

LCA is a well-established method to quantify the environmental impacts of a product or a service. The method is standardized in the standards ISO 14040 (2006) and ISO 14044 (2018). Instead of assessing single aspects of the product life regarding its environmental impact, LCA generally considers the whole life cycle of a product (including resource extraction, production, use phase and end-of-life). Thus, LCA is an effective method to assess the trade-offs between different life cycle phases (i.e. production and use phase).
Yet, the use phase is generally not the focus of LCA studies and approximated with standard values. An approach to provide more detailed insights into the use phase with scenario analysis is proposed by Betten et al. (2019), for the specific use of cars. To harness the full potential of these specific results, individualised communication strategies are needed. An approach for the identification of effective communication outputs is presented by Briem et al. (2019).

One example where LCA is used to identify different points of obsolescence based on standard use phase behaviours (Vidalec & Meunier 2015). The general recommendation of the study is that products with high production impacts should be used for a long time and products with high use phase impacts should be updated regularly to benefit from the latest technological advantages. Yet, with the trend of Mass Personalization and its individualised requirements for and individual uses of a product by the user, the case might depend strongly on the individual user. This aspect of Mass Personalization is researched among others at the High-Performance Center Mass Personalization in Stuttgart, Germany, where an interdisciplinary team of researchers from academia, applied sciences, and industry develops various enablers for the trend (Held et al. 2019). Three enablers are presented in this study: the Stuttgart models, the modelling of the LCA use phase by scenario analysis and the approach of individualised result communication.

While the presented approach is product neutral, it was developed along the example of a consumer smart phone. While some studies are available on the LCA of smart phones, the data availability is not sufficient to present reliable results based on real-world examples. Comprehensive studies used during the development of this study include Ercan et al. (2016), Proske et al. (2016), Apple Inc. (2019b) and Andrae (2016).

Mitigation of environmental impacts of consumer products depending on its obsolescence

Generic life cycle impacts of the product

The underlying idea of the approach presented is that in the production phase of a consumer product measures can be taken to prolong the lifetime of the product or increase energy efficiency but cause more environmental impacts. An example would be the technological advancement for semiconductors in electronic devices, enabling electronic products with increasingly energy efficient use phases. Thus, a switch to a newer product can lead to significant energy savings and thus less environmental impacts (Bohr 2014). On the other hand, the individual user behaviour influences the maximum lifetime of a product. In this process the individual user behaviour influences both, the absolute obsolescence (e.g. through charging cycles, temperatures) and the relative obsolescence (e.g. through preferences and environmental awareness). Based on this assumption environmental impacts can be minimized when technical aspects and user-individual needs are aligned and the obsolescence is neither delayed (missed technological advancements) nor premature (lost potential of the products). The formula in Figure 2 shows the environmental impacts (i.e. global warming potential [kg CO_2-eq.]) of a consumer product over the life cycle of a product with a high level of abstraction.

The production impacts in the nominator of the first addend are the sum of base configuration impacts, the total of impacts for additional features and potentially replaced modules. The denominator is the total lifetime of the product and allocates the production impacts to a year of use. The total lifetime is the minimum of the different obsolescence points t_{max} and added lifetime coming with the replacement of a module t_a. The lifetime of a product in its second life cycle t_s is virtual for the primary user, but used for the allocation of the impacts. The second addend represents the use phase and includes the emission factor for electricity use and an efficiency factor and the consumption based on the user behaviour W_{user}. The described dependencies are visualized in Figure 3.

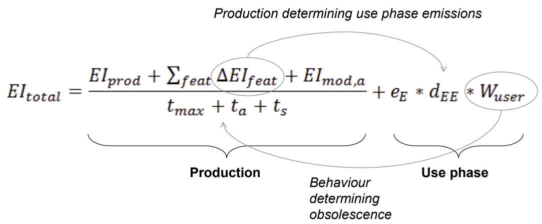

Figure 3. Visualisation of dependencies in the formula in Figure 2.

For the assessment, information about the user behaviour is used to depict the uncertainties deriving from the use phase itself. Sources for this information are public statistics, user data in possession of the company or information provided by the user directly. It can include information about the acceptance of the product, the loss probability, and use intensity. The product itself is also the object of several uncertainties e.g. battery life (possibly depending on charging cycles), likelihood of damage by an accident, technical support duration. The described parameters can be used to create possible scenarios for individual users for the product use phase taking the different uncertainties into consideration. Potential applications including forms of visualisation of the results for communication are outlined in the following.

$$EI_{total} = \frac{EI_{prod} + \sum_{feat} \Delta EI_{feat} + \Delta EI_{mod,a}}{t_{max} + t_a + t_s} + e_E * d_{EE} * W_{user}$$

with

EI_{total}	Total environmental impacts [e.g. kg CO_2-eq./year]
EI_{prod}	Environmental impacts related to production of base configuration [e.g. kg CO_2-eq.]
ΔEI_{feat}	Environmental impacts related to improvement of one feature [e.g. kg CO_2-eq.]
$\Delta EI_{mod,a}$	Environmental impacts related to replacement of a module [e.g. kg CO_2-eq.]
t_{max}	Maximum lifetime of the product based on different possible obsolescence points [a]
t_a	Additional lifetime related to module replacement [a]
t_s	Additional lifetime allocated to a second life cycle [a]
e_E	Environmental impact from electricity [e.g. kg CO_2-eq./kWh]
d_{EE}	Factor for energy efficiency [-]
W_{user}	Energy use based on specific user behaviour [kWh]

Figure 2. Generic formula describing the calculation of the environmental impacts of a product.

Support for product developers

In the product development phase a general overview on how potential users could use the assessed product and the determining obsolescence reason is helpful to direct development efforts. Figure 4 shows the number of scenarios resulting in certain environmental impacts distinguished by the different types of obsolescence (i.e. relative vs. absolute). In this graph the relative obsolescence dominates and leads to higher environmental impacts on average. A conclusion for the specific product could be that it is built too robust for the user behaviour and environmental impacts from the use phase should be reduced.

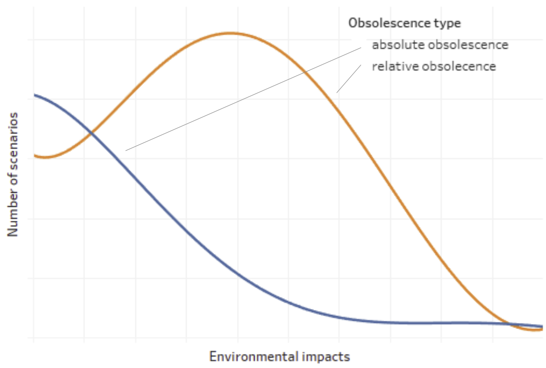

Figure 4. Share of relative and absolute obsolescence based on user scenarios.

Another example for decision support in the product development phase is shown in Figure 5. The point of obsolescence is shown in relation to the environmental impacts and the obsolescence reason. The preferable product-user combinations are on the left side of the graph, with high impact products with long lifetimes in the top area and low impact products with also short lifetimes in the lower area. Combinations on the right side cause high environmental impacts per use and should be avoided. In Figure 5 the main reasons of obsolescence for these products are technical failure of components and the users' preference for a new product (trendiness). A solution in the development could be for example to modularize the product to lower the overall emissions by exchanging parts instead of the entire product or promoting the reuse of cell phones. Both developer dashboards can be built as interactive tools for knowledge an insight creation.

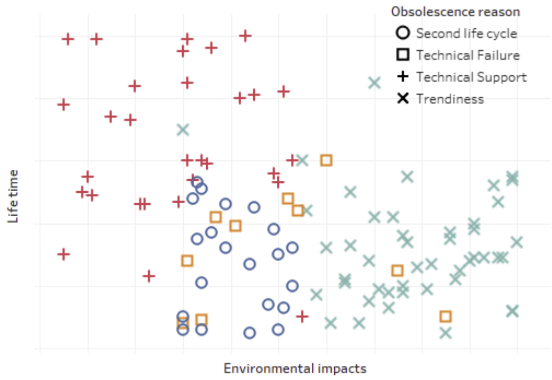

Figure 5. Obsolescence reasons over time and environmental impact.

With the aim of supporting companies and their product developers in the development of personalized products, the Stuttgart model of product development was developed (Hämmerl & Dangelmaier 2018). It outlines the necessary process steps from which requirements for the development of personalized products can be derived. Figure 6 shows the model, modified to show that it can also be used to support the minimization of environmental impacts.

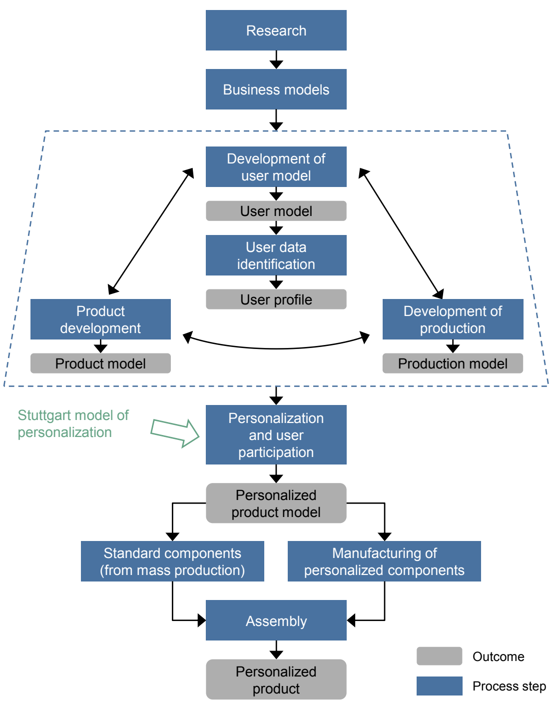

Figure 6. Graphic representation of the modified Stuttgart model of product creation.

An essential prerequisite is that all information about the product, the production and the users is recorded in a formalized way in order to enable automatic and computer-aided processing. These three elements, product, production and users, form the core of the Stuttgart model of product creation. In order to reduce environmental impacts by matching technical aspects and user-individual needs, product and user properties must be based on the same data. Therefore it is essential to develop them together. At the same time, production must be considered, because the product properties, which are expected by the users, must also be producible. These data are processed in the process step "Personalization". In order to reduce environmental influences and costs, e.g. production and logistics, have to be optimized. This can be achieved by using as many standard components as possible from mass production and personalizing only those components that are actually required. The modular design of products allows to increase the lifetime by replacing only certain modules, e.g. replace defective parts or to extend user specific obsolescence by installing a faster and more efficient processor or a new camera.

Support for individual users

Not only can product developers benefit from the information provided through the presented scenario approach, but also users of the product directly. Recommendations can be given to customers encouraging sustainable product choices based on their own behaviour and predicted future behaviour. Yet, the provided information needs to be straight forward and accessible. At the point of purchase for example, the smart phone model can be identified that would lead to minimal environmental impacts for a given use pattern and the related obsolescence reason and time. During the use phase, users can be informed about the ideal time to replace their product, for example to keep their current smart phone for a certain time longer until the breakeven point has been passed and the benefits of the new product outweigh the old. Figure 7 shows a possible way to communicate the individual break-even point to the user. In this case it is assumed the message is coming from a third party provider to ensure credibility.

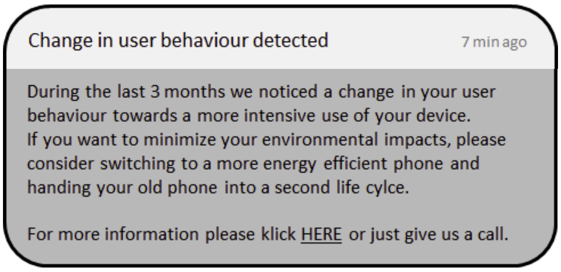

Figure 7. Recommendations for phone user regarding the ideal replacement time.

If a product is personalized, users may be confused by a too much variety of configuration (Andrade et al. 2016). At the same time, users should still be able to change the configuration. For this conflict of objectives, an automatic configuration at the initial purchase and the potential reconfiguration is necessary. For this purpose, the Stuttgart model of personalization provides a two-stage methodological approach displayed in Figure 8 (Held et al. 2019). In the first stage, the user profile is needed to define the properties of the product model leading to a first personalized product model. In the second stage, the users have the possibility to make changes. In addition, known user decisions can be used to improve the user profile. This approach can be used to configure a mobile phone in a way to reduce environmental impacts. The predicted user behaviour during use is stored in the user profile. The environmental impacts for the life cycle of a consumer product are stored in the product model. The automatic configuration determines a suitable configuration of the product and the right time to replace the product. In addition, changes in user behaviour during use can be compared with the technical properties of the product and the users can be informed with messages on the mobile (see Figure 6) to replace modules, replace the product or suggest a change in user behaviour.

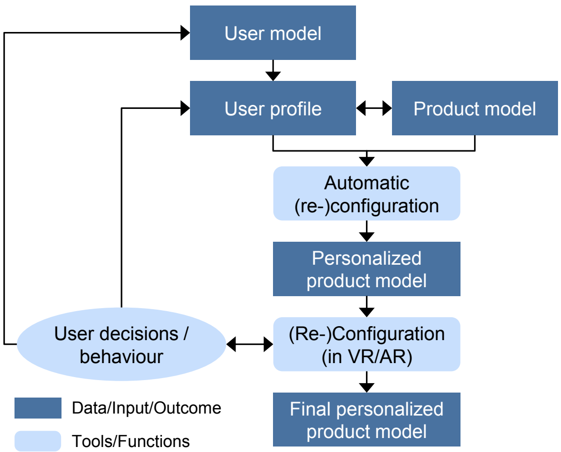

Figure 8. Graphic representation of the modified Stuttgart model of personalization.

Assessing environmental impacts within the Stuttgart models

Both Stuttgart models presented provide a solid framework to support the personalization processes on all levels, with LCA one methodology to be used to assess and quantify environmental aspects of a product. The presented approach enables the assessment and visualization of the impacts of planned obsolescence and user-induced obsolescence of a product either in the development phase or before the point of purchase/reconfiguration. The application of the method remains theoretical as the combination of production data and user data for a consumer product was not available to the authors. For future applications based on real data, several aspects are yet to be taken into account. This includes time-dependent energy emissions, realistic trajectories of energy efficiency (and in general of the correlations between production and use phase), trade-offs between different impact categories and non-linear correlations.

A key issue in the concept will be the credibility of the recommended actions. A promising concept to tackle this and the prevalent exclusion of revenue creation, long product life cycles and mitigation of environmental impacts is product stewardship, as more useful information is concentrated in one place and obsolescence can become more intentional. Especially for products with an energy intensive use phase short product life cycles could be favourable (Rivera & Lallmahomed 2016), but might have a bad impact on environmental sustainability. With a strong product stewardship of the producer combined with a good knowledge of user behaviour, use phases and remanufacturing phases could be optimized with benefits for the user, the environment and revenue streams for the producer.

Acknowledgments

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Get your Phone out of the Drawer: Revealed and Stated Preferences

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Keywords: Mobile Phone; Recycling; Experiment; Information.

Abstract: With short life cycles and fast changes in technology, more and more cellphones arrive at the end-of-use stage while retaining economic value, and many are suitable for reuse and recycling. But consumers make privately optimal decisions disregarding social externalities, and we study both the determinants of their choices via a discrete-choice experiment, and the effect of an experimentally assigned informational intervention on those choices. We present results from a comprehensive survey of 308 consumers conducted in Israel in 2014 using advanced discrete choice modeling with an efficient Bayesian design, and find that the informational intervention reduced decisional inertia for some consumers, lowered the propensity to trash an old phone, and decreased the intrinsic value of storing an obsolete phone.

Introduction

With short life cycles and fast changes in technology, more and more cellphones arrive at the end-of-use stage while retaining economic value, and many are suitable for reuse and recycling. This has led to a growing number of cellphone recovery programs and recycling systems that heavily rely on consumers' participation rate for success. Collection of such phones is different from other recycling activities mainly in terms of volume and weight and the irregularity of the recycling action. Because cellphones are small devices that also retain economic value, consumers are less likely to return them compared to other form of electronic waste such as TVs or refrigerators. The attachment to the personal data in such phones and emotional value, might also affect the willingness to participate in such collections efforts. Prior research suggests that many people prefer to keep their old cell phone in a drawer rather than participating in such collection programs for a variety of reasons. Therefore, in order to design an efficient system, one must understand consumers' preferences for cellphone collection.

A new law passed in Israel in 2014 using extended producer responsibility principles requires the collection and processing of e-waste including cell phones. That year, many people were not aware of this new law yet and we therefore used this specific point of time to learn more about consumer choices.

Pro-Environmental Behavior (PEB), and more specifically recycling, has been studied from several different points of view in past years, and different disciplines have studied different groups of variables, for example monetary incentives, demographic, norms, and social pressure factors that might influence the motivation to recycle (Speake & Yangke 2015; Welfens, et al.2016; Wilson, et al. 2017; Yushkova & Feng 2017). However, limited research has been conducted on the joint and interacted influence of the different factors. Providing incentives to recycle cellphones that better match with consumer motivation can increase participation and therefore collection rates.

In this paper, we present results from a comprehensive survey of 308 consumers conducted in Israel in 2014 using advanced discrete choice modeling with an efficient Bayesian design. Our framework combines revealed and stated-preferences jointly with participants' PEB and latent attitudinal variables. From each choice-set, the participants had to choose their preferred option, given what they did with their last phone. The discrete-choice experiment was designed using D-error Bayesian efficient design. The choice data collected together with the behavioral, attitudinal and other background variables were analyzed via the mixed-logit model,that accommodates the presence of preference heterogeneity, to estimate participants' choice preferences towards cellphone disposal choices.

The models also allow us to extract the level of relative willingness to pay/get paid for alternative collection efforts.

Data

Survey Design

The data collection was conducted through a questionnaire that consisted of four parts: (i) questions regarding the last cell-phone, including model, duration of using it, its condition and choice of treatment (give a way, recycle, etc.), (ii) a stated-preference choice experiment; (iii) an attitudinal questionnaire aimed at capturing respondents' environmental attitudes (the NEP, Dunlap et al. (2000)); (iv) a set of questions meant to assess respondents' PEB (v) a set of socioeconomic and demographic questions. The survey was conducted online by a professional survey company. Subjects were sampled from a pre-recruited online representative panel of the adult Israeli population. The respondents received a reward for their participation. A total of 310 panelists were recruited for the study with no particular screening process, 308 surveys were completed adequately which yielded 12,320 choice observations.

The stated choice experiment

Based on existing cell-phones collection systems, 3 collection options deemed relevant for our study as they actually exited on a small scale in Israel at the time the survey was held. These were described as: (i) Selling the device directly to the recycling company and receiving cash for it (Sell-recycling hereafter) (ii) Handing over the cell-phone to non-profit organization that collect the devices and sell them to the recycling companies, so that the old cell-phone is a contribution to the NGO (donation hereafter) (iii) Trade-in the old device in a store that sells cell-phones and receive a credit for the value of the device that you returned for use in the next transaction with the store (trade-in hereafter). A fourth option that is not a part of an official collecting system but may be considered by individuals is to sell through second-hand markets (Sell-2nd-hand hereafter). Each of the first four alternatives was assigned with a price the respondent will receive in case he/she choose this particular option. The fifth, opt-out option, was to maintain the "status-quo". This choice is populated from their past behavior elicited earlier in the survey. This last choice can be the same option as one of the other 5 choices, e.g. sell via a second-hand website or trade-in, but has no extra payment associated with it, so should not be chosen in that case, unless inertia plays a major role. By inertia, we refer to a latent factor that causes a person to choose exactly the same option for what to do with one's new phone as one chose to do with the last phone, even if a different choice strictly dominates. Of course, such an answer is also possible due to random error, but inertia is the factor that would cause someone to choose a strictly dominated choice on average simply because that choice was made before.

Contingent on respondents' reported last cell-phone they were assigned to a stated-preference choice task whose prices matched the phone they had. Three major categories of cell-phones were identified for with approximately same monetary value. Each respondent also reported whether the last phone was functional or not when it was replaced, which resulted with six categories. Different price levels (based on real-world prices) were assigned to each of the six categories. Half of the respondents (randomly assigned) received prior to making the choice task, information about the new e-waste law and half did not.

Trade-in is the base category to which all others are compared. In each menu, we adjust the side payments ("prices") associated with all other options by the amount shown for trade-in.

The choices people made with their old phone include 3 of the 4 choices on the menu, namely, "traded in" (including returning a work phone for a new work phone) or "sold on second-hand market" or "donated" (including giving to friends or family rather than an NGO) but there are two choices not included: trashing the phone or putting it in a drawer at home. This last is the most common alternative faced by respondents as the fifth choice, as it is the modal choice that people made with their own phone. That is, the majority of respondents faced a fifth option of "put it in a drawer at home," associated with no monetary payment but some option value.

Experimental Design

The experiment was generated using the D-Efficient Bayesian approach, which aims at yielding data that would support parameter estimation with minimum standard-errors (Vriens et al. 2001). The D-optimal design ensures that the alternatives in the choice sets provide better trade-offs between the different attributes such that no dominant/inferior alternatives are generated. This, requires prior information about the parameters' coefficients. Prior values for the parameter estimates were obtained using a pilot survey, based on orthogonal dDesign, of 150 participants. A snowball convenient sampling was employed for the pilot which was also used to confirm respondents' understanding of the choice context and task. Ngene software (ChoiceMetrics, 2012) was employed to generate all the designs used in the research. The design was a "Labeled" (alternative-specific) design were the labels being: Sell-recycling, donation, trade-in, sell-2nd-hand, and opt-out. Labeled alternatives (as opposed to generic ones) convey information and infer omitted information. For the computation of the Bayesian efficiency, we employed the Halton draw simulation procedure (Halton, 1960). We generated 24 different choice scenarios (for each of the six phone categories). The generation process of the experimental design was assigned to allocate these choice scenarios into three blocks of 8 scenarios each, such that each respondent was presented with 8 menus of 5 mutually exclusive choice situations. The D-error, which is a measure of design efficiency, is 0.000008, which is sufficiently low. To gain sufficient efficiency, the minimal number of respondents for each block was set by Ngene to 100, which is a total of 300 respondents for three blocks. Each respondent was randomly assigned to a particular block.

Methods

Following Revelt & Train (1998), we model our sample of respondents as having utility from choosing alternative j on choice occasion t is quasilinear in a vector of observed attributes relating to individual n and alternative j on choice occasion t, and a random term e that is assumed to be an independently and identically distributed extreme value, so the probability of each option being chosen takes the form of the conditional logit. We estimate the model using the maximum simulated likelihood approach of Hole (2007).

All of these models are analogous to conditional logit models, in the sense that only predictors that vary across choice occasions (decision rounds or "menus") have estimable coefficients. That is, the effect of any predictor that is individual-specific cannot be estimated, but interactions of that predictor with menu-specific predictors can be estimated.

We use a generalized structural equation model with an ordered logit link for Likert-scale responses, and empirical Bayes prediction for all latent variables (Skrondal & Rabe-Hesketh 2009). The latent factors are included in models as interactions with price. That is, past PEB cannot affect average predicted choices (since we use only within-person variation) but can affect the price elasticity of that choice. As shown in Table 1, the joint distribution of PEB and attitude has a wide variation in both dimensions and thus we can separately identify effects of both past behavior and attitudes on price elasticities.

Results

We first examine response patterns for only respondents whose last phone is a working expensive smartphone, and we ask what option they would choose for disposing of that phone, systematically varying payoffs of the options via choice menus. In Table 2, column 1, we find no impact of the informational intervention on the price elasticity, but in column 2, we see that the effect of inertia is substantial and positive (i.e. people are very likely to choose the same disposal option as they chose for their prior phone, holding all else constant) in the absence of the informational intervention, but this effect is eliminated in the presence of the informational intervention (the net effect of inertia is the sum of the two coefficients, which does not differ statistically from zero). Controlling for inertia, leaving the phone in a drawer also takes on a negative and statistically significant intrinsic value.

Comparing the alternative-specific intercept terms in Table 2, we can see that if all options were the same price, there is no strong pattern of preferences for one option over another (most do not differ statistically from zero), but there is some intrinsic value in giving the old phone to friends or family relative to trade-in (the omitted category).

In a second set of models shown in Table 3, we also interact price with two latent factors estimated from other questions on the survey pro-environmental (Pro-E) attitudes and behaviors, both of which have a mean and median of zero in the sample. Most coefficients are remarkably robust to the inclusion of these latent factor interactions, and none of the individual coefficients on attitudes and behaviors is statistically significant in column 1. However, the value of leaving the phone in a drawer is seen to be strongly negative in Table 3, relative to Table 2, suggesting that the net effects of attitudes and behaviors operate by changing the proclivity to adopt that default phone disposal method.

The attitudes factor surprisingly does not have a statistically significant impact on price elasticities, but the behavior factor is significant and has a substantial effect for those exposed to the informational intervention once we account for inertia (column 2). An increase in the interaction of price and the latent factor by its first quartile (-1.18) to its third (1.09), has the effect of reducing the price elasticity by 39 percent (in the treatment group, computing 1.09 less -1.18 times -1.083 divided by 6.369 in column 2).

We next examine response patterns for only respondents whose last phone is a working inexpensive smartphone. In Table 4, we see that the price elasticity is substantially higher in this population, and there is an estimable nonzero value to putting the phone in the trash in column 1 (which excludes the inertia effect). Controlling for inertia in column 2, the positive value of trashing the phone disappears, and the only option with intrinsic value is giving the old phone to friends or family.

In Table 5, including price interacted with pro-environmental attitudes and behaviors, we see that conditioning on pro-environmental attitudes and behavior once again does not change the qualitative pattern of results. But for respondents whose current phone is a working inexpensive smartphone, the reduction in price elasticity for those with greater pro-environmental behavior is among the control group, not the treatment group.

We next examine response patterns for only respondents whose last phone is a working regular or “flip” phone. In Table 6, we see that the price elasticity for this group is more comparable to those who own expensive smartphones, but the informational intervention dramatically increases price elasticities to make them comparable to owners of inexpensive smartphones. As with owners of inexpensive smartphones, the informational intervention makes trashing the old phone less attractive but has no apparent effect on inertia.

In Table 7, including price interacted with pro-environmental attitudes and behaviors, we see as in Table 5 that the pattern of coefficients in unchanged once we include attitudes and behavior, and that the reduction in price elasticity for those with greater pro-environmental behavior is among the control group, not the treatment group.

Conclusions

There is substantial heterogeneity across the population, both idiosyncratic variation across people within subgroups, and tremendous variation in predictable patterns of behavior between subgroups. In general, respondents are very sensitive to prices, and small variations in prices of disposal options can produce appreciable changes in predicted behavior. However, the effect of inertia is also powerful, and respondents display a strong tendency to choose to do the same thing with their current phone that they did with their last phone, which is often to simply stick it in a drawer at home. An informational intervention randomly applied to half the sample eliminated the effect of inertia for owners of more expensive smartphones, but did not for other consumers On the other hand, the informational intervention substantially reduced the appeal of trashing the phone for other consumers. This suggests that an informational campaign could affect behavior for all consumers, but through more than one channel.

Acknowledgments

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Tables

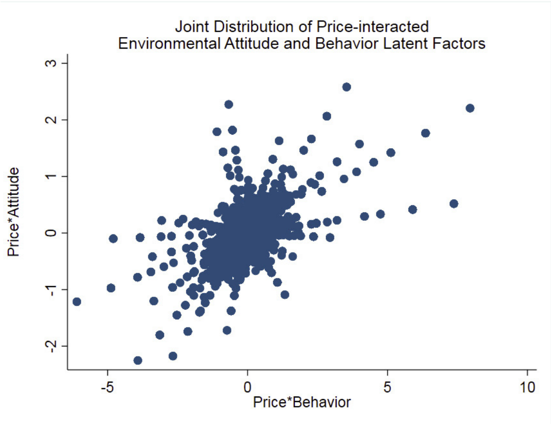

Table 1. Distribution of Pro-Environmental Behavior (PEB) and Attitude (PEA) times Price across all individuals and menus.

	1	2
Price (in ILS 1,000)	4.125*** (3.31)	6.801*** (4.40)
Price* Treatment	1.597 (0.77)	-1.738 (-1.36)
Friends/ family	4.624** (3.06)	-3.369* (-2.38)
Sell-recycling	-0.905 (-0.67)	-0.618 (-1.33)
Sell-2nd-hand	0.276 (0.29)	-0.287 (-0.49)
Donate	0.324 (0.12)	0.145 (0.19)
Drawer	-6.000 (-1.49)	-8.519*** (-4.02)
Inertia		5.657*** (4.75)
Inertia* Treatment		-4.956*** (-4.33)

Table 2. Predictors of utility of chosen options on the logit scale, for respondents whose current phone is a working expensive smartphone. Note *t* statistics in parentheses ; * *p* < 0.05, ** *p* < 0.01, *** *p* < 0.001.

	1	2
Price (in ILS 1,000)	5.234*** (5.17)	6.369*** (4.96)
Price* Treatment	0.443 (0.33)	1.505 (1.43)
Price* Attitude	1.570 (1.21)	-0.0213 (-0.03)
Price* Behavior	-0.877 (-1.53)	-0.00154 (-0.00)
Friends/ family	4.125*** (3.65)	0.202 (0.06)
Sell-recycling	-1.385 (-0.48)	-0.172 (-0.33)
Sell-2nd-hand	0.427 (0.48)	1.363 (1.22)
Donate	0.609 (0.42)	-1.674*** (-3.34)
Drawer	-1040.0*** (-972.02)	-30.38*** (-6.22)
Price* Attitude* Treatment	-1.993 (-1.28)	-1.890 (-1.49)
Price* Behavior* Treatment	0.0869 (0.14)	-1.083* (-2.29)
Inertia		3.842** (2.86)
Inertia* Treatment		-5.808*** (-4.30)

Table 3. Predictors of utility of chosen options on the logit scale, for respondents whose current phone is a working expensive smartphone. Note t statistics in parentheses ; * p < 0.05, ** p < 0.01, *** p < 0.001.

	1	2
Price (in ILS 1,000)	14.15*** (4.58)	10.51*** (3.76)
Price* Treatment	-0.387 (-0.12)	6.510* (2.04)
Sell-recycling	2.004*** (4.91)	0.745 (1.38)
Sell-2nd-hand	-0.450 (-1.02)	-0.352 (-0.83)
Donate	-2.295** (-2.81)	2.001 (1.66)
Drawer	0.00387 (0.00)	1.319 (1.11)
Trash	3.428*** (5.66)	-0.546 (-0.64)
Friends/ family	7.760*** (8.50)	3.176** (3.13)
Inertia		1.543 (0.90)
Inertia* Treatment		1.494 (1.68)

Table 4. Predictors of utility of chosen options on the logit scale, for respondents whose current phone is a working inexpensive smartphone. Note t statistics in parentheses ; * p < 0.05, ** p < 0.01, *** p < 0.001.

	1	2
Price (in ILS 1,000)	12.25*** (4.64)	13.84*** (5.99)
Price* Treatment	4.621 (1.40)	0.600 (0.30)
Price* Attitude	3.063 (0.48)	-0.646 (-0.39)
Price* Behavior	-3.060 (-1.47)	-2.101* (-2.09)
Sell-recycling	1.667** (2.58)	1.359* (2.12)
Sell-2nd-hand	-1.156 (-1.16)	-0.0549 (-0.12)
Donate	-1.867 (-1.72)	0.984 (1.73)
Drawer	-3.477 (-0.40)	-3.374* (-2.48)
Trash	3.686*** (5.23)	-9.644** (-2.90)
Friends/family	7.362*** (5.37)	1.460 (1.06)
Price* Attitude* Treatment	-1.718 (-0.26)	2.565 (1.12)
Price* Behavior* Treatment	1.075 (0.45)	1.691 (1.24)
Inertia		0.486 (0.82)
Inertia* Treatment		0.00187 (0.00)

Table 5. Predictors of utility of chosen options on the logit scale, for respondents whose current phone is a working inexpensive smartphone. Note t statistics in parentheses ; * p < 0.05, ** p < 0.01, *** p < 0.001.

	1	2
Price (in ILS 1,000)	6.738*** (3.70)	5.609*** (3.37)
Price* Treatment	8.321*** (4.78)	10.15*** (5.10)
Sell-recycling	2.110*** (4.27)	1.836*** (4.68)
Sell-2nd-hand	-1.966** (-3.23)	-1.554*** (-4.31)
Donate	-0.988 (-1.72)	-1.356** (-3.26)
Drawer	-0.742 (-0.83)	-1.912* (-2.13)
Trash	-18.66*** (-17.07)	-28.95*** (-14.10)
Friends/family	0.896 (1.12)	-0.256 (-0.26)
Inertia		0.562 (1.45)
Inertia* Treatment		0.952 (1.64)

Table 6. Predictors of utility of chosen options on the logit scale, for respondents whose current phone is a working regular/flip phone. Note t statistics in parentheses ; * p < 0.05, ** p < 0.01, *** p < 0.001.

	1	2
Price (in ILS 1,000)	7.010*** (4.10)	5.815*** (3.76)
Price* Treatment	6.973*** (4.12)	10.74*** (4.14)
Price* Attitude	0.258 (0.16)	1.752 (1.34)
Price* Behavior	-3.052* (-1.97)	-2.757*** (-3.43)
Sell-recycling	0.854 (1.38)	2.213** (3.13)
Sell-2nd-hand	-1.831** (-2.84)	-1.621** (-3.08)
Donate	-1.395*** (-3.33)	-1.581*** (-3.95)
Drawer	-3.439 (-1.01)	-1.769 (-1.81)
Trash	-23.30*** (-22.53)	-33.65*** (-12.01)
Friends/ family	-0.606 (-0.43)	-2.554 (-1.87)
Price* Attitude* Treatment	-0.782 (-0.32)	-2.948 (-1.21)
Price* Behavior* Treatment	0.204 (0.13)	0.328 (0.23)
Inertia		0.756 (0.45)
Inertia* Treatment		2.475* (2.43)

Table 7. Predictors of utility of chosen options on the logit scale, for respondents whose current phone is a working regular/flip phone. Note t statistics in parentheses ; * p < 0.05, ** p < 0.01, *** p < 0.001.

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PLATE
Product Lifetimes And The Environment

Developing Repairability Criteria for Energy Related Products

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Keywords: Repairability; Assessment Method; Electronic Products.

Abstract: Repairing modern electrical and electronic equipment is becoming increasingly difficult. The encountered challenges significantly contribute to the costs associated with repair, making direct replacement of a product often the most straightforward option for the consumer. Therefore, the Benelux Union has requested a study to investigate extending product life time by exploring repairability criteria for products. The overall aim of the proposed repairability criteria is to evaluate and, if possible, quantify the ease of repair for energy-related products (ErPs) considering the economic impact from a consumer perspective.

Introduction

As a consequence of our current throw-away society and the current lack of incentives for manufacturers to apply eco-design to their products, consumer goods are nowadays less durable and repairable than in the past. Research has shown that the average product lifetime of many products is decreasing (Bakker et al, 2014). Repairing modern electrical and electronic equipment is becoming increasingly difficult. There is a lack of appropriate repair information available and there is limited access to affordable spare parts for consumers. Additionally, rapid change of product design makes it more difficult to repair. Finally, the difficulty to non-destructively disassemble products for repair is increasing due to the more intensive application of snap-fits and adhesives.

These encountered challenges significantly contribute to the costs associated with repair, making direct replacement of a product often the most straightforward option for the consumer. Therefore, the Benelux Union has requested a study to investigate extending product life time by exploring repairability criteria for products. This research supports ongoing European standardization processes at CEN-CENELEC and research on repairability of products performed at the European Joint Research Centre (JRC).

The overall aim of this study is to evaluate and, if possible, quantify the ease of repair for energy-related products (ErPs) considering the economic impact from a consumer perspective.

In order to meet this objective, repairability criteria for ErPs are proposed. The focus of current study is repair and reuse from a consumer perspective. Many manufacturers are considering shifting their business model from selling product to selling services. In the case of product service systems, repairs usually take place in an industrial environment and are called remanufacture. In this case, the developed repairability criteria may still be useful to identify potential improvement opportunities to increase the ease of repair.

Repair activities are conducted in different ways. It can be done by the manufacturer's or retailer's after sales service (in house), it can be done by professional repairs under contract with manufacturers (outsourced), it can be done by a repair company (independent professional repair) or it can be done by the customer (self-repair). Depending on the repair route, different challenges will arise and this must be taken into account when assessing the repairability of products.

Background study

A background study has been carried out to identify existing initiatives or standards that already include a number of repairability criteria. The research focuses on scoring schemes applied in Europe and publically available information.

Qualitative evaluation methods generally consist of a number of criteria that need to be

Figure 1. Overview of existing initiative that include repairability criteria.

fulfilled in order to obtain a label, such as Blue Angel (https://www.blauer-engel.de/en), Nordic Label (http://www.nordic-ecolabel.org/) or European eco-label (http://ec.europa.eu/-environment/ecolabel/index_en.htm). These existing initiatives aim to evaluate the environmental performance of products. A number of qualitative criteria related to repair were identified such as the provision of disassembly instructions, ease of disassembly, required tools, use of standardized connections and supply of spare parts.

Semi-quantitative evaluation methods assign a weight to each criteria and sum up these weighted criteria which results in a “repairability score” for the product. The iFIXIT score card is such a semi-quantitative method that has been developed to evaluate the ease of repair for ICT products (https://www.ifixit.com/). Another example is the Austrian Technical Rules ONR 192 102:2014 that can be applied to both large household equipment (white goods) and small electric and electronic equipment (brown goods) (ONR, 2014).

Quantitative methods use measurable data to calculate a reusability index or metric. For example, the Ease of Disassembly method (eDIM) calculates the required disassembly and reassembly time (Vanegas et al, 2016), which can also be used to assess the repairability since disassembly and reassembly activities are an important part of the repair process.

Existing criteria review

In this section, the different identified reparability criteria are discussed per topic: information provision, product design and service delivery.

Information provision

The provision of adequate maintenance or servicing guidance can avoid premature failure and contribute to a longer product or component life time. Therefore some scoring and labelling scheme, such as the Austrian ONR 192 102:2014 and the Nordic Swan label, include requirements related to regular maintenance guidance.

Manufacturers usually only provide detailed information and access to relevant fault diagnosis software to selected repair service providers under contract. In order to enhance product reparability, fault diagnosis software and/or hardware should also be publically available where relevant. Unfortunately, only the Austrian ONR 192 102:2014 includes aspect related to failure/fault identification.

To effectively extend the life time of products, access to repair service information for all independent reuse and repair centers of the after-sales service is considered to be crucial. Some scoring or labelling schemes even specify that this information should be free-of-charge and available to all repair services (including those not under manufacturer’s contract). However, the (minimal) content of ‘repair and disassembly’ instruction/information is generally not provided.

Product design requirements

Many reparability criteria are related to the product design and most of them highlight the importance of design for disassembly. Some other items such as upgradability of software driven parts and the prioritization of specific parts for partial disassembly are also discussed below. Criteria related to durability tests are important to further extend product’s lifetime but they are not further discussed here because their overall goal is to avoid the need for repair activities.

Upgradability

All reviewed qualitative checklist based initiatives include requirements related to upgradability, typically for software driven devices such as computers. The iFixit reparability score card includes a criteria for upgradable RAM and storage drives for laptops.

Ease of disassembly evaluation

The ease of disassembly to facilitate repair of priority parts is key to enhance 'reparability' of products. Different sources of difficulty in performing dismantling tasks have been identified and reparability criteria have been developed to address those difficulties.The eDIM method takes most of these into consideration including: tool type, number and type of connection and accessibility. The amount of force required is considered for connection based on adhesive and modularity is partially included in the eDIM method as this can reduce the number of disassembly steps required for partial disassembly targeting a specific component. However, the requirement to use standardized design or limitation on the required skills are not included in the eDIM method.

Prioritization of specific parts

Critical parts are identified for specific product groups such as screen and battery for phones or HHD/SSD, RAM, screen, keyboard and cooling fan for computers. However no systematic method is proposed to identify the priority parts.

Service delivery

Availability of spare parts

The reparability of products is often constrained by the unavailability of spare parts for critical components. Therefore the availability of replacement parts is required for a certain period of time after the last component batch production. The length included in the different criteria vary and depend on the product group. Typically 5 years is proposed for brown goods and 10 years for white goods. Unfortunately none of the reviewed criteria include specification on the cost of spare part.

Extension of warranty period

Currently, under the Consumer Rights Directive (2011/83/EC), the final seller is liable for a product during a period of 2 years. However, the burden of proof that there was a defect at the time of the purchase lies with the consumer after the first 6 months. The Nordic Swan and EU ecolabel require an additional year of warranty without additional cost for the consumer.

New criteria development

In this section repairability criteria are proposed. The developed method is a semi-quantitative method. A general framework has been developed that provides a clear and meaningful structure for each repairability criteria according to the criteria type and the related repair step.

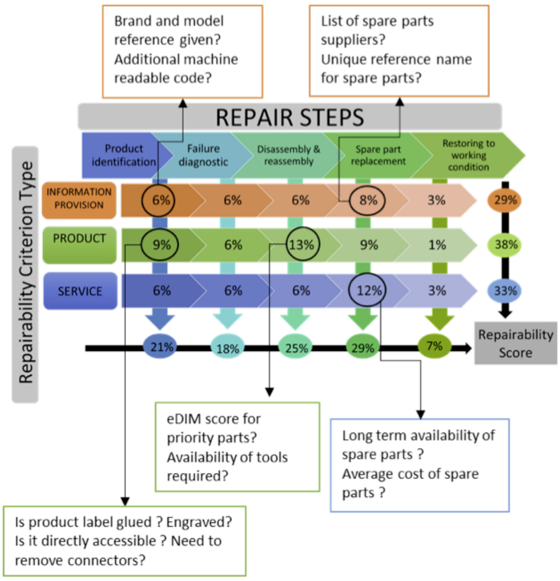


Figure 2. Repairability assessment methodology.

In total 24 criteria are proposed and each of them receive a score depending on the selected option. The different options for each criterium are described in detail and, where possible, measurable data is used. Criteria have been defined related to information provision, such as explanation of error codes, disassembly instructions or spare parts references. Other criteria assess the product design for repair, such as ease of disassembly or individual replacement of priority parts. One of the criteria, related to ease of disassembly, is based on the quantitative eDIM evaluation. Finally, there are also criteria that assess the offered repair services of the manufacturer during the use phase of the product. Although the developed criteria focus on the technical feasibility of repair, for some criteria, such as access to spare parts and repair services, the related cost has been taken into account.

Overall the weights for the generic assessment tool are quite evenly distributed, with some more emphasis on product design. Depending on the product type, the weights of the criteria can be adapted. A number of parameters has to be defined at product group level such as:

- Reference value for the disassembly metric (eDIM)
- Common failure modes
- Level of detail of provided information
- Average expected product lifetime
- Relative cost and availability of spare parts

Some criteria are dependent of the targeted priority parts. Before the start of the repairability assessment a list of priority parts should be compiled, if not already available for the relevant product group. Priority parts are independent of current difficulties to be replaced or repaired, hence the priority parts should be identified taking into account functional criticality and most frequent failure modes or misuses of products.

Application of the developed method

The developed criteria are applied in specific case studies for washing machines and vacuum cleaners. For each case study, first the selected product group is defined and characterized, the assessed product model is briefly described and, finally, the repairability criteria are applied and the selected options are justified. The main results of the case studies are summarized in Table 1.

In all cases the repairability score for a professional repairer is higher than for a consumer, partly because of the limited information that is available for consumers. For the vacuum cleaners, the accessibility of spare parts is also better for professional repairers compared to consumers.

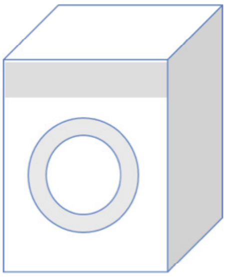
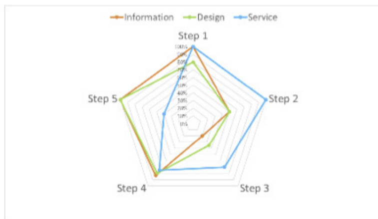
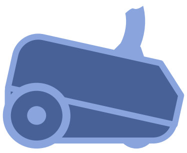
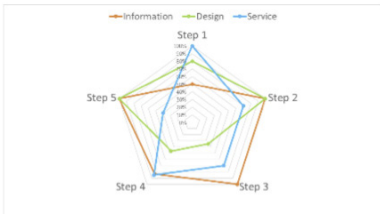
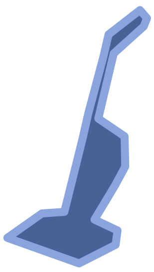
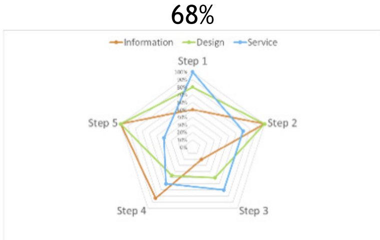
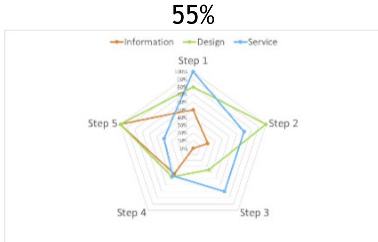
Product model	Repairability score for professional repairers	Repairability score for consumers
	77% 	70% 
	74% 	53% 
	68% 	55% 

Table 1. Case study results for applying the development repairability method.

Challenges and next steps

Some challenges have been identified when applying the developed method. These challenges need to be further explored to refine and improve the current proposed repairability criteria.

An important challenge is the identification of priority parts and failure modes. The focus of the evaluation should remain limited to the priority parts because most common product failures can be traced back to a number of specific parts. However, because all components can fail, a cut off rule needs to be defined. The cut-off can be defined as minimum number of parts (e.g. top 5 most likely to fail components) or it could be set to cover a minimum percentage of likely failures (e.g. 75% of failures). Furthermore, within a specific product group, an identified priority part may not be relevant to all product models, such as carbon brushes for washing machines. As products are continuously developed, the number and type of priority parts may change over time.

The availability of spare parts from third parties is not straightforward to take into account. First, manufacturers are not responsible and cannot control further distribution downstream of (original) spare parts. Second, the compatibility and quality of the spare parts are difficult to verify. Another difficulty is to deal with priority parts that are covered by an extended warranty.

Another challenge that was faced during the case studies is the distinction between maintenance, repair and upgrade. At the start of the project, the aim was to clearly separate between these different actions as maintenance aims to avoid repair and because upgrading provides a product with a slightly different function or capacity. In practice however maintenance instruction provided to users may also serve for repair (e.g. cleaning of a filter). Also in consumer surveys, filters were often regarded as failure requiring repair while this is considered to be part of regular maintenance by manufacturers.

In general, devices are becoming increasingly complex as they include more electronic components. The fact that there are more (electronic) components in a product will increase the likelihood of a failure occurring during the lifetime of the product. In order to achieve increased material efficiency through extended product lifetime with repair, it will not be sufficient to request more repairable products from manufacturers, also consumers should be aware that less complex products will typically be more robust. The consumer should only choose products with specific features if this is relevant for his intended use.

Further research is needed to confirm the correlation between the single score obtained with the proposed repairability method and the ease of repair in real life. In the meanwhile, a number of specific items could be selected to better inform consumers. For example the possibility to replace or upgrade priority parts, the ease of disassembly expressed in time with the eDIM metric or the maintenance and repair service offered during the use of the product.

To reduce subjectivity of the results, the repair evaluation should include as much as possible measurable parameters. Sub-aggregated results that take the interdependencies of criteria into account are useful to facilitate the interpretation of the final repairability score. Finally, the repair evaluation method should be tailored to specific product categories and weights should be assigned that reflect the relative importance of each criteria.

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Sustainability Assessment of Product Lifetime Extension through increased Repair and Reuse

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Keywords: LCA; Laptops; Repair.

Abstract: The concept of circular economy is characterized as an economy that aims to keep products, components and materials at their highest utility and value at all times. Based on data collected by reuse initiatives, computers are often considered for self-repair by consumers willing to repair their devices. In order to increase the number of successful repairs and reduce the required time, current European policy aims to improve the repairability of products. The potential environmental benefits of reuse after repair is investigated in this paper by considering a baseline, recycling and reuse scenario. The results indicate that repair of laptops should be considered before discarding for material recycling. The potential benefits of material recycling for high-end or closed loop applications remain limited. If the extended life is at least 2 years, the number of components to be replaced does not influence the decision-making. The results also show that increased energy efficiency of new laptops has a limited impact on the overall results.

Introduction

The concept of circular economy is characterized as an economy that aims to keep products, components and materials at their highest utility and value at all times (Ellen MacArthur Foundation, 2016). Although the circular economy strategy advocates repair before recycling, current end-of-life management has focused on material recycling and limited research has been carried out to investigate the potential benefits of repair and reuse of products or components.

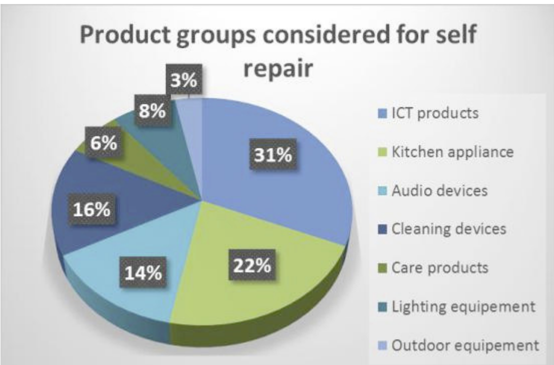

Figure 1. EEE considered for self-repair by consumers in Belgium.

In 2016, a repair organization logged 337 failed products brought to repair café's by end users.

The majority of the failed products (257 out of 337) is part of the product group electric and electronic equipment (EEE). The contribution of different product categories are shown in Figure 1.The survey indicates that ICT products are often considered for self-repair by consumers. Within this data sample, laptops represent 45% of the ICT products while mobile phone only represent 22%.

Similar conclusion can be drown from the data collected by the Restart project that tracks repair initiatives across Europe. In total 8658 products were logged between 2012 and 2018.

The product category "laptop medium" is the largest, contributing to 16% of all products considered for repair. The contribution increases to 18% when smaller related categories such as 'laptop large' and 'laptop small" are included. Desktop computers also contribute to another 2% of the total products considered for repair.

Unfortunately, there is no data available about the number of failed computers that are not considered for repair. Therefore, no clear conclusion can be drawn about the actual willingness to repair computers in general. However, the data from repair initiatives do indicate that specific end-users, that are willing to repair failed products, often perceived computers as a relevant product category.

The collected data of the Restart project also indicate that in most cases the computers can be repaired. Figure 2 shows there are differences in repair success rate depending on the computer type. In around 60% of the cases, the computer can be repaired during the repair event. In approximately 30% of the cases, the laptop is diagnosed as 'repairable' meaning it can be repaired with the appropriate tools and/or spare parts. Finally, around 10% of the computer is diagnosed as end-of-life or unrepairable.

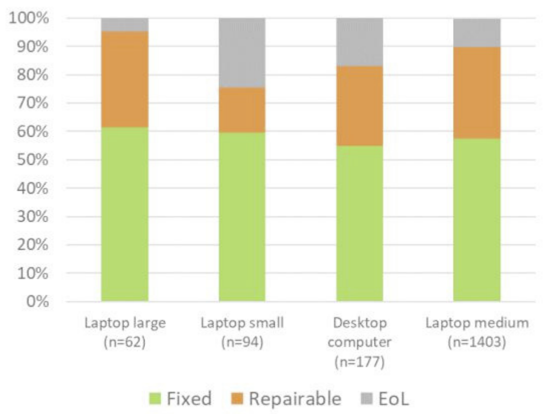

Figure 2. Succesrate of computer repair activities per product type.

In addition, based on the limited Belgian dataset, 55% of the laptops are successfully repaired. In this dataset the possibility to repair the product outside of the event was not considered. The average repair time, for both successful and unsuccessful attempts, is 89 min. In order to increase the number of successful repairs and reduce the required time, current European policy aims to improve the repairability of products (European Parliament, 2017).

Scope and system boundary

The potential environmental benefit of reuse after repair is investigated by considering three scenarios summarized in Figure 3. and described below.

The functional unit for this study is the use of a laptop during 1 year. The model is built using SimaPro 8.3 as software tool and ecoinvent 3.3 as reference database. The "allocation default" system model is used following an attributional approach. The ReCiPe (H) midpoint method with European dataset is used as impact assessment method.

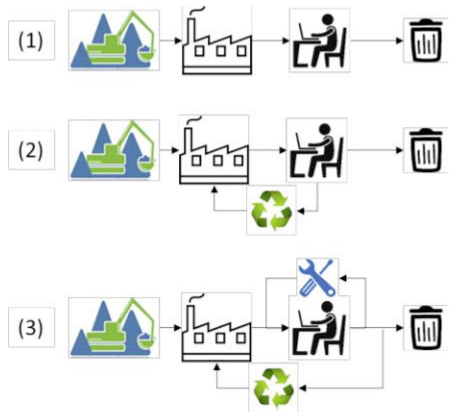

Figure 3. Scenario considered: (1) Baseline (2) Recycling and (3) Reuse.

Baseline scenario

The baseline scenario is considered to be the worst case because it does not consider any recycling or reuse and it assumes all waste is incinerated.

The baseline scenario for a generic laptop is based on the LCI data available in ecoinvent (Hischier et al, 2007). However, the data are updated to reflect applicable chemical legislations, such as RoSH that has banned the use of lead.

A professional use of 3 years is assumed with an annual electricity usage of 76 kWh from the average european grid.

For disposal, a specific incineration dataset was calculated based on the assumed laptop composition using the available ecoinvent waste tools (Doka, 2007).

Recycling scenario

In the recycling scenario the laptops are collected and sent to a recycling plant for material recovery. The production phase of the laptop is modified to reflect a closed loop for these recovered materials. For this reason, only a limited number of materials are taken into account: steel, aluminium (Al), copper (Cu) and precious metals. Although other resources, such as plastics, can be recovered, their use in new products is still limited because of their technical specification and the contamination risk with hazardous substances (Wäger & Hischier, 2015). Additionally, recovered magnesium (Mg) will most likely end up in the secondary steel production and is thus not considered as secondary resource. The recycling scenario assumes the optimistic case that all laptops are collected.

The assumed recovery rates fort he recovered streams are taken from a detailed material flow analysis for laptop recycling carried out in Belgium (Van Eygen et al, 2016). The pre-processing of the laptop is modelled assuming a manual depollution step followed by mechanical treatment (Hischier et al, 2007). The end-processing is modelled assuming remelting in an average European electro furnace, aluminium production site, copper smelter and precious metal refining (Classen et al, 2007).

Reuse scenario
For the reuse scenario, a second life of 3 years is assumed for the repaired laptop. The main environmental impact of the repair activity is the replacement of components. It is assumed the laptop requires a new hard disk drive and a new battery (Mainelli, 2016). No additional transport is assumed for self-repair. At end of life, the laptop is assumed to be recycled.

Results and discussion

The results for the midpoint impact categories are given in Figure 4 and show a benefit across all indicators for both the recycling and reuse scenario compared to the baseline. The benefits of recycling laptops are limited because the Mg, present in the housing, is not recycled as secondary resource (closed loop). The potential environmental benefits of reuse and maintaining the value of the product for a longer period are significant: for all calculated impact categories, the impact is at least 25% lower. To further confirm this, a sensitivity analysis has been carried out for the main assumptions.

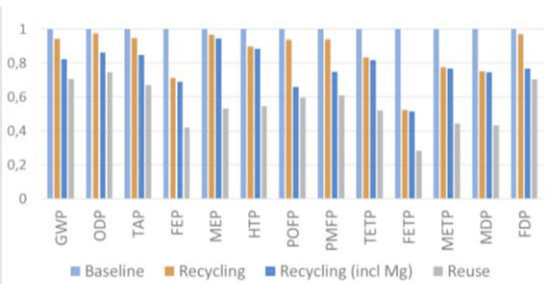

Figure 4. Mid-point category results of different scenarios.

The results show that even with an improved recycling scenario, considering Mg as secondary resource, the reuse scenario would still have substantial benefits. However, the metal depletion potential in this enhanced recycling scenario does not reflect the reduced usage of Mg as this commodity is not covered by the resource depletion characterization (Goedkoop et al, 2013).

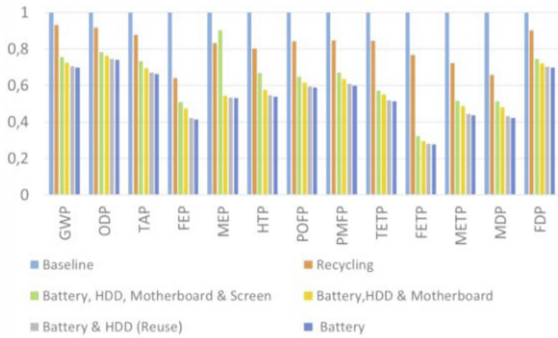

Figure 5. Sensitivity to the number of component replacement.

Figure 5 shows that, in general, the amount of replaced components does not influence the results significantly but may change the ranking of alternatives if combined with other changes such as the length of the extended lifetime.

Figure 6 shows the results taking into account the variability of the extended lifetime after repair. If only one year of additional use can be achieved, recycling may be preferable depending on the impact category that is considered and depending on the number and type of components that would require replacement.

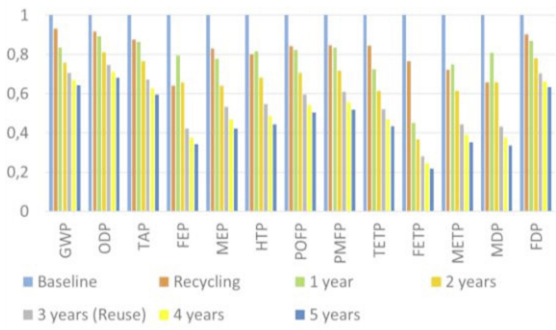

Figure 6. Sensitivity to the extended lifetime.

Often the increased energy efficiency of new products is used to justify replacement of used products. However, for laptops with an average professional use, the energy requirements should be reduced by at least 50% before achieving similar environmental benefits to reuse after repair. Figure 7 shows that increased energy efficiency of 10 or 20%

does not significantly change the overall results. Additionally, in this case study, the user profile was not modified for second use, while repaired laptops from companies are often reused in a private home environment with typically a lower usage intensity.

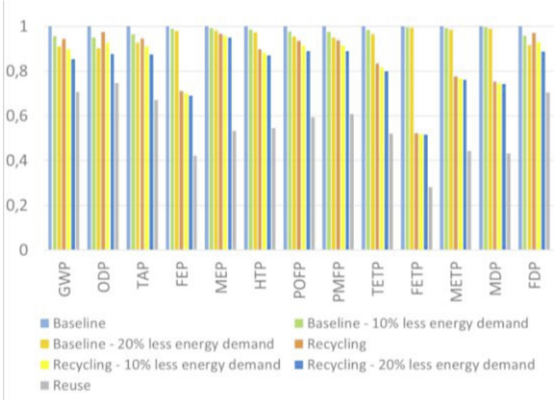

Figure 7. Sensitivity to increased energy efficiency.

Conclusions

The case study presented in this paper indicates that repair of laptop's should be considered before material recycling. Material recycling for high-end or closed loop applications remain limited to date. While recycling technology might improve in future, the content of valuable material in new products is decreasing resulting in lower potential benefits for recycling both environmentally and financially. If the extended life is at least 2 years, the number of components to be replaced does not change the ranking of the scenarios. It must be noted that the case study only considered a limited number of most likely and feasible repair activities. The results also show that increased energy efficiency of new laptops has a limited influence on the overall results. Finally, although we should consider repair before recycling, durability should remain the first priority. Therefore, policy should stimulate the development of more repairable products without compromising the overall durability of the products and their components.

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PLATE
Product Lifetimes And The Environment

Too Many Shoes? An Exploratory Study of Footwear and Sustainability

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Keywords: Footwear; Consumer Attitudes; Sustainability; Trainers; High Heels.

Abstract: As the debates surrounding fashion and its impact on the environment gain momentum, there is an urgent need to address footwear's impact on sustainability. Over the last decade a fast fashion industry has developed in the UK which could result in a shorter life expectancy of shoes. As sales increase so has the volume of footwear going to landfill. Despite all of this, shoes are notably absent from the research and discussions on the environmental implications of fashion. This exploratory paper draws from findings of a research project that investigates the UK shoe industry over the last 20 years, with a particular focus on understanding consumer relationships with shoes from purchase, use and disposal, and how that raises questions for the development of a more sustainable footwear industry. The paper will use findings from a literature review and the creation of a footwear dataset which stems from object analysis of a contemporary shoe archive, to investigate the relationship between the footwear industry and sustainability. Reflecting on data from interviews, wardrobe studies and focus groups with consumers, the paper will present perspectives on the under explored field of shoes and sustainability, addressing gaps in knowledge and fleshing out areas for future research.

Introduction

Footwear is no longer an accessory to fashion as sales of shoes have overtaken clothing (Brown, 2018). The value of the UK footwear market was £10.8 billion in 2018 (Mintel, 2019). The market has grown by 10.8% since 2014 credited to the rising popularity of trainers and casual shoes (Mintel, 2019). In 2016 sales of 'comfy trainers' overtook high heels for women for the first time (Morley, 2016), symptomatic of the athleisure trend, which has made trainers acceptable everyday wear for women. Globally there has been a shift away from high heels as comfort becomes a defining choice for women (Ell, 2018). Mintel's 2019 survey of UK footwear consumers found that 85% choose comfort over style (Mintel, 2019), demonstrating a move away from formal styling.

While there is literature (Fletcher and Tham, 2016, Gardetti and Torres, 2017) and reports that discuss the sustainability of the fashion industry (Ellen Macarthur Foundation, 2017, House of Commons Environmental Audit Committee, 2019), there is a lack of research that addresses footwear in the context of sustainability. The increase in footwear sales over the last few years is perpetuated by volumes of production, lower prices and the use of cheaper, synthetic materials. This raises serious concerns for sustainability. With sales in the UK footwear industry predicted to reach £15.6 billion by 2023 (Mintel, 2018), there is a need to consider how this sector can take positive strides towards a more sustainable future. A rise in UK sales has been coupled with a predicted 300 million pairs of shoes being disposed of in the UK annually (Dover District Council, 2018), with the majority of these going to landfill, rather than being recycled. The fact that the average pair of shoes can take at least 50 years to decompose (Grahame, 2014) has environmental implications which must be addressed.

This paper discusses findings from ongoing research investigating the relationship between shoes and sustainability. The objective is to address the knowledge gap over sustainability in the footwear industry, particularly in relation to consumer behaviour. While other research evidences consumer attitudes towards clothing and sustainability (McNeill and Moore, 2015), there is nothing that focuses specifically on consumers' attitudes and experiences of shoes from purchase through to post consumption, and how this contributes to debates on product lifetimes. To address this, we have undertaken ethnographic research involving wardrobe studies, interviews and focus groups to explore individual attitudes towards footwear.

As the research with consumers is grounded in material culture the first part of the paper explores this relationship and its value in researching footwear and sustainability. An overview of the footwear market and sustainability establishes the context. The second section discusses the project's methodology and presents the findings with a view to revealing the relationship between shoes and sustainability.

Shoes, material culture and sustainability

Shoes in the context of material culture

Shoes are objects of material culture through which relationships and consumption can be examined (Woodward, 2015). Shoes have a long history where meanings and shifts in culture, economics, politics, gender and identity can be traced (Riello and McNeil, 2006). How material culture can be applied to understand their relationship to sustainability has underpinned the theoretical framework of the project's ethnographic research. This research stems from Braithwaite's (2019) project titled Shoe and Tell which explores the relationship between shoes and identity. Reflecting on the findings from this study evidenced the very personalised relationships with shoes that individuals have, which impacts product attachment and their longevity.

The Footwear Market

The footwear industry has been slower than clothing to adopt sustainable practices. Along with the growth of fast fashion, footwear has witnessed an increase in mass production of cheaper products. The increase in trainers with synthetic soles has resulted in footwear that is not easily repairable and potentially has shorter lifespans.

Shoe manufacturers are increasingly encouraged to implement a circular economy through recycling and use of more environmentally friendly materials. In 2019 French shoe brand Veja launched its biodegradable vegan campo range made from corn waste, as an ethical alternative to its range (Chioranda, 2019). Other innovations include Adidas Parley X Collection made from plastic ocean trash, with five million pairs made in 2018 (Good News Network, 2019).

Shoes and sustainability

Footwear is complex as designers and manufacturers must consider their function to fit the anatomical structure of the foot and support the posture of the body. Consequently, shoes receive much wear and tear which has a bearing on longevity. The complex structure of footwear means they have several different manufacturing operations. Each of these can have environmental impacts including production and transportation to point of sale which impacts the carbon footprint of products (Muthu, 2013).

Lifecycle analysis of footwear demonstrates that material production and manufacturing phases were the cause of 90% of the total environmental impacts in the life of footwear, with the rest being caused by transportation and end of life (Albers et al, 2008). Leather, although preferable to synthetic materials such as canvas, polyurethane and PVC, which are commonly used in footwear manufacture, has impacts, particularly through the tanning process (Muthu, 2013). Many materials are used to make shoes along with the other elements such as nails, backers, padding and lining (Staikos and Rahimifard, 2007). All these processes have impacts that will need to be considered in the implementation of a more sustainable industry.

Methodology

The methodology was grounded in ethnographic principles. Ethnography with its focus on deep description enabled the observation of behaviours and attitudes towards shoes.

Research Sample

Young people aged 16-25 have been the primary target of this research. Selected as they are prolific consumers of fashion with significant buying power (Tilford, 2018). They are also the generation who are becoming environmentally conscious, and whose behaviour and attitude will hold weight in creating a more sustainable future (Folk, 2018). In total 100 individuals have been interviewed about their shoes. Three focus groups with a further sample of 20, have also been undertaken. Snowball sampling was used to find participants. Although not intended, most participants have been female.

Interviews and focus groups have taken the following process. Individuals were asked to bring shoes to discuss. These included favourite shoes and pairs hardly or never worn. They were asked their motivations for purchase and experiences of wear. Questions also covered care of footwear, and what they did when they no longer wanted to keep a pair of shoes. The project has data on attitudes towards 260 pairs of shoes.

Footwear inventory

In advance of focus groups, participants were asked to complete an inventory of their shoe collection to open conversations around attitudes towards all footwear they owned.

Footwear category	Frequently wear (at least once a week)	Occasionally wear (once a month or less)	Hardly or never wear
Trainers			
Flat shoes			
Heeled shoes			
Heeled boots			
Flat boots			
Flat sandals (including flip flops)			
Sandals with heel			
Slides			
Slippers			
Other			

Figure 1. Footwear inventory of shoe categories according to frequency of wear.

The categories of footwear detailed in the inventory were defined by Mintel (2019) as the most common types of footwear.

Additional Research

To understand attitudes towards sustainability from an industry perspective, interviews with three shoe designers, who define themselves as sustainable brands, were implemented. These designers are Beyond Skin, a UK vegan shoe brand, Cocolico, a New York based designer. Finally, Chau Har Lee, a shoe designer and maker who applies sustainable practice.

Creating a Footwear Dataset

Nottingham Trent University holds an archive of UK high street clothing and accessories from 2000-2017. The term UK high street fashion is synonymous with cheaper to mid-range clothing and footwear from fashion retailers. 2000-2017 is an important period in fashion as it sees increased momentum of fast fashion, and manufacture shifting towards emerging economies, such as Brazil and China. The archive contains over 200 pairs of trend-led shoes. Undertaking object-based research we catalogued each pair according to type, price, brand, country of origin and material composition. From this we created a dataset tracking price and country of origin. This could then be analysed in the context of sustainability.

As most shoes owned by our female participants were trainers and high heels the paper focuses on these categories. Trainers and high heels form the higher percentage of shoe styles in the archive. There are 103 pairs of high heels evidencing this shoe's prominence in fashion's contemporary history. The number of sneakers is comparably less at 24 pairs.

Findings and Discussion

Shoe Dataset Findings

Analysis of the material composition of high heels and trainers from the archive evidenced no surprising shifts from leather towards synthetic footwear. It confirmed that the cheaper shoes, purchased for under £20 were always synthetic. Many trainers in the archive were from retailers rather than sportswear brands (see figure 2). Exemplifying a diversification in the market, as fashion retailers use cheaper manufacture to compete with the saturated sportswear industry and offer consumers trainers at competitive prices (figure 4).

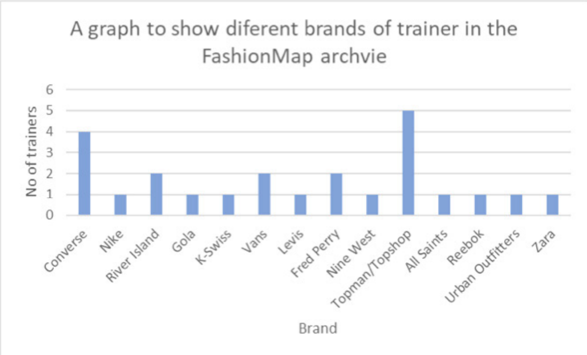

Figure 2. Graph of trainer brands in the archive.

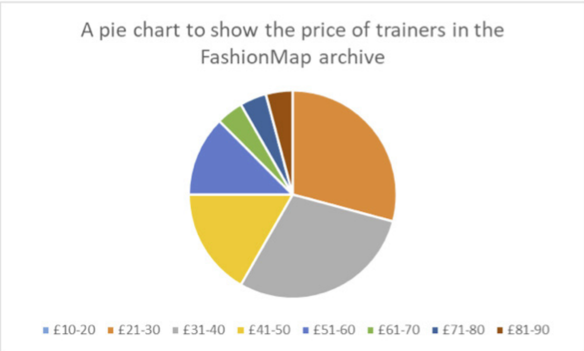

Figure 3. Price of trainers in the archive.

Figure 3 indicates the price of trainers over the 17 years of the archive. Most of these trainers were made in Asia and the fashion retail versions are unsurprisingly cheaper than branded versions. The examples detailed (figure 4) do not show on the product labelling of the shoebox where they were made. This was a common finding, with 38% of trainers not declaring country of origin. 88% of trainers were purchased between £21-£60, and 50% of these were manufactured in Asia (China and Vietnam).

	£40.00	N/A	River Island	2012/13
	£70.00	N/A	Nike (purchased from JD Sports)	2014/15

Figure 4. Examples of trainer prices from the archive.

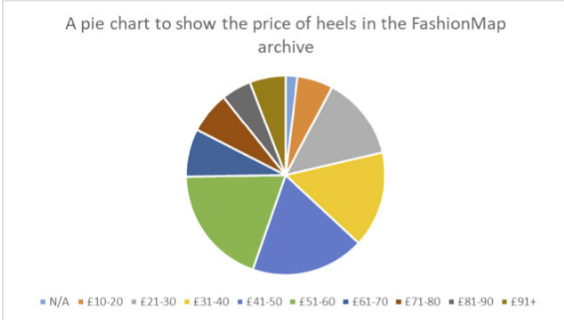

Figure 5. Price of heels in the archive.

The £21-60 price range of the archive's high heels held the largest share at 46%. Taking 2013-14 as an example, there were five pairs of heels purchased (figure 6). Most were manufactured in Spain, predominantly leather, and retailed at a higher price than the £12.99, synthetic pair, which had no country of origin detailed on the shoes or box labels. However, this pair are from Primark who source manufacture from the Asian continent (Global Apparel Forum, 2018), known for cheaper production (Business of Fashion, 2016).

	£68.00	Spain	Topshop	2013/14
	£80.00	Spain	Topshop	2013/14
	£80.00	Spain	River Island	2013/14
	£85.00	Spain	River Island	2013/14
	£12.00	N/A	Primark	2013/14

Figure 6. High heeled shoes purchased in 2013-14.

The dataset shows that 15% of heels have been manufactured in Europe, compared to 13% in China and 23% in Brazil. The first pair we have recorded as made in China was in 2004. These were synthetic wedge heeled shoes purchased for £9.99. From 2004 shoes made in Brazil and China overtook those made in Europe.

The dataset confirms the shift of manufacture from Europe towards Asia. Footwear manufacture in Europe has declined and mass production has moved to Asian countries (Armstrong-Gibbs and McLaren, 2017). The growth of fast fashion has meant that retailers source shoes from Asia as they are cheaper with quick production times (Armstrong-Gibbs and McLaren, 2017). The consequence that has on the price of shoes and their perceived disposability is key to sustainability.

Too many shoes?

The inventory highlights that the average number of shoes owned was 25 pairs. Only 21% of these were frequently worn and a significant figure of 50% were hardly or never worn. Interviews and focus groups probed deeper as to why they had so many pairs hardly or never worn. Sometimes these were high heels or formal shoes, kept for special occasions.

“I was shocked to see how many heels I own and don’t wear. Usually it is because I need to be comfortable and I keep them for special occasions. I would never get rid of them, they hold too many memories” (Em, 2018).

Keeping hold of shoes because of their association with special moments has been integral to understanding emotional attachment to footwear.

“I love my dirty black vans. There is a hole in the top and in the sole, but they are a treasured pair” (Chris, 2019).

In many cases shoes have been worn multiple times. The memories they hold means they will be kept. The findings reveal how individuals value shoes because of associated memories.

At times shoes are not worn because it is “easier just to put on what you took off the day before” (Dami, 2018). The frequently worn shoes were mostly black trainers that were muddy, worn down, but loved. At the other extreme were the pure white trainers kept clean with baby wipes, or not worn to avoid getting them dirty.

“I keep them (white Nike Air Force) white with baby wipes and would never wear them out to a club. I bought them because it is what my friends have and they feel like me” (Marsh, 2019).

Motivations for purchase were comfort, fashion, individuality, occasions and function. Few participants regularly cleaned their shoes, aside from the white trainers, or considered repair. Keeping shoes dirty was for many intrinsically linked to its memory value.

“Why would you bother caring or repairing something that cost so little and you know won’t last” (Emily, 2019).

Greater value was placed on branded trainers as they were expensive and would be worn frequently. Few participants considered the environmental impacts of footwear, or their expected lifetimes, except at the disposal stage. They tended to recycle or keep rather than throw away. However, the fact that so many pairs of shoes remain unworn, raises questions over how to address intensity of use.

Like Niinimäki and Armstrong’s study on clothing and attachment (2013), individuals have emotional connections to shoes that are embedded with memories. Although our study is limited to a small sample and the findings not generalisable to a wide population, they flesh out key themes worthy of further interrogation. The footwear industry is becoming more sustainable, consumers more sustainable, but more awareness is needed. Fulfilling individuality fuels consumption with many buying more shoes than are needed.

Shoe Designers

Interviews revealed the challenges and opportunities designers face. Beyond Skin’s use of non-animal materials is costly for an emerging brand. Cocolico has established sustainable production in Spain, relying on ethically produced leathers and locally sourced materials and component, reducing carbon footprint. Chau Har Lee uses 3-D printing to design perspex flat pack shoes that avoid toxic glues and multiple components. While more sustainable the challenge is to ensure that the shoe can be worn comfortably. These examples evidence how designers are implementing sustainability.

Conclusions

While exploratory in its initial stages our research demonstrates that along with the volume of footwear being manufactured, consumers often own too many shoes. The consequence of our fashion system and society’s desire for individuality. By understanding consumers’ relationships to footwear through purchase, wear and end of life we intended to reveal the values that underpin this. Evidently emotional attachment is key to the longevity of footwear. This creates opportunity for designers and manufacturers to consider emotion in design. The objective of further research is to understand how a more sustainable approach to ownership could become a driving force in consumers self-fulfillment.

Acknowledgments

We would like to thank all the focus group participants, interviewees and shoe designers who have shared their shoe stories with us.

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PLATE
Product Lifetimes And The Environment

Quantifying the Circular Economy Potential of Prolonging Lifetime in Energy Using Products: the Washing Machine Case

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Keywords: Circular Economy; Life Cycle Costing; Life Cycle Assessment; Product Lifespan; Washing Machines.

Abstract: Circular Economy contributes to sustainable development by decoupling economic growth from resource use and waste generation. Many circular strategies result in an extension of products lifetime. For energy using products, i.e. products that consume resources during their usage, life extension does not necessarily lead to economic and environmental gains. This is particularly relevant for washing machines, where several Circular Economy solutions such as pay per wash or the purchasing of refurbished appliances are becoming popular. Thus, the aim of this paper is to provide an estimation of the economic and environmental potential of such Circular Economy alternatives against the current linear economy scenario, encompassing the effect of prolonging lifespan for an energy using product like washing machine. To do so, this research develops an assessment model to compute the economic and environmental impacts (in terms of users total cost of ownership and global warming potential) in the current households setting and in pay-per-wash and refurbishment alternatives, adopting the customer point of view and considering different washing habits. In the model, both alternatives lead to a washing machine life extension: in the first case, pay-per-wash offers high-quality and long-lasting products while, in the latter, refurbishment gives a second-life to washing machines. Then, a users' survey is designed to collect the main data related to washing habits. Data from more than 150 Italian households are collected and used to feed the simulation model. Results show that, on average, both Circular Economy alternatives allow reducing CO2 emissions, but economic viability is far from obvious: only refurbishment allows achieving also economic savings to users.

Introduction

Circular Economy (CE) is gaining more and more attention as a means to accomplish sustainable development by decoupling economic growth from resource extraction and environmental losses (Hofmann, 2019; Merli, Preziosi, & Acampora, 2018). Companies wishing to implement CE may act on four building blocks (Ellen MacArthur Foundation, 2012). First, products should be designed in a way to narrow, slow or close resource loops (N. M. P. Bocken, de Pauw, Bakker, & van der Grinten, 2016), by e.g. extending their lifespan through the upgrading of their components, improving their disassembly and recycle phases, and adopting Design-for-X techniques (Bovea & Pérez-Belis, 2018; Khan, Mittal, West, & Wuest, 2018). Second, companies should move themselves towards the offering of servitised business models such as pay-per-use or sharing, retaining product ownership and putting the focus on product usage and functionality (Tukker, 2015). Third, supply chain management should be coupled with reverse logistics, to collect products after use for creating value from them (Batista, Bourlakis, Smart, & Maull, 2018; Bressanelli, Perona, & Saccani, 2018; De Angelis, Howard, & Miemczyk, 2018). Fourth, the disruptive potential of digital 4.0 technologies should be exploited, to enable circular product design, servitised business models adoption and reverse logistics implementation (Alcayaga, Wiener, & Hansen, 2019; Bressanelli, Adrodegari, Perona, & Saccani, 2018; Nascimento et al., 2018; Okorie et al., 2018). Consequently, several strategies can be pursued to enable a transition towards CE, such as durability and life-extension, provision of pay-per-use business models, refurbishment, remanufacturing, recycling and so forth. Most of these CE strategies results in the extension of products lifetime, attempting to slow down the resource flow of products that otherwise become waste. For energy using products (i.e. products that consume resources during their usage and become more and more inefficient due to technological progress) the extension of lifetime does not necessarily lead to CE positive results in terms of both economic and environmental gains. (Bakker, Wang, Huisman, & den Hollander, 2014; Intlekofer, Bras, & Ferguson, 2010). This applies also in the Washing Machine (WM) industry, where several CE alternatives to the business-as-usual scenario – such as the purchasing of refurbished appliances, the access to pay-per-wash offerings or the sharing of WMs in common areas – are increasingly becoming common (Amasawa et al., 2018; N. Bocken, Ingemarsdotter, & Gonzalez, 2019; Garcilaso, Jordan, Kumar, Hutchins, & Sutherland, 2007). Quantifying the economic and environmental potential savings that can be reached through each CE alternative can support households and other stakeholders in embracing a transition towards CE.

Consequently, the purpose of this paper is to provide an estimation of the economic and environmental potential of two CE alternatives (pay-per-wash and refurbishment) against the current scenario (in terms of savings for users and avoided CO2 emissions), encompassing the effects that these two strategies have on the WM lifetime. To do so, this research develops an assessment model to compute the economic and environmental impacts for the WM industry, adopting the customer point of view and taking into account different washing habits. Both CE alternatives lead to a WM life extension: in the first case, lifetime is extended because pay-per-wash offers high-quality and long-lasting WM; in the latter, lifetime is extended because refurbishment gives a second-life to WM. Then, a user survey has been designed, to collect the main data related to washing such as the number of washing cycle, the WM capacity and so forth. Data from 183 Italian households were collected and used to feed the lifecycle model.

Methodology

An assessment model has been developed, to compute the economic and the environmental impacts of WMs during their whole lifecycle. For the computation of the economic impact, the user's point of view has been taken. For the assessment of the environmental impact, the WM viewpoint has been chosen. Readers may refer to the Appendix for the nomenclature used in the model, as well as for the sources used for estimating the value of each parameter.

Model: Economic impact

The economic impact is assessed by adopting the user's point of view through the evaluation of the Total Cost of Ownership (TCO) associated to the WM purchasing and usage. Thus, Equation (1) provides an estimation of the expenses, in euro per year, that a household usually bears for doing the laundry.

$$TCO\left[\frac{€}{year}\right] = \frac{P}{L} + MR + (EC \times e_c) + (WC \times w_c) + (DC \times d_c) \qquad (1)$$

More specifically, the user's yearly TCO is given by the sum of two contribution: the purchasing and the usage cost. The first term is obtained by dividing the WM Price (*P*) for the WM lifespan (*L*). The latter, instead, is given by the sum of the Maintenance and Repair (*MR*) yearly expenditure and of the Energy (*EC*), Water (*WC*) and Detergent (*DC*) Consumption, multiplied by their specific costs.

To determine the WM lifetime in year (*L*), the number of washing cycles that a WM can potentially perform (L_{WM}) is divided by the number of washing cycles that a household do per year, i.e. the usage (*Nwc*). In doing so, an upper bound of 15 years have been considered, since usually consumers discard their WM after that period (even though it is still working) mainly for aesthetic reasons (Hennies & Stamminger, 2016). This phenomenon, usually referred to as aesthetic obsolescence (den Hollander, Bakker, & Hultink, 2017), is computed by Eq. (2).

$$L = \max\left(\frac{L_{WM}}{Nwc}\,; 15\right) \qquad (2)$$

To compute the yearly Energy Consumption (*EC*), the formula developed by Milani et al., (2015) has been adapted and included in the model. In their work, Milani et al., (2015) have modelled the *EC* as a function of WM features such as the Energy Efficiency Class (*EEC*), the WM Capacity (*C*) and the Temperature (*T*) of the washing cycles. Equation (3) thus proposes an adaptation of such formulation.

$$EC\left[\frac{kWh}{year}\right]=\sum_{T=30°C}^{T=90°C}\left(Nwc\times F_T\times K_T\times\left(EFC_{EEC}+EVC_{EEC}\times C\right)\right)\quad(3)$$

In Equation (3), the electricity consumption of a single washing cycle is given by the sum of two contribution, i.e. a fixed (EFC_{EEC}) and a capacity-dependent parameter (EVC_{EEC}). Both terms vary depending on the EEC (Table 1).

EEC	EFC_{EEC}	EVC_{EEC}
A+++	0.180	0.100
A++	0.220	0.110
A+	0.190	0.140
A	0.180	0.160
B	0.000	0.188
C	0.000	0.184

Table 1. Washing energy consumption per cycle.

To include the effect of the washing temperature (*T*), Milani et al., (2015) have introduced a temperature coefficient (K_T) that should be multiplied to the consumption of each washing cycle. Accordingly, a washing cycle done at a temperature of 90 °C consumes as much energy as 1.63 cycles done at a temperature of 60°C. This is consistent with the specialized literature in the field, which usually suggests washing at low temperatures as a means to reduce energy consumption (Laitala, Boks, & Klepp, 2011). Table 2 shows the K_T values for the main washing temperatures usually available in washing programmes. The yearly *EC* is thus obtained through Eq. (3) by multiplying the single washing cycle consumption with the number of washing cycles performed in a year (*Nwc*), in accordance with the usage frequency (F_T) of each temperature.

T	K_T
30 °C	0.34
40 °C	0.55
60 °C	1.00
90 °C	1.63

Table 2. Temperature coefficients.

To compute the yearly Water Consumption (*WC*), the formula developed by Lasic et al., (2015) has been used and adapted here. Through this formulation, the water usage of each washing cycle is given by the sum of a Water Fixed Consumption (*WFC*) with two variable parameters (WVC_C and $WVC_{C;LR}$) which, respectively, are directly proportional to the WM Capacity (*C*) and to the WM real load. To obtain the WM real load, the model multiplies the capacity *C* with the Loading Rate (*LR*). By multiplying the water usage of each main cycle by N_{RC} – a factor that has been adjusted to take into account the number of rinsing cycle per each laundry (Kim, Park, Yun, & Park, 2015) – and by the number of washing cycle done in a year (*Nwc*), it is possible to determine *WC* through Eq. (4).

$$WC\left[\frac{litre}{year}\right]=Nwc\times N_{RC}\times\left(WFC+WVC_C\times C+WVC_{C;LR}\times C\times LR\right)\quad(4)$$

Lastly, to compute the yearly Detergent Consumption (*DC*), the model uses the formula developed by Boyano et al., (2017), as reported in Eq. (5):

$$DC\left[\frac{kg}{year}\right]=Nwc\times(DFC+DVC\times C\times LR)\quad(5)$$

Accordingly, the *DC* is affected by a detergent fixed consumption per each cycle (*DFC*) and by a variable consumption ($DVC_{C;LR}$) that depends on the WM real load.

Model: Environmental impact

The lifecycle model evaluates the environmental impact by adopting the WM point of view through Life Cycle Assessment (LCA), encompassing raw materials extraction, manufacturing, assembly, distribution and usage phases. Among the several LCA impact categories available, the model computes only the Global Warming Potential (GWP), given its relevance for global warming and climate change. As in the case of the economic impact, the usage phase is affected by usage habits. GWP is thus computed through Eq. (6), which provides an estimate of the yearly GWP, in kg of CO_2 equivalent per year, related to a WM lifecycle.

$$GWP\left[\frac{kgCO2_{eq}}{year}\right]=\frac{RME_{WM}+M\&A_{WM}+D_{WM}}{L}+\left(EC\times e_{gwp}\right)+\left(WC\times w_{gwp}\right)+\left(DC\times d_{gwp}\right)\quad(6)$$

More specifically, the GWP is given by the sum of two contributions: the supply and the usage phase. The first contribution is obtained by dividing the sum of the Raw Material Extraction (RME_{WM}), Manufacturing and Assembly ($M\&A_{WM}$) and Distribution (D_{WM}) unitary impacts for the WM lifespan (*L*), where *L* is determined through Eq. (2). The latter, instead, is given by the sum of the Energy (*EC*), Water (*WC*) and

Detergent (*DC*) Consumptions, as determined in Eq. (3-5), multiplied by their specific GWP impacts. Generally, the values of RME_{WM}, $M\&A_{WM}$ and D_{WM} are computed starting from the collection of raw data such as the WM bill-of-materials or the manufacturing and distribution processes (Yuan, Zhang, & Liu, 2016). In this paper, however, a simplified approach has been taken: the infinite WMs configurations were modelled in three price-classes (i.e. low-price, average-price and high-price segments), according to the conditions provided in Table 3. The values depicted in Table 3 have been collected from previous literature (Rüdenauer, Gensch, & Quack, 2005) and are consistent with more recent findings, which stated that the environmental impact of producing new WMs is comparable to that of old devices (Ardente & Mathieux, 2014).

WM Class	Low-Price	Average Price	High-Price
Price [€] Condition	P < 300	301 < P < 500	P > 501
Average Price *P*	150 €	400 €	600 €
L_{WM} [cycle]	1,500	2,500	4,000
RME_{WM} [kg CO2 eq]	235.5	300.6	581.5
$M\&A_{WM}$ [kg CO2 eq]	74.0	90.8	96.3
D_{WM} [kg CO2 eq]	8.4	8.4	8.4

Table 3. Data related to WM classes considered.

User survey

To collect the main data related to users and to their washing habits (such as the number of washing cycle, the WM capacity, the WM energy efficiency class, etc.), a user survey was designed. Data were collected through an online survey between November and December 2018. More than 180 Italian household responses were collected. Respondents were reached via internet by sharing the survey access link on popular social networks. Table 4 depicts the characteristics of the sample (n = 183) in terms of gender and age distribution. The majority of respondents were women (78%), while the 72% of respondents is less than 50 years old. Although not representative of the entire Italian population, the sample of the survey is consistent with previous similar research (Abeliotis, Nikolaou, & Sardianou, 2011; Atlason, Giacalone, & Parajuly, 2017; Kruschwitz, Karle, Schmitz, & Stamminger, 2014), and large enough for its intended aim, i.e. feed the assessment model to see how it behaves in a real environment.

Age (years)	Male	Female	Total
Lower than 29	18	48	66
Between 30 and 49	16	50	66
Between 50 and 64	6	39	45
Higher than 65	1	5	6
Total	**41**	**142**	**183**

Table 4. Sample characteristics.

Scenarios definition

The assessment model has been used to compute the economic and environmental impacts of the following three scenarios.

Linear Economy scenario

To assess the economic and environmental impacts of the AS-IS situation (i.e. the linear economy scenario, with current WM lifetimes), the data collected through the survey have been used to compute the TCO and the GWP thanks to Eq. (1) and (6). Figure 1 depicts the distribution of the Household Size (*HS*) of the sample, i.e. the number of people living in each household. Figure 2, instead, depicts the usage characteristics of the sample, in terms of frequency (F_T), loading rate (*LR*) and number of washing cycles per year (*Nwc*). Lastly, Figure 3 depicts the WM characteristics in terms of EEC, capacity (*C*) and average price (*P*), split into the three classes low-, average- and high-price. From an environmental point of view, it is interesting to note that a large share of WMs have an EEC greater than 'A', meaning that users keep in consideration this aspect in their purchasing decision. Moreover, the tendency to wash at low temperatures can be here confirmed, even though a room for improvements still exists.

Figure 1. Household Size of the sample.

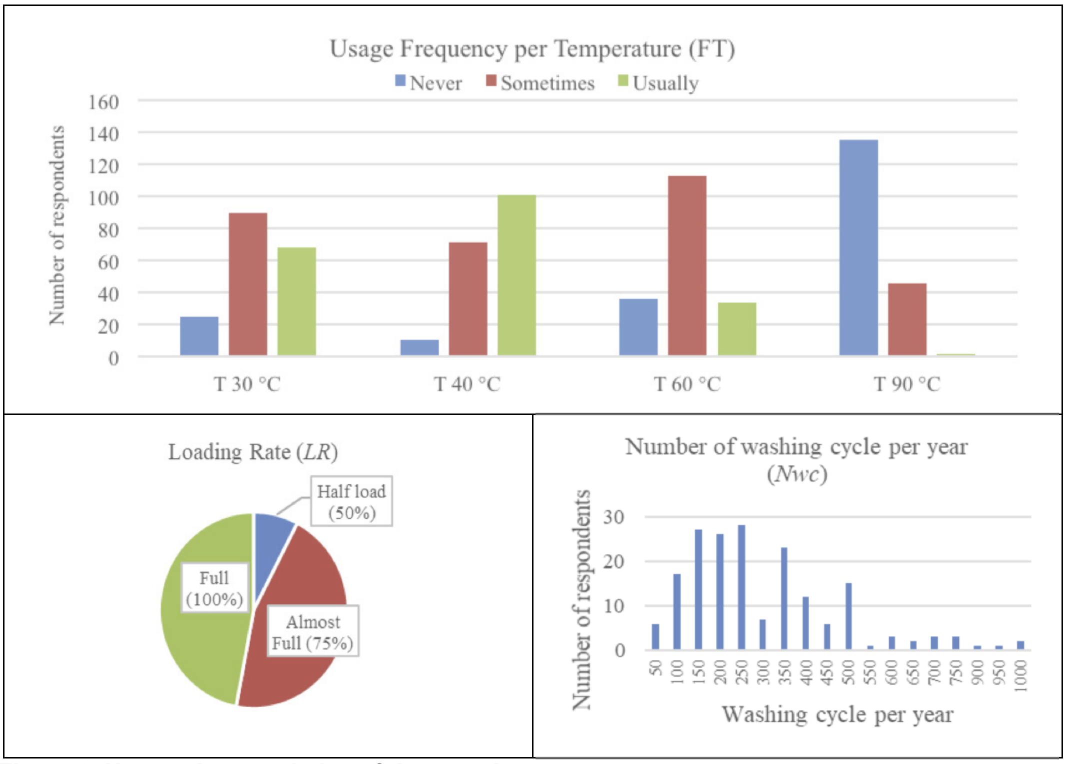

Figure 2. Usage characteristics of the sample.

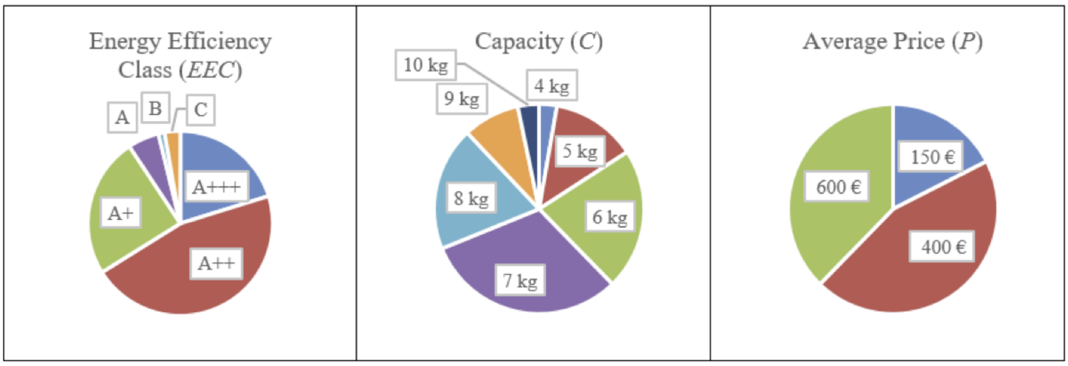

Figure 3. WMs characteristics of the sample.

Pay-per-wash scenario

In a pay-per-wash CE scenario, users no longer buy and own a WM. Instead, they access a high-efficient WM (with EEC = 'A+++') at home, without having to pay its retail price. Maintenance and repair costs are also included in the pay-per-wash fee. WMs typically have a large capacity (*C* = '8 kg') and are equipped with an automatic-dosing detergent dispenser and with a capacity-recognition system, to both reduce detergent consumption and increase the loading rate. This kind of servitised business model usually works with an IoT kit to connect the WM to the internet, in a way to enable payments and remote monitoring (N. Bocken et al., 2019). Consequently, the CE building blocks involved in this CE scenario are servitised business models and digital 4.0 technologies. To assess the economic and environmental impacts of this CE scenario, Eq. (1) and (6) of the lifecycle model are adjusted to compute the TCO and the GWP of the pay-per-wash scheme. More specifically, instead of considering the purchasing price, the pay-per-wash fee (F_{ppw}) is taken into account, using an average value of 1.30 € per washing cycle (N. M. P. Bocken, Mugge, Bom, & Lemstra, 2018). Moreover, a 10% reduction in *DC* is assumed, due to the automatic detergent dosing system. Data regarding lifetimes and GWP values of the supply side are those referring to a high-price WM segment class (Table 3). Lastly, the number of washing cycle (Nwc_{ppw}) is determined by Eq. (7), where the original total amount of laundry is now washed in a WM with a high capacity (*C*) of 8 kg and a Loading Rate (*LR*) equals to 100%, due to the capacity recognition system installed.

$$Nwc_{ppw} = \frac{Nwc \times C \times LR}{8\,kg \ \times 100\%} \qquad (7)$$

Refurbishment scenario

In a refurbishment CE scenario, users no longer buy a brand-new WM. Instead, they buy a refurbished one, i.e. a WM that have been previously used by another household, collected, refurbished and then resold. Consequently, the main CE building block involved in this CE scenario is the reverse logistics supply chain management. To assess the economic and environmental impact of this CE scenario, Eq. (1) and (6) of the assessment model have been adjusted to compute the TCO and the GWP in a refurbishment scheme. More specifically, instead of considering the WM purchasing price, we consider an average refurbishment WM price (P_{Rfb}) equals to 200 €. Moreover, instead of considering a single WM lifetime, we define L_1 and L_2 as respectively the first and the second WM life (i.e. before and after refurbishment). The average L_1 (WM life before refurbishment) was assumed equal to 5 years (WRAP, 2010). Thus, according to the rational underlying Eq. (2), L_2 is derived as in Eq. (8):

$$L_2 = max\left(\frac{L_{WM}}{Nwc}\,;10\right) \qquad (8)$$

It is worthwhile to stress that the TCO uses L_2, since it adopts the users' viewpoint, while GWP uses L_1 + L_2, since it adopts the WM perspective. Furthermore, it was assumed an EEC equal to A++, while the GWP values of the supply side are those referring to an average-price segment class of WM (Table 3). No modifications in *C*, in F_T and in *LR* have been considered, since it was assumed that users buying a refurbished WM do not change their washing habits.

Results and discussion

To compare the results of the assessment model fed with the data collected through the user survey, an average TCO and an average GWP for each scenario is computed. To compare results from different households (with different household size *HS)*, the result for each household *i* has been divided by its number of components, as indicated in Eq. (9) and (10):

$$Average\,TCO\left[\frac{€}{year \times person}\right] = \sum_{i=1}^{183} \frac{TCO_i/HS_i}{183} \qquad (9)$$

$$Average\,GWP\left[\frac{kg\ CO_2 eq.}{year \times person}\right] = \sum_{i=1}^{183} \frac{GWP_i/HS_i}{183} \qquad (10)$$

Figure 4 depicts the results. From an economic point of view, the refurbishment of WMs allows achieving an average TCO lower than in the linear economy. As shown in the top part of Figure 4, the TCO is reduced from 86 to 78 € per person per year. Since the sample average *HS* is equal to 3.5 people, these savings amount to about 28 € per year per household. The refurbishment scenario is beneficial for the environment too, since it allows a reduction of about 31.5 kg CO_2 eq. per year per household (bottom part of Figure 4, from 71 to 62 kg CO_2 eq. per person per year). Thus, refurbishment can be seen as an effective CE solution.

However, greater environmental savings can be achieved through pay-per-wash, as shown in the bottom of Figure 4: this CE business model allows reducing CO_2 emissions from 71 to 58 kg CO_2 eq. per person per year. Unfortunately, this solution does not seem to be economically promising for the user, as shown in the upper side of Figure 4: with the assumed pay-per-wash fee, users' costs increase from 86 to 147 € per person per year.
In other words, both CE alternatives allow reaching environmental savings compared to the AS-IS situation, but only the refurbishment scenario generates also economic savings for the users.

These results should be also compared with the lifetime distributions computed by the assessment model per each scenario (Figure 5). While in the current (AS-IS) scenario, the lifetime (computed through Eq. 2) is quite evenly distributed over the different time-classes (average WM lifetime equals to 10.5 year), both pay-per-wash and refurbishment alternatives increase WM lifespan (average WM lifetimes equal to 13.7 and 13.2 respectively). Consequently, both CE alternatives lead to a WM life extension: in the first case, lifetime is extended because pay-per-wash offers high-quality WM, able to perform 4,000 washing cycles; in the latter, lifetime is extended because refurbishment gives a second-life to WMs. This result is valid also because the model does not take into account a possible intensively-usage of appliances by users. However, this hypothesis can be justified by the fact that such intensive-use is generally discouraged (at least for the first alternative): in pay-per-wash business models, users are economically incentivised to reduce the number of wash cycles (and thus the usage) of WMs.

Conclusion

This study has investigated the economic and environmental potential of CE alternatives in the WM industry, which result in prolonging WMs lifetime. An assessment model to compare the TCO and the GWP of two CE scenarios (pay-per-wash and refurbishment) with the AS-IS (linear) situation has been developed. A user survey was then designed, to collect data to feed the model.

Results showed that both the CE alternatives investigated allow reaching environmental savings compared to the AS-IS situation but, on average, only the refurbishment scenario generates also economic savings for the user. Combining pay-per-wash offerings with refurbishment thus seems to be a potential hotspot for the advancement of CE. To date, few studies have tried to quantify the economic and environmental potential of CE alternatives utilising real users' data. This work is a first attempt to shed some light in this regard, at least for the WM case. The model, although built around the WM industry, can be also easily extended to comprise other energy-using products.

This study has also some practical implications. The findings contribute in reducing the uncertainties regarding the eco-environmental potential of CE alternatives (at least in the WM industry), shedding lights on users' potential economic savings and on environmental impact improvements. Practitioners may use these results in the design of an overall and effective CE solution.

Finally, this study has limitations too. A strong hypothesis was made in Table 3, i.e. the assumption that the environmental impact of manufacturing a WM is merely a function of its price. Moreover, the end of life phase of the WM has not been directly taken into account in the model. Among the several LCA impact categories available, the model only assesses GWP. Furthermore, besides addressing historic trends in energy efficiency, the model does not directly take into account future energy efficiency trends that may affect optimal replacement lifetimes. Considering such trends constitute a promising avenue for future research. Lastly, Figure 4 only compares average TCO and GWP values, computed using average parameters taken from literature. Sensitivity analyses to see how much the results of the model depend on the hypotheses would add value to the research and provide insights to practitioners, e.g. on how to design a suitable pay-per-wash fee.

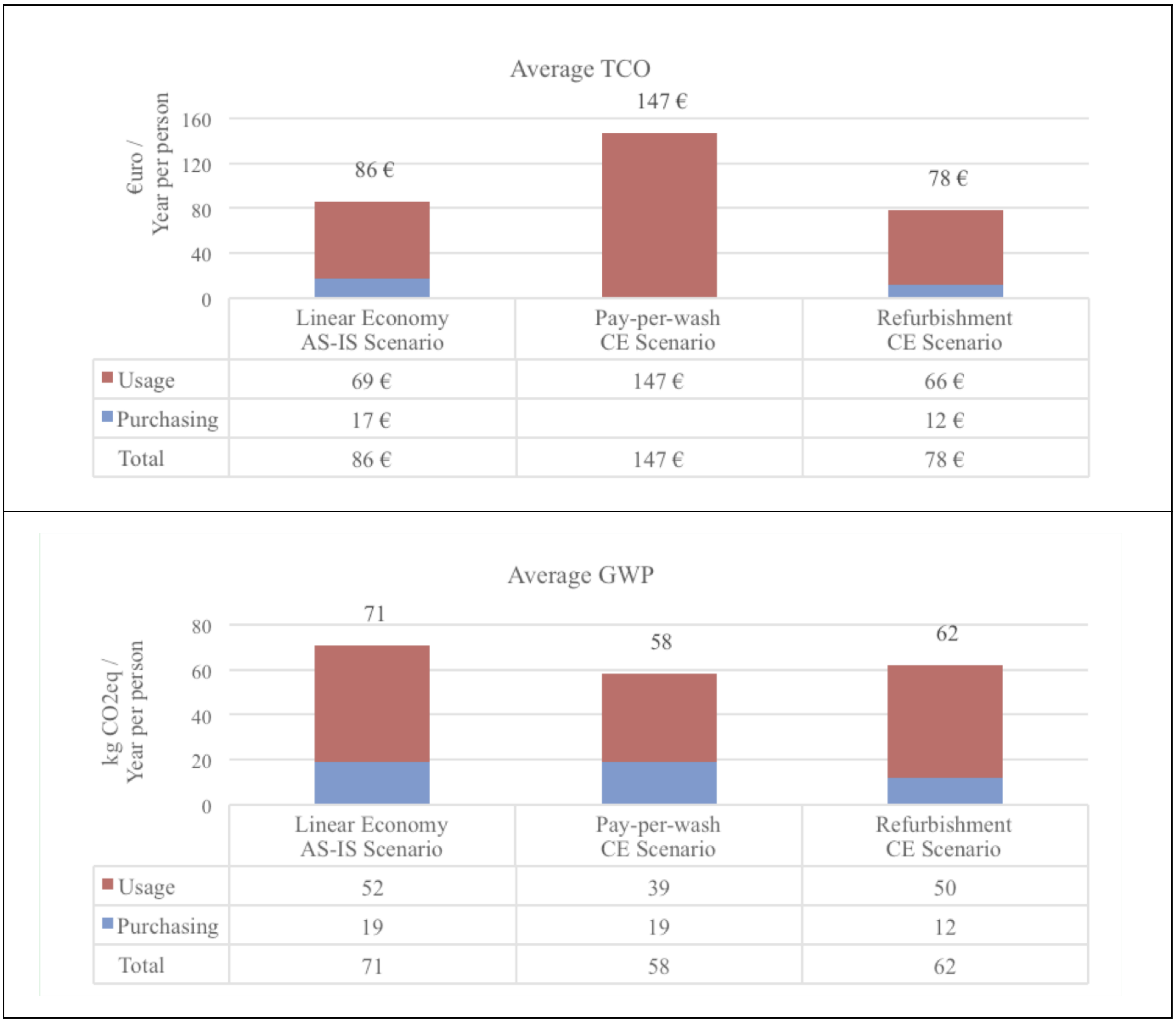

Figure 4. Average TCO and GWP for each scenario.

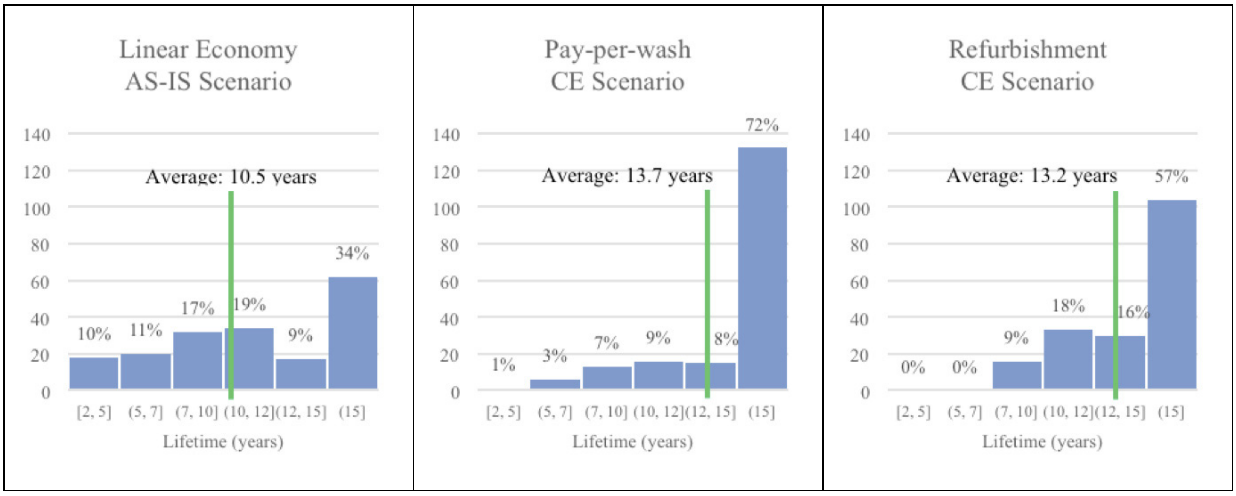

Figure 5. WM Lifetime distribution of each scenario.

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Appendix. Nomenclature used in the model

Symbol	Description	Measure	Source and value
HS	Household Size, i.e. number of person	Person	Users Survey
EEC	Washing Machine Energy Efficiency Class	Dimensionless	Users Survey
C	Washing Machine Capacity	kg	Users Survey
P	Washing Machine average price Three price class (P = 150€; 400€; 600€)	P	Users Survey
Nwc	Usage number of washing cycle per year	Number / year	Users Survey
LR	Washing Machine Loading Rate	%	Users Survey
T	Temperature of washing cycle (T = 30°C; 40°C; 60°C; 90°C)	°C	Users Survey
F_T	Usage frequency per each temperature	%	Users Survey
N_{RC}	Average Number of Rinsing Cycle per each washing cycle	Number / Nwc	(Kim et al., 2015) N_{RC} = 2
K_T	Temperature coefficient	Dimensionless	(Milani et al., 2015)
EFC_{EEC}	Washing Energy Fixed Consumption, depending on EEC	kWh / Nwc	(Milani et al., 2015)
EVC_{EEC}	Washing Energy Variable Consumption, depending on EEC	kWh / (Nwc * kg)	(Milani et al., 2015)
WFC	Water Fixed Consumption per each washing cycle	Litre / Nwc	(Lasic et al., 2015) *WFC* = 4.166
WVC_C	Water Variable Consumption per each washing cycle, depending on the Washing Machine Capacity	litre / (Nwc * kg)	(Lasic et al., 2015) WVC_C = 0.476
$WVC_{C;LR}$	Water Variable Consumption per each washing cycle, depending on the real amount of laundry	litre / (Nwc * kg)	(Lasic et al., 2015) $WVC_{C;LR}$ = 1.725
DFC	Detergent Fixed Consumption per each washing cycle	kg / Nwc	(Boyano et al., 2017) *DFC* = 0.04
$DVC_{C;LR}$	Detergent Variable Consumption per each washing cycle, depending on the real amount of laundry	kg / (Nwc * kg)	(Boyano et al., 2017) $DVC_{C;LR}$ = 0.012
L_{WM}	Washing machine expected lifespan, as number of washing cycles that a WM can perform	washing cycles	(Rüdenauer et al., 2005)
MR	Maintenance and Repair costs for the WM	€ / year	(Boyano et al., 2017) *MR* = 3.6
e_c	Energy unitary cost	€ / kWh	(YAECI Project, 2013) e_c = 0.23
w_c	Water unitary cost	€ / litre	(YAECI Project, 2013) w_c = 0.004
d_c	Detergent unitary cost	€ / kg	(Boyano et al., 2017) d_c = 3.5
RWE_{WM}	Global Warming Potential associated to the Raw Material Extraction phase of the WM	kg CO_{2eq} / WM	(Rüdenauer et al., 2005)
$M\&A_{WM}$	Global Warming Potential associated to the Manufacturing and Assembly phases of the WM	kg CO_{2eq} / WM	(Rüdenauer et al., 2005)
D_{WM}	Global Warming Potential associated to the Distribution phase of the WM	kg CO_{2eq} / WM	(Rüdenauer et al., 2005)
e_{gwp}	Energy unitary global warming potential	kg CO_{2eq} / kWh	(Kim et al., 2015) e_{gwp} = 0.41
w_{gwp}	Water unitary global warming potential	kg CO_{2eq} / litre	(Kim et al., 2015) w_{gwp} = 0.0011
d_{gwp}	Detergent unitary global warming potential	kg CO_{2eq} / kg	(Boyano et al., 2017) d_{gwp} = 1.89
F_{ppw}	Average pay-per-wash fee	€ / washing cycle	(N. M. P. Bocken et al., 2018) F_{ppw} = 1.3
L_x	X Lifespan of the refurbished WM (where X = 1; 2; …)	years	(WRAP, 2010) L_1 = 5
P_{Rfb}	Price of the refurbished WM	€	Own estimation P_{Rfb} = 200

Economic Consequences of Consumer Repair Strategies for Electrical Household Devices

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Keywords: Repair; Repairability; Product Lifetime; Life Cycle Cost; Monte Carlo Simulation.

Abstract: This paper investigates to what extent a consumer's repair strategy impacts the annual costs of ownership of a washing machine and two types of vacuum cleaner. The annual cost of ownership is determined by calculating the annual life cycle cost (LCC) for the respective devices. The annual LCCs of the different scenarios allow a comparison of the different repair strategy options. A Monte Carlo simulation is run to introduce parameter variability. The device's failure rate is estimated by a combination of datasets on the devices' performance. Results demonstrate that the repair of the devices considered is a more favourable option over replacement. A consumer who aims for the lowest annual LCC should allow for a high number of repairs per device, without putting a maximum on the cost per repair. However, the consumer should become more cautious when a device approaches the end of its expected lifetime. Finally, the purchase of warranty can be interesting when the warranty covers a sufficiently long proportion of the device's (expected) lifetime and when its cost does not exceed a threshold proportion of the initial purchase price.

Introduction

The main goal of this paper is analyse the impact of different repair strategies on the life cycle cost (LCC) of a canister vacuum cleaner, an upright vacuum cleaner and a washing machine from the consumer point of view. The modelling and comparison of the LCC for different scenarios allow the identification of the most favorable consumer strategy in case a failure of the owned device occurs. In this rationale, the LCC is calculated as the Net Present Value (NPV) of all current and future costs related to the ownership and usage of the considered household device. To further improve the consumer strategy, the contribution and influence of a few specific consumer choices are investigated by means of an uncertainty analysis.

Theoretical framework

LCC calculation is subject to a wide range of methodological freedom. This study applies the fundamental principles of LCC (UNEP SETAC LCC Code of Practice), i.e. the 'single end user' perspective. This implies that only the private, and aggregated costs are considered, and that future costs are discounted.

Results

Figure 1 first discusses the average composition of the LCC for each device.

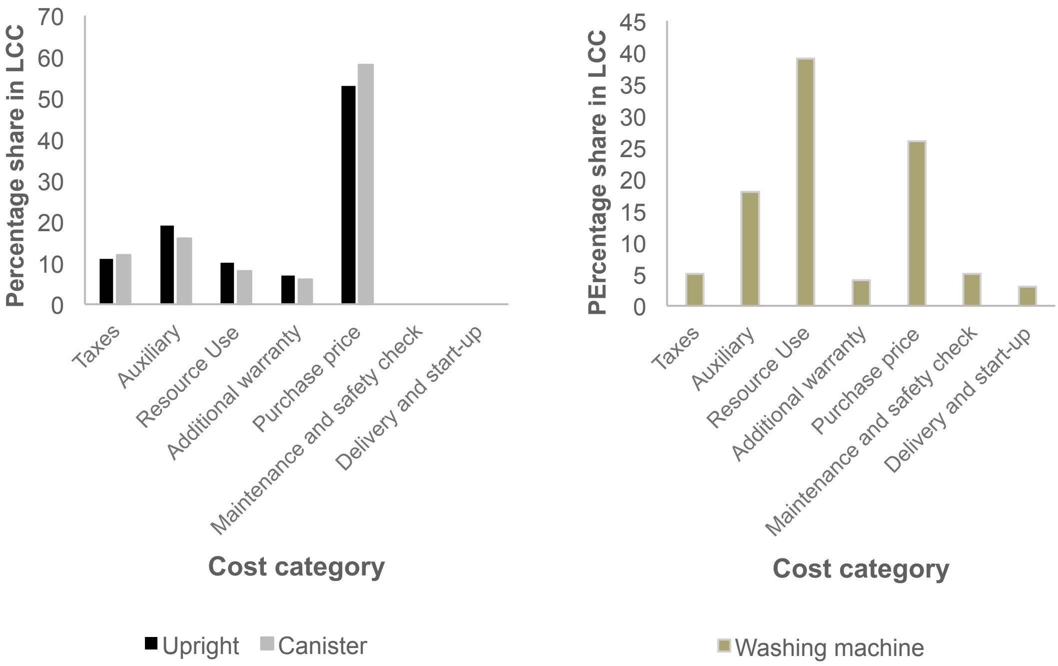

Figure 1. Average percentage composition of the LCC per device.
NOTE.- Not all cost categories are applicable for each device. ‘Auxiliary’ differs among the devices. For washing machines this encompasses detergent and filters, for vacuum cleaners this encompasses bags. The resource use also encompasses the water usage in case of the washing machine. For vacuum cleaners, the resource use only encompasses energy use. No replacement or repair is assumed.
Notice that the figure above visualizes the average composition of the LCC, in case broken devices are not repaired, nor replaced. Due to variability in the Monte Carlo simulation, also variability in terms of the LCC composition can occur.

Table 1 presents the LCC for the three devices as well as proportion to the initial purchase price (purchase price = 100). Moreover, Table 1 also presents the lifetime for each device, as well as the annual LCC and the standard deviation (providing an indication for the variance in the annual LCC). The annual LCC is a useful indicator as it better allows comparison between scenarios with different lifetimes.

Comparison Repair and Replace scenarios

In case a defect occurs outside of the warranty period, a consumer can either dispose and replace the device or opt for a repair. The repair will prolong the lifetime of the device. Table 1 presents the LCC for the three devices in case they face a defect and are repaired at the expenses of the consumer. This scenario is compared to the ‘replace’ scenario in which the device faces a defect (outside) the warranty period and is disposed of and replaced.

Comparison between the repair scenarios and the replace scenario clearly demonstrates that the repair of the three considered devices is the favored option over the replacement of the devices. For all devices, the repair scenarios’ LCC is significantly below the replace scenario’s LCC, as confirmed by a T-test of the bilateral comparison of the scenarios’ means, significance level of 95 %). Consequently, also the annual LCCs are lower for all devices in the repair scenario. The difference in annual cost between the repair and replace is highest in case of the upright vacuum cleaner (-22.03 %), followed by the canister vacuum cleaner (-21.59 %) and the washing machine (-11.07 %). Notice that the standard deviation for the three devices’ annual LCC is also higher in the replace scenario in comparison to the standard deviation in the repair scenarios.

Device	Scenario	Mean / Scale parameter Annual LCC	St. Dev. / shape parameter Annual LCC	Mean Total LCC	Average lifetime	Found distribution
Washing machine	Repair	32.22	6.34	531.96	16.51	Log-normal
	Repair with maximum repair cost	32.72	7.51	492.13	15.04	Log-normal
	Repair without warranty	32.22	7.68	532.92	16.54	Log-normal
	Replace (without repair)	36.23	8.35	598.11	16.51	Log-normal
Vacuum cleaner Upright	Repair	17.73	4.01	240.89	13.52	Log-normal
	Repair with maximum repair cost	20.74	5.35	231.41	11.16	Weibull
	Repair without warranty	19.40	3.34	246.55	12.71	Log-normal
	Replace (without repair)	22.74	5.69	307.48	13.52	Log-normal
Vacuum cleaner Canister	Repair	17.25	5.00	209.75	13.44	Log-normal
	Repair with maximum repair cost	21.00	6.75	184.50	10.40	Gamma
	Repair without warranty	18.75	8.50	194.50	12.11	Log-normal
	Replace (without repair)	22.00	6.50	265.75	13.44	Log-normal

Table 1. Overview of (annual) LCC per device, per scenario NOTE. - All LCCs are presented as proportion to the initial purchase prices for reasons of non-disclosure of the producer identity.

Diversity in Repair strategy

This section zooms in on the high impact the variable 'number of repairs allowed' accounts for (up to 70.4 % in the case of the washing machine - see Table 2), which suggests that increasing the number of repairs allowed decreases the expected LCC of a device.

This is further examined by means of a sensitivity analysis in which the Monte Carlo simulation is re-run, for pre-determined levels of the number of repairs allowed. Table 2 presents the results of this analysis and indicates that increasing the number of repairs allowed unambiguously decreases the annual LCC for each of the considered devices. Note, however, that the decrease in annual LCC is highest in case fewer number of repairs are allowed.

Device	Number of repairs allowed				
	1	2	3	4	5
Washing machine	35.06	31.55	30.55	30.05	29.88
Upright vacuum cleaner	19.73	17.39	16.72	16.72	16.72
Canister vacuum cleaner	19.00	16.75	15.75	15.50	15.25

Table 2. Average annual LCC in the repair scenario per device, per number of repairs allowed.

Table 1 also presents separate scenarios to investigate two other aspects related to the repair options of a consumer: the maximum repair cost allowed and the option to purchase additional warranty. Some larger repairs (e.g. a lot of time is needed, or important parts are replaced) might seem disproportionally expensive in comparison to the purchase price of the washing machine. In these cases, consumers could refuse a repair. This is further examined by the introduction of a consumer-specific maximum repair cost (per repair). A log-normal distribution is constructed for the maximum cost per repair. The LCC increases for all three devices after the introduction of this additional parameter in the Monte Carlo simulation (compare 'repair' scenario with 'repair with maximum repair cost' scenario). While the increase is only marginal in case of the washing machine (+1.55 %), the increase is more considerable in case of the upright (+16.98 %) and canister (+21.62 %) vacuum cleaner. Furthermore, the lifetime of all devices decreases in the newly created 'repair with maximum repair cost' scenario and the standard deviation increased considerably. Also, the variability is negatively impacted in the new scenario as it increased for all three devices.

Finally, the option to purchase a warranty is analyzed. In contrast to all previously mentioned elements of a consumer's repair strategy, the conclusions related to the purchased warranty are not the same for all devices. The 'repair' scenario is compared to the 'repair without warranty' scenario. In case of the washing machine, the purchased warranty does not impact the annual LCC. The variability is slightly positively impacted by the purchased warranty (i.e. lower standard deviation in the 'repair' scenario with warranty) while on the other hand the lifetime is slightly shorter in case of the warranty. In case of the vacuum cleaners however, the purchased warranty appears to be an interesting option. For both vacuum cleaners, the annual LCC is lower in case of purchased warranty. In addition, the purchased warranty also increased the lifetime of both vacuum cleaners.

Discussion

Repair versus replace

In the modeled scenario's, the repair of the devices is found more beneficial in comparison to the disposal and replacement of the devices. This turns the repair strategy into an interesting option for risk-averse consumers who favor a more predictable LCC. This might come as a surprise as the repair scenario might require a high number of interventions (repairs), which in theory increase variability. However, the monetary costs related to the individual interventions are in general limited. In contrast, the replace scenario is characterized by one main intervention (i.e. the replacement), but this sole intervention comes with a high cost. This explains the increased variability in the replace scenario.

The study outcomes confirm that the repair strategy is preferred to the replace strategy. However, the economic attractiveness of the repair strategy can be further improved. First, products designed for repair can facilitate the disassembly and repair of the considered devices, as the required disassembly time partially determines to the related labor costs of repair. This provides opportunities to 'further increase the economic feasibility of product lifetime extension and therefore increase the viability of a circular economy in industrialized regions' (Vanegas, et al. 2017). Second, producers can further improve the availability of, and access to spare parts to decrease the costs of the spare parts. This analysis did not consider the transaction costs related to repair, but improved availability of spare parts will also decrease these transaction costs. Third, both governmental policies and business model innovation can aim to reduce the barrier of the reverse logistics (Whalen, et al. 2017). This claim especially holds in the case of vacuum cleaners, as these devices' repair costs are also driven by the costs of sending the devices and spare parts for repair. This demonstrates the potential of self-repair options.

Optimal Repair strategy

This paper stresses the importance of the choices made as part of the consumers' repair strategy. Four aspects are analyzed in detail.

First, the results indicate that consumers should allow a high number of repairs to optimize the annual LCC of ownership of a washing machine or vacuum cleaner. This might be difficult if a consumer is confronted with numerous defects for a single device and subsequently loses faith in the device. Nevertheless, this paper's analysis demonstrates that once a consumer opts for the repair of a device, this strategy should be pursued, and new repairs should be allowed in case of new defects. The rationale behind this finding is that a limit on the number of repairs allowed also limits the earn-back potential of the previous investments in repair. Note that in the context of allowing multiple repairs, this paper does not consider a decreasing willingness to pay for repairs over time. This phenomenon is observed in highly-technological and fast evolving devices such as mobile phones which typically have a short life span (Sabbaghi, et al. 2016). Washing machines and vacuum cleaners do not meet these criteria.

Furthermore, the consumer has the possibility to purchase an extension of the legal warranty period (two years following the purchase) by an additional three years. This option does not directly link to the repair/replace decision a consumer faces in case of a malfunctioning device. It does however eliminate the occurrence of these repair/replace decisions during the first 5 years of a device's lifetime as during this period the malfunctioning device should be repaired or replaced at the expenses of the producer. The potential benefits of the purchased warranty depend on the considered device and the warranty cost.

In case of the washing machine, the warranty does not manage to decrease the impact of the annual LCC, while also the lifetime is not significantly impacted. However, the standard deviation is statistically significantly lower in case of the purchased warranty (6.34 with purchased warranty versus 7.68 without purchased warranty). Hence risk adverse consumers, who wish to better control their future ownership costs, might be tempted by the option to purchase additional warranty despite the lack of an economic benefit in terms of decreased annual LCC.

In contrast, the vacuum cleaners' annual LCC does significantly decrease following the purchase of warranty (-8.61 % and -8.00 % for respectively the upright and canister vacuum cleaner). The explanation for this decrease due to the purchased warranty is twofold. First, the additional warranty period is relatively long compared to the entire expected lifetime in case of the vacuum cleaners. Second, the relative cost of the purchased warranty (expressed as proportion of the devices' initial purchase price) is higher for the washing machine (15.03 %) in comparison to the upright and canister vacuum cleaner (respectively 13.38 % and 10 %). A higher relative warranty cost can be justified if the avoided repair costs are relatively higher as well. But the avoided relative repair costs are comparable for all considered devices, making the purchase of warranty less interesting for the washing machine.

Conclusion

In general, the repair, instead of displacement and replacement, of the considered devices is found the most interesting consumer strategy in economic terms. This strategy manages to decrease the annual LCC related to the ownership of the three considered device. The washing machine's LCC decreases by 11.07 % while the upright and cannister vacuum cleaners' LCC decreased by respectively 22.03 % and 21.59 %. The potential benefit is most elevated in case the life time is extended most and depends on specific choices made by the consumer.

This paper finds that the repair strategy should be applied without too many prejudices or reservations. No maximum should be put on the repair costs, and a high number of repairs should be allowed. This allows to sufficiently extend the lifetime of a device to spread the ownership costs over a higher number of years (decreasing the annual LCC). However, the willingness to repair should be tempered when the device approaches its end-of-life.

Additionally, it is observed that the repair scenario is less prone to variability compared to the replace scenario. The repair scenario faces an elevated number of interventions, but in contrast the costs associated to the interventions is lower compared to the replacement of the device.

The purchase of a warranty is an interesting option, on the precondition that the extended warranty period covers a sufficiently long period of the extended lifetime. In addition, the cost of the purchased warranty should be relatively low in comparison to the initial purchase price, especially if the avoided repair costs are limited.

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Circular Design Tools: (How) do they Understand the Consumer?

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Keywords: Circular Design Tools; Circular Economy; Circular Consumption; Human-centered Design; User Perspective.

Abstract: A move towards a circular economy will require fundamental changes in the way products and services are designed. However, tools for design in the context of the circular economy mostly have a narrow product or service focus without acknowledging the role of addressing behaviors and changing practices. This paper presents the results of an exploratory study investigating to what extent circular design tools consider and integrate aspects related to consumption and consumers. Using five circular tools publicly available, the research team analyzed how they address three aspects: circular consumer behaviors, consumer acceptance factors and conditions for adoption. Our analysis shows that although some of the tools acknowledge the need to gather insights around consumption and consumers, they do not address such aspects in detail. When the tools considered consumer aspects, they did so by acknowledging circular consumer behaviors. Rent and rebuy are the most frequently mentioned behaviors, while remunerate, retain and renounce are absent from the tools. Other behaviors such as receive, ritualize, regard, revalue, resell and relinquish are mentioned only once. The tools' lack of consideration of acceptance factors and contextual conditions is slightly surprising, as most of them advocate for a human-centered approach to product development. Existing circular design tools could thus benefit from integrating concepts and frameworks from fields such as design for sustainable behavior and practice-oriented design.

Introduction

A move towards a circular economy will require fundamental changes in the way products and services are designed, so that they enable circularity through slowing, narrowing and closing material loops (Bocken et al., 2016). Such new products and services must not only serve a market need but also be designed in a way so that they are accepted and adopted by consumers. The development of successful offerings depends on acknowledgment of the role of consumption and consumers during the design process. However, design in the context of the circular economy is most commonly considered as a tool for "engineering product life extension" (Lofthouse and Prendeville, 2018, p. 454), and does not extensively acknowledge the wider role of design in addressing behaviors (Boks, 2006) and changing practices (Pettersen et al., 2013).

Some efforts have been made to highlight the role of consumption and consumers. For example, Mugge (2017) described factors that influence people's decisions to engage with circular strategies. Wastling et al. (2018) and Cerulli-Harms et al. (2018) explored behaviors that people need to perform in the context of the circular economy, and Selvefors et al. (2019) explored design strategies that can be used to address users' concerns and make circular offerings preferable over linear ones. Although these and other aspects related to consumption and consumers are gaining attention in literature, they are as of yet not extensively addressed by available circular design tools.

The aim of this paper is to contribute to the discussion about the role of design in the circular economy by investigating how existing circular design tools consider and integrate aspects related to consumption and consumers. The paper initially provides a short overview of important aspects related to consumption and consumers based on existing literature. The methods and sources for the analysis is then presented followed by the main findings and conclusions.

Consumption and consumers in the Circular Economy

Literature highlights a multitude of aspects related to consumption and consumers that are relevant to consider when developing new circular offerings. This paper will focus on three key topics. First, circular consumer behaviors are presented based on previous work (Camacho-Otero et al., forthcoming), building on recent studies about consumption, circular economy and design (Selvefors et al., 2019; Wastling et al., 2018). Second, an overview of factors influencing acceptance of circular solutions and the behaviors they entail, are provided based on existing literature on the topic (Camacho-Otero et al., 2018a). Finally, aspects that could enable the adoption of such offerings and behaviors using a social practice theory perspective (Camacho-Otero et al., 2018b) are addressed.

Consumer behaviors

Emerging circular business models require companies and consumers to interact with products and services in different ways, with the commercial relationship moving beyond the point of purchase. In a forthcoming book chapter, Camacho-Otero et al. discuss several ways through which consumers can interact with products and services offered based on circular business models, here referred to as circular consumer behaviors. As illustrated in Table 1, these circular consumer behaviors can be related to the different moments of consumption defined by Evans, (2018) (acquisition, appropriation, appreciation, devaluation, divestment and disposition), as well as the circular business strategies suggested by Bocken et al. (2016).

Moment of consumption	Behavior	Circular business strategies
Acquisition	Re-buy	Extending product value
	Rent	Access-based consumption
	Receive	Classic long-life
Appropriation	Remunerate	Classic long life
	Ritualize	Classic long life, extending product value
	Retain	Classic long life, extending product value
Appreciation	Regard	Classic long life, extending product value, access-based consumption
	Repair	Classic long life, extending product value
Devaluation	Revalue	Classic long life, extending product value, Access-based consumption
Divestment	Renounce	Classic long life, extending product value, Access-based consumption
Disposition	Re-sell	Classic long life, extending product value
	Relinquish	Classic long life, extending product value
	Return	Access-based consumption

Table 1. Circular consumer behaviors by consumption stage and circular business strategies.

Factors of acceptance

Acceptance is a term used in different context such as information technology (Davis, 1993; Venkatesh et al., 2002) and electronic commerce (Ha and Stoel, 2009). In this study, we used the term defined by Schrader (1999) in the context of eco-innovations. He suggested that acceptance is the positive intention of a person to engage with an eco-efficient solution. This intention does in turn depend on different individual factors. In a recent review, (Camacho-Otero et al., 2018a) mapped the different factors offered by the literature on consumer acceptance of product service systems, collaborative consumption and remanufacturing Figure 1 illustrates. Key factors include personal characteristics, product and service offering, knowledge and understanding, experience and social aspects, risks and uncertainty, benefits, and other psychological aspects. However, intention does not always translate into adoption of new offerings or behaviors (Michaud and Llerena, 2011; Welch and Warde, 2014). Hence, additional aspects and conditions should be considered if adoption is to be understood.

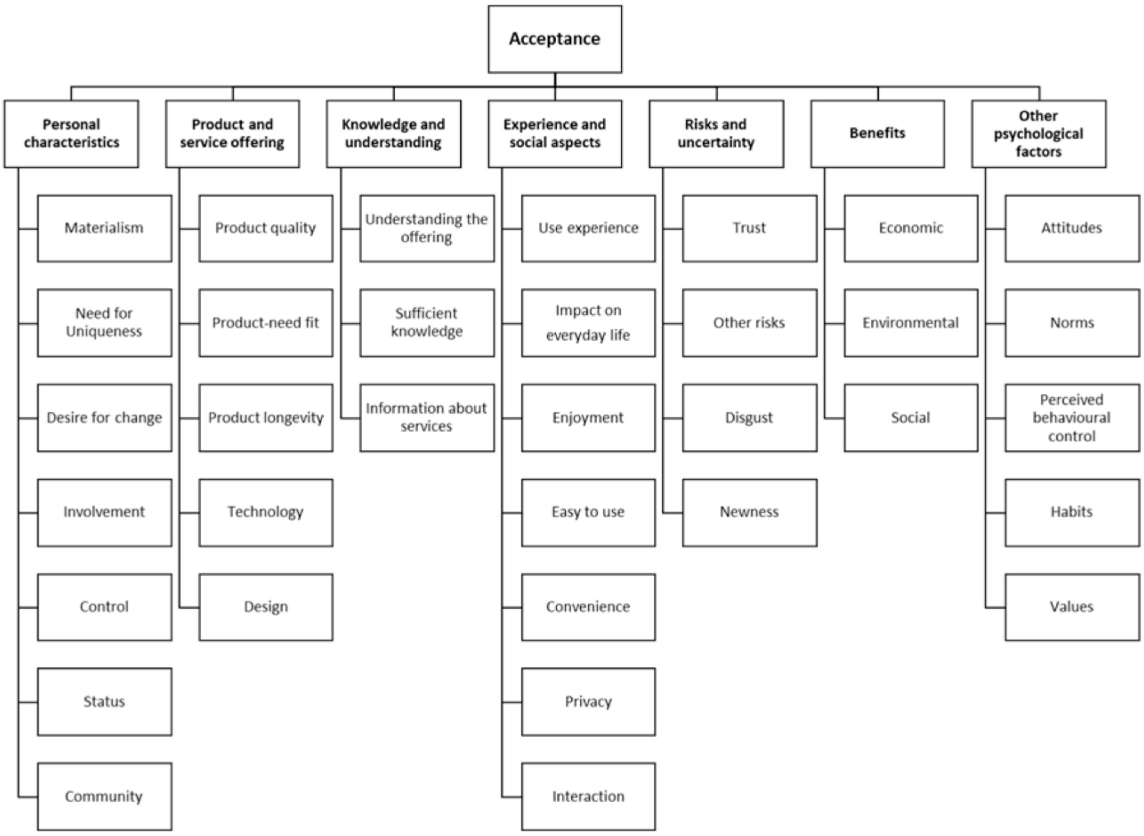


Figure 1. Factors influencing the acceptance of circular offerings (Camacho-Otero et al., 2018a).

Conditions for adoption

Different perspectives exist when investigating the adoption of innovative offerings, for example Rogers' (2003) Diffusion of Innovations Theory, the Multi-Level Perspective by Geels (2005) and more recently, Social Practice Theory -SPT-(Shove et al., 2012). For this study we opted to us the latter based as it has been argued that it can support resource use reductions (Pettersen, 2016).

Social practices are defined as "embodied, materially mediated arrays of human activity centrally organized around shared practical understanding" (Schatzki, 2001, p. 11). Shove and Pantzar (2005), simplify this, suggesting that practices comprise materials, meanings and skills. In addition, Mylan (2015) argues that practices change because their elements change, the interlinkages between elements change, and/or the connections to other social practices transform. In SPT, practices are not just adopted by people, they recruit practitioners. Huber (2017) argues that this process depends on the opportunities for performing the practice which in turn depend on exposure to the practice, personal histories and capitals, and the ability of the practice to integrate with other practices. Thus, studying why people engage with circular offerings requires understanding why new practices emerge and how they recruit people.

Benefits of considering behaviors, acceptance and adoption

The aspects described in the sections on circular consumer behaviors, factors of acceptance and conditions for adoption, are in different ways relevant to consider if aiming to develop successful circular offerings. Considering both how circularity influences behaviors and which behaviors that circularity may entail, may unveil opportunities to create new offerings that make circular behaviors attractive. Addressing factors of acceptance will further increase the potential for positive perceptions by consumers. Moreover, considering the practice that serves as context to the offering (including its other elements and the interlinkages between them and other practices) and the processes by which the practice recruit practitioners, will facilitate development of offerings that can more easily be adopted by people and integrated into everyday life. In sum, we argue that it would be beneficial for circular design tools to address circular consumer behaviors, factors of acceptance and conditions of adoption.

Materials and methods

Circular design tools were selected for this study based on literature reviews on circular economy and design (Lofthouse and Prendeville, 2018; Mugge, 2018) and a web-based query in academic databases. From this analysis, 38 documents were identified and screened, only 11 were described as design tools. Of these, we selected five tools using purposeful sampling, see Table 2.

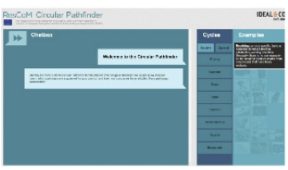
Tool	Source	Description
The circular design guide (CDG) 	Industry (IDEO and Ellen MacArthur Foundation, 2017)	CDG consists of 24 worksheets organised in five groups, Understanding, Define, Make, Release and Advance. The tool includes workshop guidelines for product redesign and safe materials selection.
The circulab board (CLab) 	Industry (Wiithaa, n.d.)	CLab is a business canvas board. It includes instructions to use the board and conduct a workshop.
The circular economy toolkit (CET) 	Academia (Evans and Bocken, 2013)	CET is an online tool intended to be used in a workshop setting by companies looking for opportunites to transition to a circular business model.
Business as Unusual (BAU) 	Academia (Makatsoris et al., 2017)	The BAU is a workshop tool to define new customer journeys based on 2030 scenarios. It offers three worksheets for exploring opportunities for engagement during the design, purchase, use and disposal of a product.
The circular pathfinder (CPF) 	Academia (Van Dam et al., 2017)	CPF is an online tool that aids companies to identify and evaluate circularity strategies. By asking a series of questions, an algorithm suggests alternative strategies for a selected product.

Table 2. Selected circular design tools.

Name	CDG	CLab	CET	BAU	CPF
Scope	Business model, Service, Product	Business model	Business model, Service, Product	Business model, Product	Business model, Service, Product
Type of tool	Analogue design tool	Analogue analysis tool	Online and analogue prioritization tool	Analogue analysis tool	Online identification tool
Expected outcome	Designs released on the market	Opportunities for design	Prioritized opportunities	Opportunities for engaging users in the design process	Identified circular strategies
Consumption and consumer related aspects considered	Explicit: Customer experience, feedback, needs and value	Explicit: Customer needs and contexts	Implicit: Consumer behavior	Explicit: Consumer needs, experience and involvement	Explicit: Consumer behavior, consumer preferences

Table 3. Overview of the analyzed tools

A template for analyzing how the five circular design tools consider and integrate aspects related to circular behaviors, acceptance and adoption, was developed. Insights about the tools were documented in four sections: section one summarizes general information about the tool; section two refers to the type of behaviors that are implicitly or explicitly considered; section three covers factors of acceptance; and section four addresses how the tools consider conditions of adoption. The analysis was carried out based on the data available online and documents provided by the developers of the tool. Worksheets and workshop guidelines were downloaded and used along with online instructions, reports and academic papers. Camacho-Otero and Selvefors conducted five within-tool analyses using the developed template. Once all tools were analyzed, a cross-tool analysis (Creswell, 2014) was performed to explore similarities and differences among the tools.

Results

As illustrated in Table 3, the selected tools address different scales of design. While all address business models, CDG, CET, CPF and also BAU to some extent address service and product design. Only CDG aids the entire design process, including the creation, testing and release of a design. The rest of the tools address specific phases in the design process, and aid companies in exploring opportunities to go circular, but do not provide guidance on how to realize these opportunities. All tools except CET explicitly acknowledge the role of the consumer in their design process, and customer needs and experiences are considered the departing point for the development process. The following three sections describe how the tools consider circular behaviors, factors of acceptance and conditions for adoption, respectively.

Circular behaviors

As summarized in Table $ BAU is the tool that4considers most behaviors while CLab does not consider any, which may be due to its focus on customer needs and contexts. CET and CPF acknowledge the need to consider consumer behaviors because they are part of the offering but do only explicitly include a few behaviors. Rent and rebuy are the most frequently mentioned behaviors, while remunerate, retain and renounce are absent from the tools. Other behaviors such as receive, ritualize, regard, revalue, resell and relinquish are mentioned only once.

Consumption stage	*Behavior*	CDG	CLab	CET	BAU	CPF
Acquisition	*Re-buy*	-	-	Re-buy	Re-buy	Re-buy
	Rent	Rent	-	Rent	Rent	Rent
	Receive	-	-	-	Receive	-
Appropriation	*Remunerate*	-	-	-	-	-
	Ritualize	-	-	-	Ritualize	-
	Retain	-	-	-	-	-
Appreciation	*Regard*	-	-	-	Regard	-
	Repair	-	-	Repair	Repair	-
Devaluation	*Revalue*	-	-	-	-	Revalue
Divestment	*Renounce*	-	-	-	-	-
Disposition	*Re-sell*	-	-	-	Re-sell	-
	Relinquish	-	-	-	Relinquish	-
	Return	-	-	Return	Return	-

Table 4. Circular consumer behaviors considered by the tool.

Factors of acceptance and conditions for adoption

Table 5 summarizes which of the key acceptance factors the analyzed tools address. Notably, only two tools do include references to aspects that may influence people's intention to engage with the solution. These factors include functionality and quality of the offering, the experience with the service, benefits for well-being, emotions and values. CDG focuses on addressing emotion, a psychosocial factor, through marketing strategies. It also suggests emphasizing the symbolic value of the offering so cultural aspects such as identity and status can also be addressed. CPF considered aesthetic aspects of the product and trust.

The findings also show that only a few tools address conditions for adoption, and when they do, it is only tangentially. For example, CDG suggests that to contribute to a regenerative system, companies need to think of their context, which is expressed as the social conditions of their environment and their employees. CDG guidance focuses on exploring options to increase the value for employees to work with the company and for local communities where the company operates. It does not refer to the social practice in which the product or service is embedded. CLab indicates the need to understand the relevant contexts in which the offering can resolve the problem but does not provide further detail on how to do it. The rest of the tools do not analyze the context of the solution.

Name	CDG	CLab	CET	BAU	CPF
Personal characteristics	-	-	-	-	-
Offering	-	-	-	-	Function, quality
Knowledge and understanding	-	-	-	-	-
Experience and social aspects	Experience	-	-	-	-
Risks and uncertainty	-	-	-	-	Trust
Benefits	Wellbeing	-	-	-	-
Psychological factors	Emotions, values	-	-	-	Values

Table 5. Factors of consumer acceptance considered by the tool.

Conclusions

The aim of this study was to investigate whether existing design tools consider consumption and consumer related aspects. Our results coincide with (Lofthouse and Prendeville, 2018) who indicated that so far, design has not focused enough on the role of consumers in the circular economy. Our analysis shows that although some of the analyzed tools acknowledge the need to gather insights around consumption and consumers, they do not address such aspects in more detail.

Circular consumer behaviors is the topic that most of the tools addressed. Acquisition and disposition behaviors such as rent, re-buy and return were more prominent among the tools than appropriation, appreciation, devaluation and divestment behaviors. This can be a consequence of a restrictive understanding of the consumption process. Nonetheless, in the context of a circular economy, behaviors such as remunerate, and repair become relevant.

The very limited consideration of acceptance factors and contextual conditions in the tools is slightly surprising, as most of them advocate a human-centred approach to product and service design. The tools that considered some factors focused on values, emotions, product quality and experience, but dismissed personal characteristics, knowledge, and risks. This is problematic as lack of acceptance of circular solutions often is associated with materialism, lack of trust and contamination. Finally, we detected a minimal consideration of the context of the offerings. This can contribute to a slow or even lack of adoption, even when the offering is accepted, and people are willing to engage. If an offering is difficult to be integrated into existing practices or become part of new practices that recruit practitioners, it is unlikely to succeed. Thus, the need to better understand the context and evaluate the risks regarding adoption.

We suggest that circular design and circular design tools should focus more on consumer behaviors needed in the context of circular offerings, as well as on factors of consumer acceptance and conditions for adoption. Existing circular design tools could therefore benefit from integrating concepts and frameworks from fields such as design for sustainable behavior and practice-oriented design.

Acknowledgments

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Spark Joy and Slow Acquisition: the KonMari Method and its Impact on Moments of Consumption

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Keywords: Sufficiency; Sustainable Consumption; Slowing Consumption; Decluttering; Circular Economy.

Abstract: Circular economy (CE) models and practices have grown in influence and popularity over the last few years, particularly with respect to business and policy. The remit of the consumer however has been somewhat neglected, and yet when it comes to product lifetimes and obsolescence it is usually consumers who decide the lifetime of a product, often by discarding it whilst it is still serviceable. Moreover there is to date very little research that explicitly connects the concept of sufficiency with the 'slowing' or reduction of consumption that is implied by most CE frameworks.
In this study we compare research conducted in Sweden and the UK & Ireland with practitioners of the KonMari method of decluttering. The KonMari method was created in Japan and has been exported around the world in the form of books and more recently a Netflix series. Through our surveys and qualitative analysis of our interviews we investigate the relationship between KonMari decluttering practices and 'moments' of consumption as characterised by Evans (2018). We show that the ritualised KonMari method seems to not only speed up devaluation, divestment and disposal but also to reinforce appropriation and appreciation, and perhaps most importantly to reduce acquisition. By becoming more aware of what brings them joy (both in terms of favoured possessions and a tidier home environment), participants tend to reduce their purchasing activities and simultaneously make time for more fulfilling activities.

Introduction

The burgeoning volume of research on circular economy has thus far not paid much attention to the role of the consumer and more specifically the concept and practice of sufficiency in consumption. In this short paper we investigate the relationship between six different 'moments' of consumption (Evans, 2018) and the KonMari decluttering method as a means to slow down the moment of acquisition in particular, by stimulating a more discerning approach to consumption of material goods. Our empirical study compares survey and interview data from two affluent European geographies (Sweden and the UK & Ireland) and discusses the initial findings.

Sufficiency as a Response to Planetary Limits

The growing literature on sufficiency (Spangenberg & Lorek, 2019) presents the concept both as a logic or principle that needs to be at the foundation of a sustainable society and economy (Princen, 2005; Schneidewind & Zahrnt, 2014) and as a choice of lifestyle for individuals who want to decrease their environmental impact (Heindl & Kanschik, 2016; Speck & Hasselkuß, 2015). What can be said to define sufficiency in both these aspects is that it treats the issue of limits - that ecological restraints set absolute limits for the resource use of societies and individuals. In this sense, sufficiency addresses the volume of our consumption and, consequently, the question of affluence. This article starts from an understanding of sustainability as the need to stay within the planetary boundaries or in the "safe operating space for humanity", as defined by Rockström et al (Rockström et al., 2009). This understanding also includes the embracing of sufficiency as a principle that builds on "ecological rationality"(Princen, 2005). In regards to sufficiency on the individual level, this has been treated as being a question either of a voluntarily chosen lifestyle or of sufficiency as obligatory, in the sense of forced onto the individual in the shape of poverty or drastically reduced income due to i.e. unemployment

(Gorge et al., 2015; Heindl & Kanschik, 2016). Aiming to bridge this theoretical gap between voluntary and involuntary sufficiency, we will explore the KonMari method of decluttering as a possible unintentional entry into sufficiency (Callmer, forthcoming 2019).

Circular Economy and the Slowing of Consumption

The place of sufficiency within a circular economy and the role of the consumer in bringing this about are areas in need of further research. CE models such as those from the Ellen MacArthur Foundation (2013) take for granted the role of the consumer in accepting new business propositions and adopting changed practices, but there is little explanation or discussion as to how such transitions will take place (Camacho Otero et al., 2018; Kirchherr et al., 2017). Likewise, the existence of the sufficiency concept is implicit but rarely explained: there are more than 114 definitions of a CE, and the concept of 'reduction' or 'reduce' is present in 55% of these (Kirchherr et al., 2017), not to mention the 'R' frameworks (reduce, reuse, recycle) which are a core component of CE and prioritise reduction as a priority for action. Bocken et al (2016) introduce several CE strategies for 'slowing and closing' resource loops, one of which is encouraging sufficiency through the reduction of end-user consumption (Bocken et al., 2016). The Ellen MacArthur Foundation also emphasises the 'power of the inner circle', and the importance of moving towards the innermost loop (Ellen MacArthur Foundation, 2013) – in other words reducing and slowing material flows – but there remains a lack of research as to the role and motivation of consumers in this process.

Moments of Consumption

The study of consumption has a long history in the fields of both sociology and sustainability, and in the last 30 years has moved from a preoccupation with identity, social communication and culture to acknowledge the importance of infrastructure, technology, habit and routine (e.g. Jackson, 2005; Warde, 2014; Evans, 2018). The 'turn to practice' has seen increased attention given to 'inconspicuous' or 'ordinary' consumption, with associated environmental impacts contingent upon consumers' daily routines and activities (Evans, 2018). Following Warde (2005, 2014), Evans (2018) describes consumption as a series of 'moments' that occur during the performance of other practices, and more specifically as the 'acquisition', 'appropriation' and 'appreciation' of goods, services and experiences, followed by their 'devaluation', the consumers' 'divestment' or de-attachment with them and, finally, their 'disposal' of them (Evans, 2018; Warde, 2005, 2014). These are described as moments rather than practices, though Gregson et al (2007) for instance argue that divestment is a practice in its own right. Moreover the links or relationships between practice elements or practices themselves may prove to be critical intervention points with an influence on sustainable consumption (Pettersen, 2015). Gregson et al (2007) highlight the relationship between practices of divestment and other consumption practices, and suggest ridding as a way of becoming a more competent practitioner of consumption. 'To be a competent practitioner involves a thoroughly reflexive engagement with the ways in which objects are used, even *not* used…' (p.197), they argue, as divestment is not just about getting rid of stored goods but also divesting from the practice of accumulation (Gregson et al., 2007).

Aim and focus of the study

The aim of this article is to explore the possible impact of the KonMari decluttering method on different moments of consumption (Evans, 2018; Warde, 2014). Addressing the need for a stronger focus on sufficiency within sustainable consumption, we specifically inquire into the impact of the KonMari decluttering method on the moment of acquisition and ask if and in what ways the extensive and reflective discarding of belongings might affect the acquisition of new things.

Studying KonMariers and the Joy of Decluttering

Recent years have seen a growing interest in 'decluttering' – the process of discarding items in one's home in order to get rid of 'clutter', the stuff that is seen as being an obstacle to a tidy home. This article focuses on a very specific method of decluttering, namely the *KonMari method,* created by the Japanese tidying consultant Marie Kondo. The method was presented in Kondo's bestselling book *The Life-changing Magic of Tidying Up* (2014) which has been followed by other books (e.g. *Spark Joy*, 2016) as well as the Netflix show *Tidying up* *with Marie Kondo* in 2019 (Netflix, 2019), all contributing to growing global interest in the method. At the centre of the KonMari method is Kondo's idea about our home being a place where we only surround ourselves with the things that we love, the things that *spark joy* to us. Nothing more. Kondo stresses the importance of going through every single item in one's home (in a certain order by category), hold it, and decide whether or not it sparks joy. If not, it should be discarded. In Kondo's opinion, the question about what we want to own is actually a question about how we want to live our lives (Kondo, 2014).

Methodology

The research was conducted as a comparative study of KonMari declutterers in Sweden and the UK & Ireland. Participants were found via the Facebook groups *KonMari UK and Ireland* and *KonMari Sverige*. Surveys were conducted in January 2018 (Sweden) and October 2018 (UK and Ireland), and received 318 and 314 responses respectively. Following the surveys, interviews were conducted with willing participants (11 in Sweden, 12 in the UK) and completed by December 2018. No survey participants from the Republic of Ireland put themselves forward for the interviews, so these came solely from Sweden and the UK. Not all interviewed participants had completed all of the KonMari categories of decluttering, but this was representative of the wider group of survey participants. The two surveys were identical apart from three additional questions in the UK & Ireland survey which addressed possible rebound effects. They elicited socioeconomic information about the participants, their motivations behind starting with KonMari, and their experiences of it with particular focus on 1. Their attitude towards their belongings before and after KonMari and 2. Their attitude and behaviours in regards to consuming new things before and after KonMari. Interviews were qualitatively coded using a combination of emic and etic approaches, and the survey results used to triangulate and confirm the interview findings. Of course, we recognise the limitations in recruiting participants from among KonMari practitioners who are already motivated enough to join the relevant Facebook group, and we bear these in mind in the following discussion.

Results and discussion

Motivations for starting with KonMari

The reasons behind starting with the KonMari method were various; however, a few motivations stood out as most common both in the survey and in the interviews. The most frequently occurring explanation that the informants gave for wanting to start with KonMari was a discontent with their homes in one or several ways: it could be that it was too cluttered, that they felt that they did not have enough space, or that it was just too difficult to keep the home tidy. Related to this was the experience of simply having too much stuff, often combined with a sense of feeling overwhelmed, of not having control over their things, and/or a frustration stemming from a feeling of not having enough, or not having the right things, even though they may have owned an abundance of things:

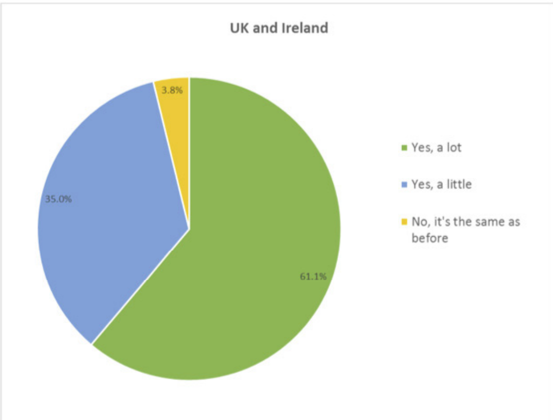
> I think it started with frustration. This feeling of… 'I have nothing to wear!'. And I have a walk-in closet, so there's quite a lot of clothes there (and there used to be more). So to stand there and have that many clothes and still never have anything one feels good in or that fits well… that's not fun.
> (Woman, Sweden, 46 years old)

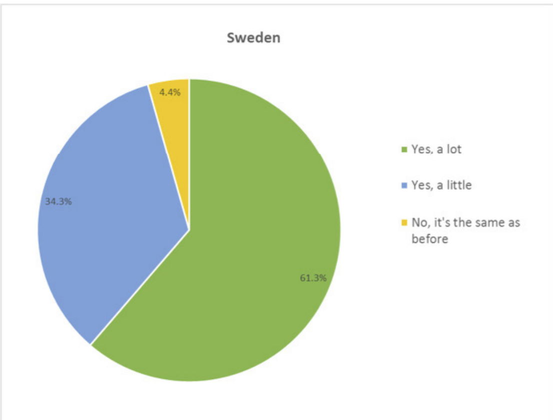
Another motivation was simply a wish to *facilitate one's everyday life* and an interest in various methods that could be of help when trying to organize and tidy one's home. In addition to these internal motivations, quite a few *external "triggers"* were noted as prompting the KonMari process. These could be events such as a recent or upcoming move (in a few cases moving abroad), inheritance of an estate, the arrival of a child or an illness in the family, or a wish to facilitate rehabilitation in the event of depression. Others mentioned that they simply were curious about the method and wanted to try it out as sort of a challenge.

After KonMari: Slowing Down Consumption?

One experience that KonMariers in the UK & Ireland and Sweden seem to have in common is a new sense of ease or harmony in relation to their homes. All informants further seemed to view the KonMari method as being more than a decluttering method and described how it had changed their life beyond merely enabling a tidier home. The process of going through every single item of one's belongings was repeatedly mentioned as being a process of reflection also in a wider sense, about what is really important in one's life.

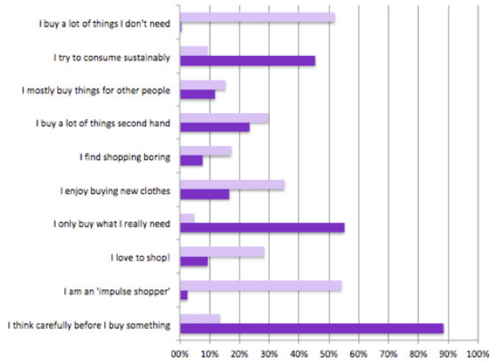
With regards to consumption behaviour, the studies from the UK & Ireland and Sweden show almost identical results, namely that practising KonMari has had an extensive impact both on the informants' attitude towards buying new things and on their actual consumption behaviour. 95.6% of the participants in the Swedish survey and 96.1% in the UK & Ireland survey stated that KonMari had changed their attitude towards buying new things (see Figures 1 and 2).

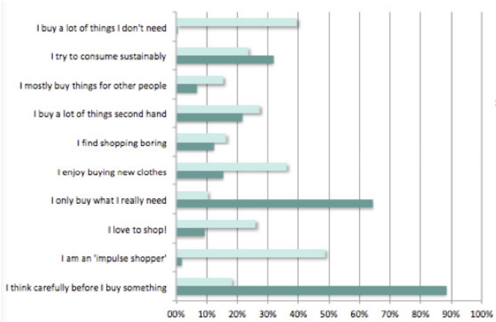




Figures 1 (UK & Ireland) and 2 (Sweden). Survey answers to the question "Has your attitude towards buying new things changed after you started KonMari?".

Respondents were asked to choose which statements best described their consumption habits before and after KonMari, by selecting up to three statements out of ten. Once again results are very similar in the Swedish and UK & Ireland surveys, with around 50% of the participants in both agreeing with the statement "I shop on impulse" before KonMari, and this figure being reduced to 2% in both surveys after the KonMari process (see Figures 3 and 4). Instead, the statements best reflecting the consumption habits of respondents after having conducted KonMari were "I think carefully before I buy anything" and "I only buy what I really need" (Figure 3 and 4), showing that most of the participants are now far more discerning about what they buy, reflecting on whether it is something that they really need or want.





Figures 3 and 4. show 'before' and 'after' responses to survey questions for the UK & Ireland (3) and Sweden (4).

This altered consumption behaviour seems to be directly linked to an increased ability among the informants to decide what it is that "sparks joy" for them and what it is that does not, something that was also emphasised in the interviews, for example by this British woman:

> I think differently and my whole attitude towards things and shopping has changed… it's ruined shopping for me, I can't go shopping really anymore... now I'll look at things and say 'oh it's really nice', and before I'd have bought it but now I'm like 'well where am I going to put it and do I really love it, and does it spark more joy than the other objects that have been in that place already?
> (Woman, UK, 36-44 years)

These shifts in behaviours give an early indication of an overall reduction in the KonMariers' volume of consumption.

The impact on moments of consumption

Many consumers are unlikely to prioritise sustainable actions in day to day life even though they have knowledge about environmental issues (Jackson, 2005; Kollmuss & Agyeman, 2002). This being the case, our studies show that the KonMari method potentially has an important role to play in reducing consumption, as it can serve as a sort of unintentional (rather than voluntary) entry into sufficiency (Callmer, forthcoming 2019) that might be more easily available to consumers that do not usually prioritise sustainable actions. Our research into the KonMari method shows a relationship between different moments of consumption as the practice can work to speed up the process of devaluation, divestment and disposal and simultaneously delay and reduce the moments of acquisition. For example, results from both Sweden and the UK show a remarkable reduction in activities such as impulse shopping after taking up the KonMari method. Rather than wanting to stop consuming as might be dictated by increased attention to green values, the Konmariers seem to stop wanting to consume because they learn to appreciate the physical items which actually spark joy and become reluctant to reclutter their homes with things that do not. The KonMari method, and potentially other decluttering practices, may thus work to *slow down* the acquisition moment in a way that reduces the sheer volume of consumption of new things and thus the material resources flowing through the system. This slowing of consumption may have significant implications for the spread of more sufficiency-focused approaches within the research on circular economy (e.g. Bocken et al, 2016).

The ritualised decluttering of the KonMari method comprises a more reflexive approach to the activities involved in sorting, clearing and organising personal possessions in a home. Not only does the process of touching or holding things to decide whether they 'spark joy' accelerate the processes of devaluation, divestment and disposal of some belongings, but it may also reinforce appropriation and appreciation of treasured items, probably delaying their disposal. Further it seems to reinforce appreciation of the tidier, calmer home environment which often comes with having fewer possessions, as well as of the more intentional lifestyle associated with literally decluttering one's schedule.

Unlike other decluttering methods, KonMari involves focusing on what people love and want to keep rather than what they should get rid of, and this distinction appears to be critical in shifting the attention of participants away from feelings of guilt and loss and towards the positive reinforcement of pleasure or joy in everyday possession. To echo Gregson et al (2007), it seems that practices of decluttering may in fact create more competent and conscious consumers. As one UK informant expressed it, the Konmariers come to hone their own 'joydar' through the process - i.e. they become increasingly aware of what sparks joy for them - rather than having the agents of marketing, or indeed of green living, intervene on their behalf.

The limited scope of this paper has not allowed us to describe our findings and expand on this discussion to the level of detail it warrants. Nevertheless, we have shown that in affluent countries such as Sweden and the UK there seems to be a correlation between decluttering processes - or accelerated divestment, devaluation and disposal - and reduced acquisition. Despite the limitations of recruiting already-enthusiastic practitioners of the method, the comparative nature of the study in finding such similar results in two different geographies as well as the triangulation of survey with interview results still lends strength to our research arguments. Moreover, we acknowledge the almost-entirely female gender of our survey and interview participants, and speculate that this has to do with the historical and traditional role of women in the domestic sphere, as well as the gendered language of the KonMari book. We suggest that further research should explore the gendered nature of decluttering with particular relation to acquisition or shopping, as well as providing greater detail on the links between 'ridding' and the acquisition moment of consumption. Aiming towards sufficiency in consumption of material goods is crucial in order to target the problem of overconsumption, and further research is therefore needed to understand the motivations behind decluttering and its potential for slowing consumption and thus reducing the flow of material resources.

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Understanding Consumer Disposal Behaviour with Food to Go Packaging in a Move to Circular, Zero Waste Packaging Solutions

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Keywords: Circular Economy; Chilled Food Packaging; Consumer Behaviour; Zero Waste; Sustainable Design.

Abstract: It is clear that a shift from the current make-use-dispose mentality of product consumption is required to move to the ideal of a Circular Economy (CE), where the world's resources are kept in use for as long as possible and their value retained. The idea of waste as a resource within a CE is not new, but the pressure to apply it to the Fast-Moving Consumer Goods (FMCG) packaging industry has been growing in momentum since 2016. Many research studies have focussed on recycling behaviours in the home, but few have looked at consumers behaviour with food to go (FTG) packaging disposed out of the home.
This research set out to assess the habit strengths of millennial consumers disposing of FTG packaging out of the home within the UK. The outcome of this research showed that millennial consumers have strong habits (upper quartile) in relation to their FTG packaging disposal routine. However, a significant percentage of participants were placing FTG packaging into incorrect recycling bins, showing there is still confusion amongst consumers about how to dispose of waste out of the home. Understanding of habit strengths at the packaging disposal stage could be one element to help in the design of interventions within packaging or waste system design, developing the responsible consumer behaviours required for a circular, zero waste society to exist.

Food to Go Packaging, Millennials and the move to a Zero-Waste Society

The UK's food to go (FTG) packaging industry is currently facing challenging times. There has been a global change in consumer eating habits, which has seen the rise of on the go eating. A rapidly growing market sector, FTG products are developing to satisfy the on the go eating needs of the time-poor Millennial UK consumer. However, the development of a range of convenient to use packaging solutions for this market sector is conflicting with the environmental concerns surrounding single-use packaging (Hamilton, Feit, Muffett, & Kelso, 2019). With growing pressure to move to a zero waste society (Cole, Osmani, Quddus, Wheatley, & Kay, 2014), designers are being challenged to develop sustainable packaging solutions to help facilitate the transition to a CE.

Food is the largest packaging end-use sector in the UK, representing 36.6% of overall sales in 2015 (Smithers Pira, 2014a, p.74). From a functional point of view packaging plays a vital role in the protection, preservation, and promotion of FTG products in a complex UK food supply chain from food processor to store shelf to consumer use and disposal.

FTG is a growing market sector with Mintel reporting that three in five Brits ate lunch out of the home in 2018 (Mintel, 2018a). Indeed, the sector is predicted to grow by a further £2bn in the next three years, accounting for almost a quarter of eating out spending (Lutrario, 2019).

Millennials, the largest generation group in the UK population (Mintel, 2018b), are aged between 22–37 in 2018 according to Pew Research Centre (Shugerman, 2018) and split into two groups, younger and older Millennials (Macke, 2018). They have grown up in the digital age, have a good amount of disposable income, and are more open to new ways of doing things (Macke, 2018). However, a UK study completed in 2017 found that Millennials are the least likely group to recycle (Serco & Future Thinking, 2017). The Serco study found that for those aged 16-34 years old the most common reason for not recycling was confusion over what can be recycled (Serco & Future Thinking, 2017). The packaging of FTG products, often consumed by time-poor Millennials on the go, may be at risk of being disposed of in the most convenient method possible out of the home due to confusion and apathy (Serco & Future Thinking, 2017).

By the year 2030, at least 70% by weight of municipal waste from households and businesses should be recycled or prepared for reuse, according to draft legislation adopted by the European Parliament (Martin, 2017). The availability of recycling and reuse facilities out of the home in England is less developed than the systems already in place in the home. This is in direct conflict with the aim of the UK Government who want to;

> *"move towards a 'zero waste economy'. This doesn't mean that no waste exists - it's a society where resources are fully valued, financially and environmentally. It means we reduce, reuse and recycle all we can, and throw things away only as a last resort,"* (GOV.UK, 2015).

The World Economic Forum and Ellen MacArthur Foundation have raised concern about the economic and environmental impact that single-use packaging is having globally (Ellen MacArthur Foundation, 2016; World Economic Forum, 2017). This has been widely publicized within UK media. A staggering 32% of plastic packaging globally escaped collection schemes, generating significant economic costs (World Economic Forum, 2016). Their solution is to move to a Circular Economy where the value of materials is kept within a closed loop economy for as long as possible.

Current approaches to CE solutions for packaging are typically focussed on transformative technological solutions (McDonough & Braungart, 2009; Gaziulusoy & Brezet, 2015; Lacy & Rutqvist, 2015; World Economic Forum, 2017; Ceschin, Fabrizio, Gaziulusoy, 2018) or legislative restrictions (McDonough & Braungart, 2009; GOV.UK, 2015; Moore, 2017; DEFRA, 2018). Academic and Industry white papers agree that sustainable design innovation is required alongside a better understanding of societal behaviour in order for CE systems to succeed (De los Rios & Charnley, 2017; Lofthouse & Prendeville, 2017; World Economic Forum, 2017).

Many research studies have focussed on sustainable packaging behaviours in the home (Rokka & Uusitalo, 2008; Williams, Wikström, Otterbring, Löfgren, & Gustafsson, 2012; Cole et al., 2014; Magnier, Schoormans, & Mugge, 2016; Wikström, Williams, & Venkatesh, 2016; Williams, Wikström, Wetter-Edman, & Kristensson, 2018), but few have looked solely at consumers behaviour with FTG packaging disposed out of the home. Therefore, there is a lack of knowledge that requires new research and insight that could support designers as they develop sustainable packaging solutions in the transition to a CE.

Understanding Consumer Behaviour

The study of consumer behaviour by social psychologists, especially within healthcare, has led to a range of models detailing different theories behind how behaviours are formed (Jackson, 2005). Triandis' Theory of Interpersonal Behaviour (TIB), see Figure 1, is a well validated model which places habit as the priority influencing factor to behaviour, over intention and facilitating conditions (Darnton, Verplanken, White, & Whitmarsh, 2011). Verplanken and Aarts define habits as "*learned sequences of acts that have become automatic responses to specific cues and are functional in obtaining certain goals or end-states*" (Verplanken & Aarts, 1999, p.104).

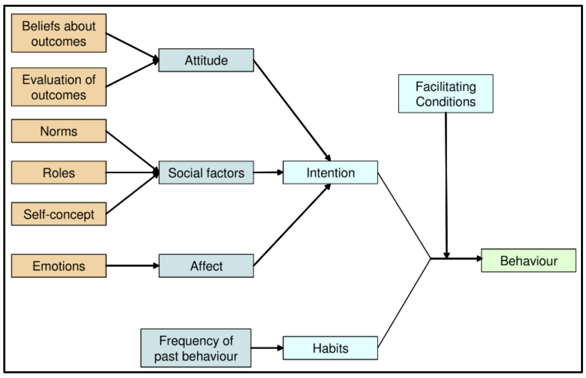

Figure 1. Triandis' Theory of Interpersonal Behaviour (TIB), (1977) (Jackson, 2005) p.93-95.

Wilson (2013), used the work of Triandis' TIB and Verplanken's model of Habits to develop an Augmented Model of Behaviour in relation to reducing domestic energy consumption within UK social housing. The model includes habits, intentions (both attitudinal and societal) and facilitating conditions, such as contextual factors. Wilson's findings illustrated the success of using the augmented design process towards the design and evaluation of a Design for Sustainable Behaviour (DfSB) strategy led intervention (Wilson, 2013; Wilson, Bhamra, & Lilley, 2016).

Verplanken and Orbell's Self Reporting Habit Index (SRHI) is the most commonly used habit measure (Lally & Gardner, 2013). They found that the SRHI may be useful as a dependent variable, or to determine or monitor habit strength without measuring behavioural frequency, (Verplanken and Orbell, 2003, p.1313). The research by Darnton et al. confirmed that "*Measuring habit strength is important for designing in interventions, as it can help determine the type of intervention that is required,*" (Darnton et al., 2011, p.26).

Verplanken and Orbell (2003) developed a set of twelve questions which form the SRHI, six relating to automaticity of behaviour and six relating to frequency of behaviour. The twelve questions of the SRHI are exhibited in Table 1. The items are accompanied by response scales anchored by agree / disagree and preferably should contain five or more response categories. A 7 or 11-point Likert response scale is used.

Behaviour X is something I do…	
1.	I do frequently
2.	I do automatically
3.	I do without having to consciously remember
4.	That makes me feel weird if I do not do it
5.	I do without thinking
6.	That would require effort not to do it
7.	That belongs to my (daily, weekly, monthly) routine
8.	I start doing before I realise I'm doing it
9.	I would find hard not to do
10.	I have no need to think about doing
11.	That's typically "me"
12.	I have been doing for a long time

Table 1. Twelve questions forming the SRHI (Verplanken & Orbell, 2003).

From their exploration of the research method within the healthcare sector they found that "*on the basis of features of habit; that is, a history of repetition, automaticity (lack of control and awareness, efficiency), and expressing identity, high internal and test retest reliabilities were found,*" (Verplanken and Orbell, 2003, p.1313).

This study is interested in the application of the Augmented Model of Behaviour within the packaging design process and whether better understanding of FTG packaging disposal habits out of home can aid DfSB packaging solutions in the transition to a CE. This study focusses solely on habits, the frequency of past behaviour, and automaticity, see Figure 2.

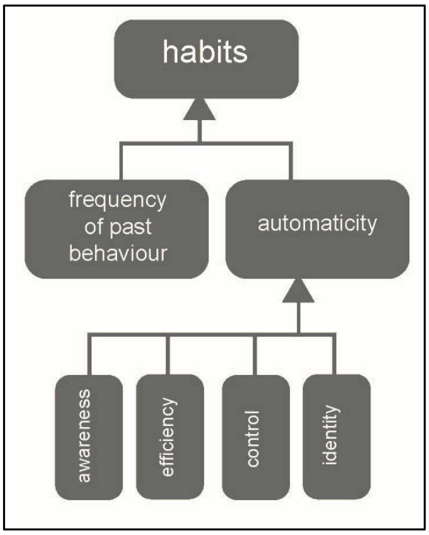

Figure 2. Diagram explaining the formation of habits (adapted from Wilson, 2013).

Darnton et al. used the work of Bargh (1994) to explain that "*through repetition, our behaviour acquires 'automaticity', which is defined as: lacking awareness of our action; lacking conscious intent; being difficult to control; and having efficiency*" (Darnton, Verplanken, White, & Whitmarsh, 2011, p.25). They continue to explain that to become automatic repetition must occur in a stable context (Darnton et al., 2011). This study aims to better understand the frequency and automaticity of habits by consumers disposing of FTG packaging purchased from one UK retail chain, out of the home.

Study on Consumer Disposal Habits

Method

For this study the focus is on understanding the habit strength of consumers disposing of FTG packaging out of home. A survey was developed to measure the habit strength of 100 Millennial consumers (aged 22–37) who bought FTG products for lunch from Marks & Spencer (M&S) stores (see Figure 3), to eat and dispose of out of home. M&S is a well-recognised retailer in the UK selling FTG items within their large and small retail outlets across cities, towns, train stations and motorway services.

Figure 3. A Typical M&S FTG retail display.

The survey was designed to be conducted face-to-face with a participant, at lunch time, within a busy retail environment. Participants who had bought FTG items were approached instore by the research team (the authors of this paper; a design PhD student, a lecturer in Industrial Design and a senior lecture in Industrial Design) following purchase of their goods at the self-service checkout (see Figure 4). The surveys took place at one of three M&S stores located in the East Midlands, UK on nine separate occasions, between November 2018 and January 2019. Participants were provided with a Participant Information Form and Informed Consent Form before answering the questions.

Figure 4. A Typical M&S self-checkout area.

The survey was split into two parts. Section A aimed to 'warm up' the participant into the study and enquire about the products they had purchased for their lunch, where they were going to eat the food and dispose of the packaging, and finally what kind of bin they would use to dispose of the packaging.

Section B used Verplanken's SRHI method. Six SRHI response categories were used, in relation to the disposal behaviour identified by the participant in the previous question. Each response category was answered using a 7-point Likert scale where 1 equalled Agree and 7 equalled Disagree. Three of the SRHI questions related to automaticity of disposal behaviour and three related to frequency of disposal behaviour. Some of the questions were reworded from those in Table 1 in line with the behaviour under study (see Figure 5).

"Disposing of my lunch food packaging as identified in question A4…"

B1: Is something I do frequently
B2: Is something I do automatically
B3: Is something that belongs to my daily / weekly / monthly routine
B4: Is something I start doing before I realise, I'm doing it
B5: I would find hard not to do
B6: I have been doing for a long time

Figure 5. Example of SRHI questions in this study.

The answers provided by the participants who completed the survey were quantitively analysed using SPSS. Each response option was given a code to enter into the database, allowing nominal data from Part A and ordinal from Part B to be analysed concurrently. Frequency tables and graphs were used to analyse the data output. Normality of data was tested using the Shapiro-Wilk test, the Internal consistency of answers to section B were tested using Cronbach's Alpha.

Findings

An overview of participants surveyed:

- 100 Participants aged 22–37 years on the day of the survey.
- All participants were purchasing at least one food to go item from an M&S store.
- The gender split of participants was: 57 Female, 43 Male.
- 95 participants were employed, 5 were students.

Following analysis, it was found that 75 participants were both employed and eat their lunch at work. It is this group of individuals that this study is most interested in and will be the focus of the findings in this section. Of this group 43 were female and 32 were male. The study found that all participants who ate their FTG products at work disposed of the packaging waste at work.

The frequency of FTG products purchased by participants in this study is shown in Figure 5. The most frequently purchased FTG items during this survey are listed in Table 2.

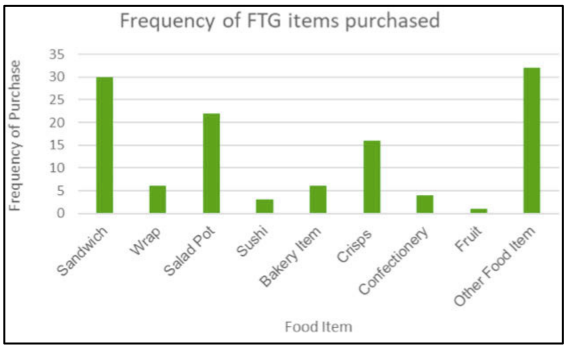

Figure 6. Frequency of FTG items purchased.

Product	% who bought product	Typical Materials	Ideal disposal (WRAP, 2018)
Sandwich	40	Laminated carton board	Recycle ALL
Salad Pot	29	PET pot, flexible film lid label	Recycle SOME (PET pot)
Crisps	21	Multi-layer film	General Waste

Table 2. Top three products purchased in study.

Frequency of disposal method

Almost half of participants surveyed (49%), said that they were going to dispose of all of their packaging waste within a recycling bin at work on that day. In contrast 32% stated they would dispose of their FTG packaging within a general waste bin at work. Only 19% were intending on disposing of their FTG packaging waste within a combination of recycling and general waste bins at work.

Accuracy of chosen disposal method

As M&S current FTG packaging is produced from a range of recycled and non-recycled material formats, as illustrated in Table 2, it is unlikely that all packaging purchased by a participant would be suitable for recycling. The data was analysed further to understand if participants are placing the correct packaging into the bin at work using WRAP's Recycling Guidelines to determine the ideal disposal bin for each FTG pack type (WRAP, 2018).

This identified that thirty participants (40% of study) had selected the **correct** disposal method for the FTG products purchased that day. Forty-five participants (60% of study) selected the **incorrect** disposal method for the FTG products they purchased that day. Most participants in this study were selecting the **incorrect** disposal method for the range of FTG packaging items they purchased that day. This incorrect behaviour included recycling packaging materials which should not be recycled such as flexible films or throwing recyclable materials such as carton board and PET trays into general waste.

Comparison of Habit Strength

The habit strength of the participants who had chosen the **correct** disposal method was

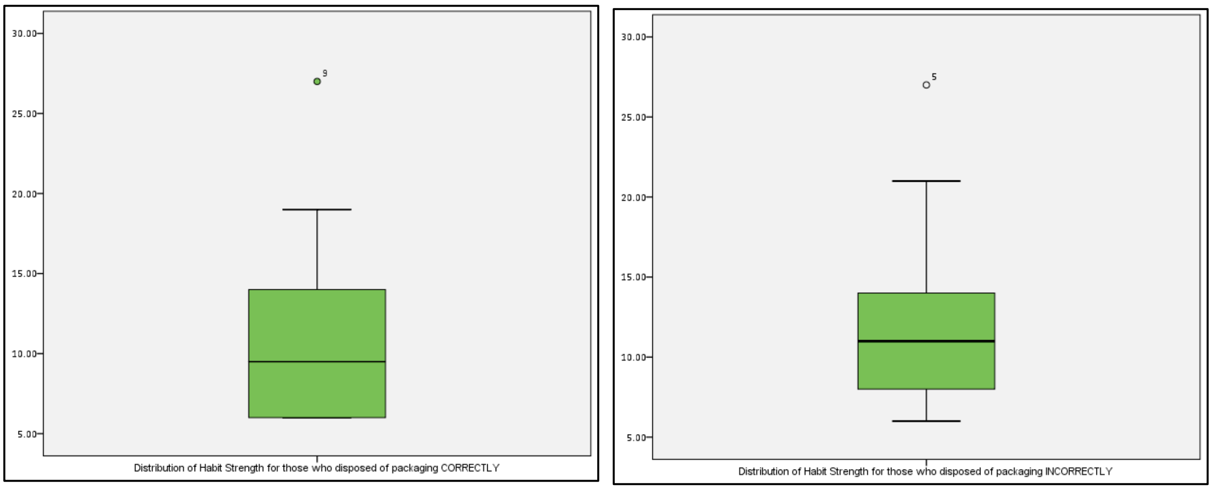

Figure 7. Box plots showing distribution of habit strength for those who disposed of packaging correctly compared to incorrectly.

compared against those who had selected the **incorrect** disposal method. In this study the habit strength scale went from 6 (the strongest habit strength) to 42 (the weakest habit strength). Following the completion of a Shapiro-Wilk test for normal distribution the habit strength data for both correct and incorrect groups was found to be not normally distributed. Therefore, non-parametric comparison analysis of habit strength data was used to compare the results of the two groups (see Table 3).

	Correct Disposal Group	Incorrect Disposal Group
% with strong habit strength of 6	30	18
Median Habit Strength	9.50	11.00
Habit Strength Range	21.00	21.00

Table 3. Correct versus Incorrect disposal method habit strength analysis.

The median score of 9.50 for **correct** disposal habit strength shows a stronger disposal habit compared to those of **incorrect** disposal where the median is 11.00. Both groups had a minimum habit strength value of 6.00 and maximum habit strength value of 27.00, therefore a range of 21.00. Figure 7 compares the distribution of habit strength for the two groups using box plots.

The **correct** disposal group have slightly strongly formed habits towards their disposal behaviour, with a median of 9.50 compared to the **incorrect** group's median of 11.00. With a strong habit strength they are more likely to continue this correct disposal behaviour on other occasions when disposing of packaging at work.

One third of the **incorrect** group had a habit strength score of 9.00 or lower. This shows that these individuals have strongly formed habits towards their disposal behaviour, selecting the **incorrect** disposal method for their FTG packaging on the day of the survey. With a strongly formed habit they are more likely to continue this incorrect disposal behaviour on other occasions when disposing of packaging at work.

Internal Consistency of the SRHI answers

The Cronbach Alpha test was used to measure the reliability of the SRHI data obtained in section B relating to habit strength. In order to be considered reliable the Cronbach Alpha score needs to be greater than .7 (Dancey, Christine P, Reidy, & Rowe, 2012). The Crohnbach alpha score for the participants answers to section B is .595, indicating that the data is not internally consistent.

There are variations in how the participants answered each of the questions in section B showing differences in automaticity and frequency of habit strength within their own answers. In order to be internally consistent we would have expected a participant with a strong habit to have answered all questions to section B with a 1 or 2, and those with weaker habit strength to have answered 6 or 7. This did not happen and we had a significant proportion of participants answer at different points of the Likert scale.

Implications for packaging design and future research

Based on our findings a practical and scalable method has been developed which could be applied to other retail outlets, or in other countries, to better understand the automaticity of consumer packaging disposal habits.

Due to the low levels of consistency within the habit strength results the survey would be used most effectively as part of a broader study which also considers the impact of consumer intentions and contextual factors which can influence behaviour. Future studies will use the SRHI survey as part of a mixed methods triangulation approach, alongside a diary study and interview. The research will seek to better understand consumer behaviour by analysing what consumers say they do, compared to what they actually do in relation to the disposal of FTG packaging out of home.

Once packaging disposal interventions have been designed and implemented the SRHI could also be used to monitor the formation of habits amongst individuals in longitudinal studies to measure the success of behaviour change methods in a move to a CE using DfSB strategies.

Conclusions

Millennials are purchasing a range of FTG products packaged in a variety of convenient single serve formats requiring disposal in a combination of recycling and general waste bins. The time poor nature of their lifestyles is in direct conflict with the effort required during their lunch break to correctly determine and dispose of the FTG packaging in a range of bins at work. The findings from this study show that over half of participants surveyed disposed of their FTG packaging incorrectly, either placing recyclable materials into general waste or non-recyclable items into recycling. Either way this has implications for the quality, quantity, and consistency of supply of recycled packaging material within a zero-waste system, a goal of a CE.

The aim of this study was to better understand the habit strength of millennial consumers disposing FTG packaging purchased from one UK retail chain, out of home. The findings indicate that millennial consumers have strong habits (upper quartile) in relation to their FTG packaging disposal routine whether they are correct or incorrect in their disposal behaviour. However, the study found internal inconsistencies within their responses which indicates that self-reported habits cannot be used in isolation to determine disposal behaviour. It is one part in a set of behavioural cogs which need exploring further in order to design interventions to increase sustainable packaging disposal behaviour in a transition to a CE.

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Benefits and Pitfalls of Better Lifetime Data – The Case of Batteries in Mobile Electronic Equipment

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Keywords: Batteries; Lifetime; State-of-Health; Mobile Devices, Circular Economy.

Abstract: Batteries are continuously gaining prominence in an ever-increasingly connected and mobile world. Battery lifetime is a topic of extensive research and discussions. Smart batteries are able to quantify, track, and report their own health status during their use phase, however, the availability of such data to consumers, repair, reuse, and recycling actors is often restricted. This paper establishes how batteries in mobile electronic devices track and report their own health status and to which extent this feature is implemented in today's smartphone and notebook batteries. The paper further illustrates potential benefits and drawbacks of full battery health data transparency with respect to the lifetime of products and the Circular Economy at large.

Introduction

Premature obsolescence of products, including electric and electronics equipment (EEE), has been a topic of much debate in recent years, amplified by the political and societal ambition to transition the EU to a Circular Economy, in which products last longer and the generation of waste is minimized. The reliability of products, including the identification of common failure modes and mechanisms, is usually evaluated extensively before products are released to the market, using accelerated stress tests and lifetime models. However, the environmental conditions and use patterns during real use of products in the field can only be approximated with such methods. In most cases, once a product is in the hands of users, little information is available about the actual degradation processes until a failure occurs. The actual failure mode and mechanism that have occurred, may or may not be identifiable in an ex post analysis.

Batteries in electronic devices have a special status in this context. On the one hand, they are considered "consumables", even in case of rechargeable batteries, as they are expected to degrade quicker than the overall product under normal use conditions. On the other hand, batteries are, in principle, able to track details of their own state of health and ageing progress, something that few other product component can actively do.

In the following sections, this paper aims to shine a light on the technical prerequisites of battery state of health tracking, the extent to which manufacturers make use of it, and the potential benefits and drawbacks such insights bring to consumers, repair actors, the second-hand market, and the recycling sector.

Battery lifetime data tracking

Smart batteries make use of battery management systems (BMS) composed of dedicated integrated circuits (IC) to track and report lifetime data in addition to carrying out safety and performance-related tasks such as monitoring battery voltage, current, and temperature. For instance, fuel gauge ICs estimate a battery's state of charge (SOC) in order to inform the user on the remaining use time until the next charge is required. Estimations make use of a variety of approaches involving look-up tables, ampere-hour integral, model-based estimation, or data-driven estimation methods (Xiong et al. 2018). The state of health (SOH), defined as the capacity the battery can store at a given time expressed in percentage of the battery's design capacity, is estimated via measurements of cell impedance or resistance, coulomb counting, or compute-intensive adaptive battery models (Berecibar et al. 2016). The SOH informs users on the irreversible capacity fade that progresses over time and with use. Smart batteries may also count the number of charge-discharge cycles, defined as an amount of discharge approximately equal to the battery's design capacity (SBS IF 1998).

These data points may serve as simple indicators of a battery's health status and may enable fact-based decision-making regarding replacing a battery with faded capacity or continued use of a healthy battery in a second-hand or re-use scenario. For instance, if a smartphone battery is only one year old, has been subjected to 200 charging cycles and reports a SOH of 94 %, it can be assumed to be in perfect working order and is qualified for a continued use.

Implementation of lifetime data tracking in mobile ICT devices

Due to space constraints, printed circuit boards (PCB) embedded in smartphone batteries tend to be minimalistic. Figure 1 shows a PCB from an Android smartphone single-cell battery. The PCB is populated with one electronic package, housing a combined protection IC and dual channel MOSFET, in addition to a current sense resistor, the battery interface and a small number of passive components. The protection IC provides detection of overcharge, overdischarge, and charging and discharge overcurrent. The FETs are used for switching on an off negative and positive output terminals (ITM Semiconductor 2012).

Additional BMS components may be embedded into the smartphone electronics rather than into the battery. However, a survey of available online information suggested that Android smartphones do not track additional lifetime data. As such, no data on the SOH, cycle count or battery age exist to inform relevant actors on the condition of a used device battery. This gap is partially filled by third-party apps that estimate SOH via access to basic battery data such as current, the SOC and the nominal capacity (Figure 2). However, due to the absence of sepcialized hardware, these apps have no information on cycle count and battery age either, and they require multiple charge-discharge cycles to produce accurate SOH estimates, making the process time-consuming and therefore not ideal for quick decision-making.

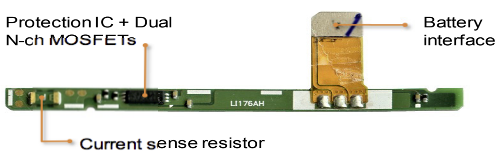

Figure 1. Battery management PCB extracted from an Android smartphone battery.

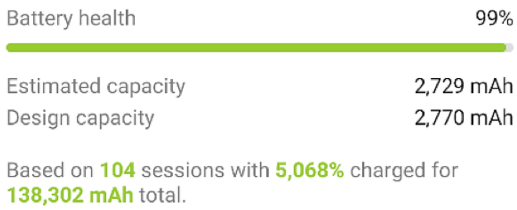

Figure 2. Screenshots of the Android application AccuBattery displaying the estimated design capacity, full charge capacity and SOH.

In contrast, batteries in iOS-operated smartphones commonly have more complex BMS hardware embedded into the battery PCB. In addition to protection ICs and MOSFETs, this typically includes a fuel gauge IC that tracks and reports the cycle count, SOH, and manufacturing date, among others (Texas Instruments 2018). iOS devices hence are able to track and report their health status to the user and other interested parties. The cycle count, design capacity and cell temperature are not immediately accessible in iOS but can be displayed via third-party apps (Figure 4).

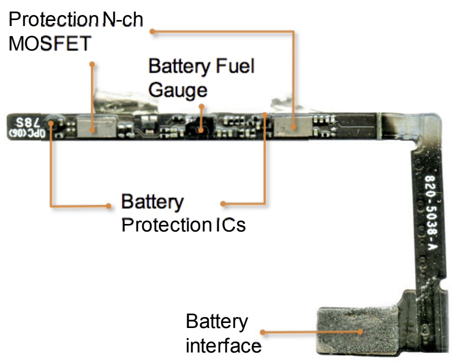

Figure 3. Battery management PCB extracted from an iOS smartphone battery.

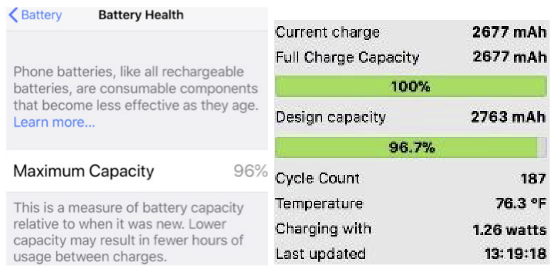

Figure 4. Screenshots of the battery health settings within the iOS settings displaying the SOH (left) and the coconutBattery application displaying additional data incl. the cycle count (right).

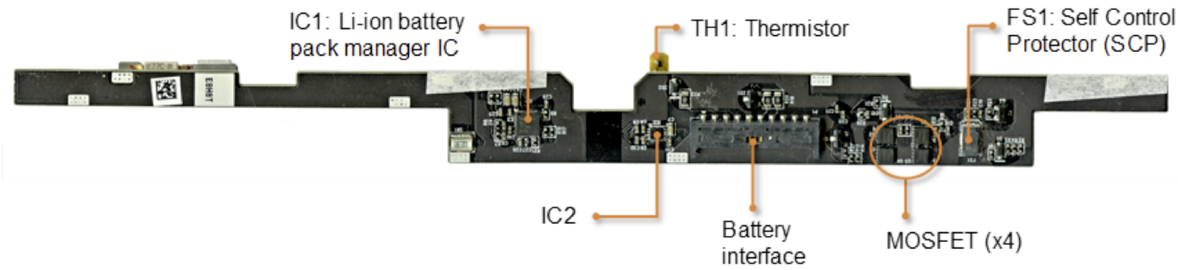

Figure 5. Battery management PCB and its components extracted from a business notebook battery.

Space constraints also apply to notebook battery PCBs, but to a comparatively lesser degree. Current notebook battery packs commonly consist of three, four or more cells and include a larger PCB with additional components and functionality. Figure 5 shows the example of a PCB extracted from a current-generation business notebook. IC1 controls and regulates charging, cell balancing, and determines the SOC, SOH, and cycle count, among other functions. The thermistor senses the temperature in one of the cells. The battery interface connects the battery pack to a host device, and fuse (FS1) and MOSFETS are responsible for preventing overvoltage, undervoltage, overcurrent and overtemperature. The exact function of IC2 could not be identified. With this hardware setup, notebooks batteries commonly track the relevant health data, including SOH and cycle count. However, previous studies found that not all relevant data are always accessible to the user (Clemm et al. 2016).
It can be concluded that, in principle, both smartphone and notebook batteries are technically able to track and report on their health status. However, it depends on the device manufacturer (OEM) to invest into the additional hardware and software to enable such features, and it is also up to the OEM which actors are granted insight into the data.

Benefits and potential pitfalls of better availability lifetime data

As has been pointed out in the previous sections, users of mobile ICT devices currently only have limited access to the lifetime data of their device batteries. Several studies have recommended that full access to basic battery health data should be given to relevant actors (e.g. Tecchio et al. 2018, Clemm et al. 2016).
The following subsections illustrate potential benefits and pitfalls of better availability of lifetime data for users, second-use and repair actors, and the recycling sector. All considerations are based solely on the authors' deliberations and no in-depth impact assessments were carried out to quantify potential benefits and drawbacks to date.

Users

Keeping mobile electronic products in use longer is considered a significant lever to decrease their overall environmental impact (Proske et al. 2016), and the durability of the battery may have a direct impact on the use phase of the product it powers. If the battery's health status was to be fully accessible, it is conceivable that users adapt their behavior accordingly, for instance by adapting battery-saving charging habits. Furthermore, in cases where device batteries degrade quicker than expected, users' warranty claims may be underpinned with factual data.
Table 1 illustrates potential benefits and drawbacks of full transparency on battery health data for consumers.

Full access to battery health data for users
Potential benefits
▪ Incentive for users to adopt behavior that slows down battery degradation ▪ Consumer empowerment with regard to in-warranty battery failures ▪ Users may benefit from a "race to the top" as manufacturers are incentivized to optimize battery durability
Potential pitfalls
▪ Observable degradation of battery may elicit "psychological obsolescence" (e.g. "My device is not perfect anymore, I want to replace it") ▪ Incentive to deliberately provoke battery ageing before expiry of warranty period in order to be eligible for in-warranty battery replacement

Table 1. Potential benefits and drawbacks of battery lifetime data availability for consumers.

Repair actors and second-hand market

After the first use phase in a mobile device, batteries may still retain a substantial share of their initial capacity and may be qualified for a second life in the same application or as a spare part, rather than being disposed of. Table 2 lists potential benefits and drawbacks of full battery-health data transparency for this sector.

Full access to battery health data for repair actors and the second-hand market
Potential benefits
▪ Continued use of batteries that may otherwise be disposed of due to unknown health status ▪ Increased trust in used devices by potential buyers due to known battery health status
Potential pitfalls
▪ Conservative SOH-based decision-making may lead to premature disposal of used batteries ▪ Second-hand market buyers may not be willing to buy devices with battery health below a certain threshold

Table 2. Potential benefits and drawbacks of battery lifetime data availability for repair actors and the second hand market.

Remanufacturers and repair shops are in need of battery health data to be able to choose an alternative to disposal of used batteries. Making an informed decision based on technical facts may help keep the battery or the device itself in use for as long as possible, thereby saving precious resources. Data availability may enable quick decision making in regard to continued use or disposal of a used battery.

The potential effects of full battery health data transparency on the second hand market are considered ambivalent. While transparency may lead to increased trust towards used devices, it may also lead to devices with lower battery health, which are in otherwise great condition, not being accepted in second hand markets. Figure 7 shows the example of a second-hand market battery offer on a popular German-language second hand platform, stating the SOH of a spare iOS smartphone battery.

Figure 7. Screenshot of an offer for a used iPhone battery on a second-hand market place, stating the remaining capacity and SOH (ebay 2019).

Recycling sector

The EU economy is reliant on the import of many strategic metals, some of which are considered critical raw materials (CRM). Securing access to these materials is crucial in order to stay competitive and avoid shortages in the future. Batteries contain CRM, and their market penetration is ever-increasing. More than 26,000, tons of batteries placed on the European market in 2018 were batteries in electronic devices, with an increasing trend (RMIS 2019). In an effort to close the loops of precious materials from batteries, reliable data on the timeline when batteries reach their end-of life is crucial. However, such data is hardly available. More precise estimations on the time spent in stock, meaning the time between battery sale and waste collection, is needed to improve the knowledge base on urban mine stock and flow models. For instance, the Urban Mine Platform (UMP 2019) was developed under the EU-

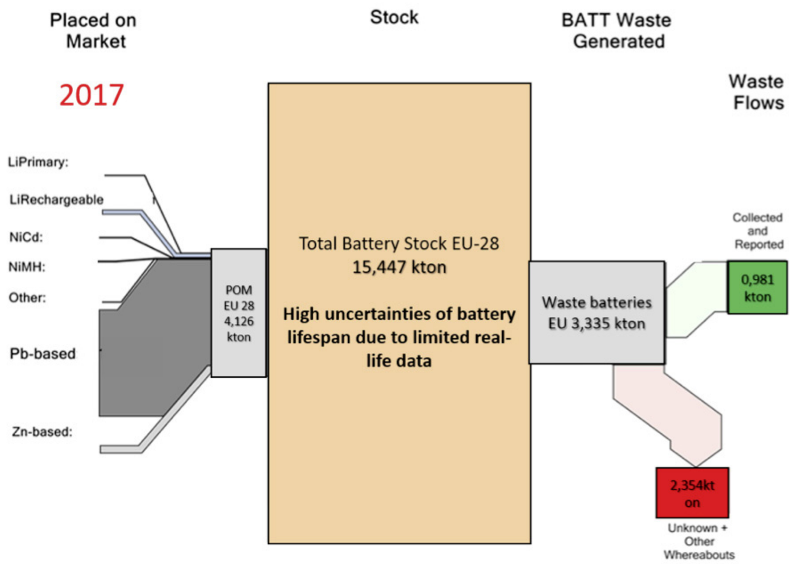

Figure 6. Stock and flow model of batteries in Europe for 2017 (adapted from Huisman et al., 2017).

funded ProSUM project and provides a state-of the art data platform, where an extensive amount of data from multiple sources was combined to comprehensively estimate the stocks and flows of batteries and their material content in the European market (Figure 6). However, the method used to estimate the duration of batteries' use phases could very well lead to underestimations of the total battery lifetime, by not taking into account second-use scenarios. The absence of reliable real-life data was identified as one of the weak points in the modelling. Having real data from the field would improve the stock and flow model and lower the uncertainty level and thereby give more reliable predictions of return flows on material level. This information is valuable for recycling companies to make strategic decisions on e.g. future investments. Furthermore, improved data could provide a better indication of the flows which are labelled as "unknown whereabouts" in the model (Figure 6). No data is available for these battery flows making up over 70 % of the estimated waste streams, leaving a large amount of valuable CRM flows untracked.
No pitfalls have been identified for the availability of such data to the recycling sector. However, questions remain on the practicability and accessibility of the data from the manifold battery-driven electronic equipment in facilities along the e-waste recycling value chain. At the very least, the potentially available information base for the age and condition of smart batteries could be increased. For instance, data could be retrieved from device batteries via sampling of functional devices.

Device manufacturers

Last but not least, several potential benefits and drawbacks were identified for the hypothetical case of full battery health data transparency from the manufacturer's point of view (Table 3).

Full access to battery health data for OEMs
Potential benefits
▪ Knowledge on battery behavior and battery-related user behavior in the field may allow for optimizations ▪ Potential to stand out from the competition with comparatively higher battery durability
Potential pitfalls
▪ Increased cost for data tracking ICs in BMS ▪ Increase of in-warranty battery failure claims ▪ Lower battery durability compared to the competition may look unfavorable ▪ Efforts required for standardization of metrics to create a level playing field for SOH estimation

Table 3. Potential benefits and drawbacks of battery lifetime data availability for OEMs.

Conclusions and recommendations

While the ability of batteries to track and report their own state of health is a unique feature, the effects of full transparency of such data in a Circular Economy are not unambiguous. Much depends on the users' behavior, resulting in the need for sociological studies to underpin assumptions on benefits and drawbacks. In addition, impact assessments should be carried out to quantify the effects on product lifetime and consequently resource consumption. Before considering tracking and reporting of battery lifetime data as a requirement under product policy instruments such as ecolabels or the Ecodesign Directive, additional costs for manufacturers should also be quantified. Additionally, standardization efforts on the estimation of SOH and other relevant parameters is encouraged to warrant a level playing field when comparing the durability of batteries from different manufacturers and in different applications.

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PLATE
Product Lifetimes And The Environment

New-Old Jeans or Old-New Jeans? Contradictory Aesthetics and Sustainability Paradoxes in Young People's Clothing Consumption

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Keywords: Youth; Clothing; Aesthetics; Novelty; Product Ageing.

Abstract: This paper reports on an ongoing research project exploring the role of aesthetics – particularly aesthetics related to the multiple meanings of ageing – in young people's interventions in the material lives of their clothes. Provoked by the trend for 'pre-aged' jeans, this study interrogates how material manifestations of the passing of time shape young consumers' relationships with their clothes. Specifically, this enquiry focuses on the multiple, intersecting and sometimes contradictory aesthetics of aged garments. It examines the extent to which – and circumstances in which – young consumers view the visible lived history of their garments as positive, and the role played by personal manual interventions (e.g. acts of repair, customization, upcycling or repurposing) in transforming an un(der)loved and un(der)used item into one with heightened forms of value. Drawing on practice-based workshop-interviews with twelve 18-24 year olds, plus peer-led research with a further sixteen participants (and four 'peer researchers'), this research seeks to contribute to emerging debates around sustainability, consumer agency and the aesthetics that shape product lifetimes in specific relation to the consumption of fashion.

Introduction

In a white paper published by sustainable clothing activists Fashion Revolution in 2015, the millennial age group (young people aged 17-34) was named as the demographic group best positioned to drive the shift towards a more ethical and sustainable fashion industry. In part this is the result of young adults (under the age of 34) being the biggest consumers of fast fashion (Bhardwaj and Fairhurst 2010). With the rapid obsolescence that characterises fast fashion widely acknowledged to be one of the biggest drivers of unsustainability within the fashion industry, a shift away from such stylistic churn will be key to longer-lasting relationships with clothing and thus less textile waste. Environmental threats driven by unsustainable consumption are increasingly high on the youth agenda; recent activism and growing awareness of consumption impacts may herald a turning of the tide against too-easily-disposability. However, another important driver of more sustainable clothing consumption comes from a purported increasing willingness from young consumers to consume second-hand clothing (Satenstein 2016).

Such has been the cultural caché of the 'old' aesthetic that it has been enthusiastically embraced by fast fashion producers, with the ubiquitous 'pre-ripped' jeans constituting the ultimate symbol of this 'new-old' tension. In direct response to this apparent paradox, these items – pre-ripped jeans – formed the starting point for this inquiry into the tensions between aesthetics of 'newness' and 'oldness' in young people's clothing consumption. The project sought to examine what kinds of 'oldness' are considered cultural acceptable and stylistically desirable by young consumers, and in what kinds of contexts something temporally 'old' might be made acceptably 'new'. Understanding the subtleties and nuances in young consumers' responses to these characteristics of garments may usefully inform the approaches of those seeking to promote and embed longer garment lifetimes.

Aesthetic Implications in/for Sustainable (Clothing) Consumption

Whilst much debate concerning the product lifetimes of clothing has focused on matters of physical durability and the environmental impacts of material choices, how garments look, feel and even smell plays an equally significant part in their longevity. Although studies explicitly located at the intersection of multi-sensory aesthetics, sustainability and material consumption remain rare, these concerns have intersected in studies from a range of disciplines, from product and fashion design, to sociology, anthropology and human geography, amongst others. The discussion that follows pinpoints some of these intersections and articulates key conceptual contributions which help to inform emergent debates around aesthetics of/for sustainable material consumption.

Venkatesh and Meamber's 2008 paper examining aesthetics in the context of everyday consumption practices notes the relationship between the multi-sensory nature of aesthetics and the pursuit of hedonic experience – or pleasure – through various forms of consumption. Beyond the affective response based on how something looks, as Roe (2006) demonstrates, practical interaction with an object – embodied experience of its texture and smell – can either amplify or contradict that initial response. Our multi-sensory interaction with the multiple aesthetics of an object make us either inclined, or not, to consume it – and this (dis)inclination is equally shaped by a range of personal subjectivities accrued across lifetimes of embodied experiences.

To date, concerns with sustainability have been brought into productive discussion with this framing of consumption aesthetics in several ways. One response has involved making the impacts of product use a conspicuous part of that product's design, such as Backlund et al.'s (2006) designs for lighting that etches delicate lines into the surrounding lampshade to show the light's energy consumption. Another response has focused on designing products that face considerable everyday 'wear and tear' in materials which are both physically and stylistically resilient. Lilley et al. (2016) have experimented with this approach, designing smartphone casings from materials ranging from cork and wood to leather, in order to gauge consumer responses to the emergence of an aged patina generally considered attractive in non-tech contexts, such as home furnishings.

Within the domain of sustainable fashion, increasing attention is being paid to how garments might be designed for changeable style and functionality, thus producing – via one item – multiple garments and multiple (visual) aesthetics (e.g. Koo et al. 2014). Here, whilst novelty is 'designed in' to the object to increase interest in more frequent and/or longer-term wear, fulfilment of that aim rests on the willingness of the consumer to engage with the potentialities of that design. Relatedly, research has suggested that consumers have found the aesthetic repertoire within existing 'eco-fashion' and ethical clothing ranges somewhat limited (Niinimaki 2010), thus limiting its consumption. Here only the strongest environmental values overpower consumer commitment to aesthetic variety. Given the important of clothing consumption for articulation of both sense of self and peer group affiliation (Venkatesh and Meamber 2008), a limited garment palette may be problematic, especially for young consumers for whom conspicuous identity articulation can be particularly important.

It must also be remembered that access to modes of consumption with strong ethical and sustainability credentials is also limited by cultural and economic capital. In their research into the Slow Food movement, for example, Sassatelli and Davolio (2010) argue that, whilst this mode of consumption is environmentally sensitive and aesthetically enjoyable, it has the potential to be socially exclusionary by virtue of the capitals required to access and participate in it. Nevertheless, as Gill et al. (2016) argue, forms of sustainable consumption are accessible to everyone; the challenge is making those modes of consumption culturally desirable. Specifically, they suggest that making visible the worn-life of clothing, as emphasised through practices of maintenance and laundering, makes sustain-abilities (i.e. ability to sustain) of clothing conspicuous and valuable, by demonstrating the importance of everyday acts of care for prolonging garment lifetimes both materially (i.e. ensuring material durability) and culturally (i.e. the social acceptance of worn-looking clothing).

In sum, a growing number of theoretical and empirical strands across a range of disciplinary literatures are informing debates around sustainability, aesthetics and material consumption, although these are yet to cohere around distinct positions. Most salient for this discussion in this paper are those debates concerned with the expressive capacity of consumption – specifically how consumers feel their (new, old, worn or (un)cared for) garments are seen and interpreted by peers – and the labour involved in keeping objects in use. Following a brief overview of the research methodology, empirical findings are used to elucidate some of these ideas.

Research Methods

Two small scoping studies inform this paper. The first, which took place in 2016, took the form of a series of one-to-one 'workshop interviews'. Following similar approaches discussed by Shercliff and Twigger Holroyd (2016; knitting) and Straughan (2015; taxidermy), a format was designed in which participants were invited to bring to the workshop interview a garment or other textile item which required some form or repair, maintenance or upcycling. Since items worn by participants are ideal stimuli for discussion about clothing aesthetics (Eckman and Wagner 1995) the intention was to direct conversation through the garment and the work that would be applied to it. Twelve participants aged between 18 and 24 took part in a one-to-one workshop lasting between 60 and 120 minutes. All materials required for the repair/maintenance/upcycling task were provided. The specific tasks participants engaged in included: patching jeans/ dungarees; darning socks; sewing up holes in hoody cuffs/jacket seams; repairing a broken rucksack zip. These items and the work they demanded invited conversation around topics including: object novelty; ageing of garments; fashion; style; garment quality/-ties; skill. (A more detailed overview of this methodology can be found in Collins and Dixon 2016.)

The second study, which ran from January to April 2019, took a peer-research approach. Four undergraduate students (in Geography) were recruited and tasked with devising a qualitative study through which they could explore their peers' attitudes towards the ageing of garments. Taking a peer-research approach addressed the power imbalance inherent when an older researcher, particularly one in a particular power relation like an academic staff member in a university setting, seeks access to young participants' experiences. Instead, having young consumers interview their peers enabled discussion between 'equals' with shared cultural emplacement (Murray 2006; Northcote and Tarryn 2019). The four peer-researchers conducted sixteen object-led peer interviews in total, each of which lasted 30-45 minutes. A standard semi-structured interview approach was augmented by the incorporation of three key clothing items: jeans, coats, pyjamas. Each interviewee was asked to bring these items to the interview to facilitate discussion. In addition to using these items to structure discussion, the peer-researchers also asked questions about their participants' understanding of the terms 'vintage', 'retro' and 'old' in relation to clothing.

Transcripts for both the 2016 workshop interview and 2019 peer-led interviews were produced and subjected to a process of open coding and grounded theorisation. Key themes from this analysis are presented below. All participant names used are pseudonyms, but the real names of the peer researchers are used to acknowledge their role as co-researchers in this project.

Discussion

V is for… Very Old (or not) (a.k.a. Vintage)

The contradictions that characterise the temporal registers of young people's clothing consumption were made evident in the ways they talked about 'old' clothing in relation to 'vintage' clothing. This was summed up neatly in this exchange between Hannah, one of the participants in the peer research project, and Abbie, her interviewer:

Hannah: "I think that the term vintage has changed over the past few years to what it actually means which I'll go onto but now it's actually like a trend a fashion trend, shops have vintage sections, I was in Primark today and they have vintage jeans which are not vintage because they're brand new. Vintage should mean, well personally I think it should mean old clothes that have been re-, like, given a new life. To be sold on again, it's second-hand stuff but now I think vintage has become like a style. But vintage to me is going into a shop, and there's loads of old brands and styles and you can go, like, 'oh cool, a nice Adidas coat from 50 years ago'. That's what I think vintage is."

Whilst 'old' clothes were described by participants using words such as 'dated', 'ruined', 'tacky', and 'worn-out', there was consensus that items which had a strongly evocative style – often clearly associated with a past era – could, and often were, framed as 'vintage'. Rosie (a workshop participant) described how she liked to imagine 'glamorous' or 'exciting' past owners of 'vintage' clothes (see also Goulding 2002), which formed part of their appeal. Loveland et al. (2010) link this nostalgic view of these garments as indicative of a need to relate, belong, and feel a sense of embeddedness in a more distinctly articulatable cultural grouping than is often possible in postmodern consumer culture. Indeed, the appeal to some young consumers of clothing tied to distinct cultural epochs might be situated in a broader consideration of the loss of conspicuous youth sub-cultures and an associated convergence or homogenisation of youth identities. Beyond 'glamorous' or nostalgic perspectives on vintage clothing, participants' comments suggested that constructing vintage as a style (rather than a temporal characteristic of garments) might also have the effect of limiting its appeal – by culturally historicizing garments in ways that detract from their banal, practical utility. As Mair (workshop participant) noted wryly, "It's a little silly… those things were still nice before you had to stick a label on it for it to be good."

Across both research projects, participants' levels of comfort with consuming 'old' and/or second-hand clothing was varied. Participants were more likely to embrace the 'old' where those garments were worn further from the skin. Coats and jackets were commonly worn until they started to materially fail (e.g. through holes, failing fastenings), and there was widespread ease with the idea of wearing a second-hand garment. In contrast, whilst participants in the peer-led interviews were comfortable wearing very old pyjamas (generally replaced only when they started to fall apart), some did not like the idea of wearing second-hand nightwear, likening it to second-hand underwear because of the proximity of the garment to the wearer's skin. This reflects widely documented anxieties about the intimacy of proximity to (un)known others' bodily traces (e.g. sweat) through second-hand garment consumption (e.g. Roux 2006).

The discussions around new/old pyjamas elicited by the peer-researchers may also offer a partial explanation of the desire to consume new-old jeans. Jeans are designed to be worn intensively. Leading brands (including Levi's, Tommy Hilfiger, Hiut and Nudie) advocate not laundering jeans, at least for the first six months of wear (O'Connor 2016). This intensity of wear invites a range of deeply embedded bodily traces – both through emissions such as sweat, but also the shape of the wearer's body itself – that imprint upon the item. For wearers uncomfortable with such conspicuous proximity to a prior owner – especially if the garment does not have the stylistic caché of 'vintage' – second hand 'old' jeans may be unpalatable. Yet a cultural aesthetic has been produced in which visibly new denim is not as 'cool' as visibly old denim. (More generally, Rosie suggested, having anything that looks brand new is 'not cool'.) Adam (workshop participant) reflected that many young consumers will wear garments with holes in if the holes were produced by a machine or some kind of industrial process, but not if another person has worn that hole organically. Thus, amongst these young consumers, there was widespread acceptance of – even enjoyment in – an 'old' aesthetic, but much more limited consumption of temporally (rather than stylistically) 'old' clothes.

Sanctions: Fear and Loathing in Clothing Consumption

Beyond the challenges associated with navigating the 'right' kind of new and the 'right' kind of old in their clothing consumption, participants revealed their varying (dis)inclination to keep garments in long-term use through acts of maintenance, repair or upcycling.

There was quite widespread willingness to engage in 'quick win' adjustments. Hannah, for example, removed some frills from a pair of jeans: "Frilly bits on the end, that was so in fashion for, like, six weeks and then everyone stopped wearing them, so I just chopped them off and now they're just my, like, one pair of good skinny blue jeans." Although all the participants in the one-to-one workshops had the necessary basic level of sewing competence to engage in their chosen repair/upcycling project, all noted that repairing, maintaining or upcycling clothing was not something they would normally do as a matter of course – only if the item was particularly treasured or important. For Emily (workshop participant), this was because she felt it was simply an 'uncool' use of time:

"… for my age group it's just kind of a bit uncool, like there's that stigma of, "Oh, she makes her own clothes", or like, "She sews her own thing up", it's quite, like, uncool, and we're in an age where you can just so easily, if you rip your top you can go out and get another one for two quid, so I don't think people are that concerned when it's that cheap."

She was, however, keen to point out that she did not consider the practices themselves, or their aesthetic effects, to be uncool. Because of her personal interest in cosplay (where participants dress up in costumes as fictional characters), along with the style aesthetic of her immediate friends and family, the broader youth-cultural 'uncoolness' of sewing up a frayed hem did not prevent her from doing so. This raises interesting questions about the cultural (un)acceptability amongst young people of giving time to their possessions, through acts of maintenance or repair, and creates a timely tension with growing youth activism around sustainability and environmental threats due to over-consumption.

Luke (workshop participant) was less concerned about spending time on repairing garments. Instead, he explained, he was worried about doing the repair 'incorrectly', and being seen by peers as having been 'wrong' to even try. In contrast, he said, a newly bought garment was automatically 'correct' or 'acceptable'. Research over the last two decades (e.g. Russell and Tyler 2005; Isaksen and Roper 2012) that has examined the sanctions young people can face by getting clothing consumption 'wrong' highlights the significant emotional impacts of these cultural errors. The fear of judgement Luke articulates may be an alternative narrative of Emily's report that, amongst her peer group, repairing or upcycling is seen as an 'uncool' use of time (cf. Breunig et al. 2014; Ojala 2007). Samantha (workshop participant) noted that she finds her peers simply judge whether an upcycled or repaired garment looks nice or not, rather than wondering who did the work, how long it took and how much skill might have been required.

This emphasises the extent to which consumption-based peer and self-esteem within this group is primarily produced through conformity to established aesthetic codes via consumption, rather than the development and application of practical skills via production.

There is evidently, then, a strong set of culturally produced disincentives for young consumers to act on their clothing to keep it in use. This is despite their professed acceptance of multiple 'old' aesthetics, and the evidence that we tend to keep and use for much longer any items (not only clothing) that we have had some part in the (re)making of, precisely because we have invested our time (and arguably part of ourselves) in it (Cooper 2005; Maller et al. 2012). The purported desire for individuality commonly sought by young consumers through their consumption is, thus, firmly situated within the safety of defined stylistic boundaries. Further, there is a widespread reluctance to self-produce any element of this individuality through acts of maintenance, repair or upcycling, or even basic customization. Buying off the peg is not only practically easier, it is culturally safer.

Conclusions

It was clear that, for the participants in these two studies, decisions about whether or not to wear (or purchase) 'old' clothing were made in the context of how socio-culturally acceptable that 'old' garment was imagined to be – or, perhaps more accurately, whether the garment was the 'right' kind of 'old'. The data indicates that garment aesthetics based on fabric wear or stylistic ageing, conspicuous upcycling, or that feature elements of (in)visible repair, were not inherently undesirable to this group. As such, these aesthetics can be argued to be compatible with a more sustainable approach to fashion consumption amongst young consumers. The key appears to be finding a balance between what this group considers to be the 'right' kind of new (i.e. not visibly, conspicuously new) and the 'right' kind of old (i.e. perhaps associated with a clear cultural epoch; probably limited to garments worn some distance from the skin). It will be important to remember that – at present, at least – young consumers seem quite willing to consume these garments, but not *prosume* them. Although prosumption (producing for one's own consumption) is gaining traction both theoretically and practically as a means of relocalising production and drawing long-overdue attention to matters of labour, skill, identity and self-efficacy (e.g. Knott 2013; Ritzer 2014), the participants in these studies reported that spending time on maintaining their garments was simply not 'cool'. This admission points the way to a number of important questions for future research, including the extent to which the 'uncoolness' of maintenance and repair is a façade for an experiential deficit (i.e. feeling unskilled, lacking confidence).

More practically, given that there are 'old' aesthetics that are demonstrably appealing to this group, and given that garments are seen to be more appealing when they aren't 'too new', there may be scope to make more of clothing designs, ranges or retail mechanisms that allow 'old' garments (or their fabrics) to be re-made into a new item. (Companies such as RE/DONE are already active in this space.) Here, the garment is sanitised through the re-making process, but retains cultural caché through the fabric's history and offers sustainability benefits by reducing/avoiding the need for virgin materials. At a more localised scale, there are opportunities to culturally normalise spending time on clothing maintenance and repair by making it more common, making it enjoyable and making it a mechanism through which peer esteem and relations can be nurtured. Providing these kinds of opportunities in a range of spaces will not only contribute to the normalisation of the practice but should go some way towards addressing the risk that everyday action towards sustainable clothing consumption is only for some, when it must be for all.

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Consuming the Million-mile Electric Car

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Keywords: Million-mile Car; Circular Economy; Product-service Systems; Modular Design.

Abstract: Unlike for many consumer products, there has been no strong environmental case for extending the life of internal combustion engine cars as the majority of their environmental impact is fuel consumed in use and not the energy and materials involved in manufacturing. Indeed, with improving fuel efficiency, product life extension is environmentally undesirable; older, less fuel-efficient cars need to be replaced by newer more fuel-efficient models.
Electric vehicles (EVs) are predominantly considered environmentally beneficial by using an increasingly decarbonised fuel – electricity. However, LCA analyses show that EVs have substantial environmental impacts in their materials, manufacturing and disposal. The high 'embedded' environmental impacts of EVs fundamentally change the case for product life extension. Thus, product life extension is desirable for EVs and they are suited to it. While petrol and diesel cars have an average lifetime mileage of 124,000 miles (200,000 Kilometres), the case for the million-mile (1.6 million Kilometre) electric car appears strong.
Although it may be technically possible to produce a million-mile EV, how will such vehicles be consumed given that the car consumption is complex, involving, for example, extracting use and symbolic value? In this contribution we explore the nature of the relationship between cars and the consumer that moves beyond technical and functional value to understand what form of access consumers require to an EV across its entire 50-year life. If such consumption aspects are overlooked then, even if the million-mile car is technically viable, it is unlikely to be adopted and the environmental benefits they may yield will be lost.

Introduction

Popular literature about the Million-Mile Car (Car and Driver 2018, Popular Mechanics 2012, Wired 2010) has generally framed vehicular longevity as a feat of personal responsibility achievable only by careful and dedicated drivers, assuming that the million-mile car is to be designed and consumed using existing practices only supported by the fanatical devotion of their owners. This article explores the notion of a Million Mile Car, more specifically the Million Mile Electric Vehicle (EV), not as a rare feat achievable by the dedicated but as an attractive choice not just environmentally but also in terms of user convenience and business proposition. Additionally, we argue that the Million-Mile EV is a logical conclusion of developing industry trends, although significant changes in the ways cars are designed, consumed and supported will be required. In this contribution, we explore the nature of the relationship between cars and consumers that moves beyond technical and functional value to understand what form of access consumers require to such an EV across its entire 50-year life. Here, consumers are likely to desire not just functional value from EVs but also symbolic value to project a social image. Cars become soon aesthetically and technically obsolete and lose symbolic value for consumers, leading to frequent replacements, so the million-mile car needs to be designed for both technical and stylistic/social upgrading over its 50-year life. New business models and utilisation patterns will be needed to absorb the high initial costs of electric vehicles, to facilitate such a customised refurbishment process and to enable consumers to exchange vehicles frequently.

The Case for the Million Mile EV

Unlike for many consumer products, there has been no strong environmental case for extending the life of internal combustion engine (ICE) cars as the majority of their environmental impact is fuel consumed in use and not energy and materials involved in manufacturing and end-of-life disposal (Patterson et al 2011). Indeed, with improving fuel efficiency, product life extension is environmentally undesirable. Older, less fuel-efficient cars need replacing by newer more fuel-efficient models.

EVs are predominantly considered environmentally beneficial by using an increasingly decarbonised fuel – electricity. However, life-cycle analyses show that EVs have substantial environmental impacts in their materials, manufacturing and disposal (*ibid).* The high 'embedded' environmental impacts of EVs fundamentally change the case for product life extension. Further, electric motors have fewer moving parts, requiring less maintenance and have the technical potential for a much longer life compared to ICE cars. Thus, product life extension is desirable for EVs and they are suited to it. While petrol and diesel cars have an average lifetime mileage of 124,000 miles (200,000 Kilometres) (Ricardo-AEA 2015), the case for the million-mile (1.6 million Kilometre) electric car appears strong.

The Challenges of the Million Mile EV

Although it may be technically possible to produce a million-mile EV, how will such vehicles be consumed given that car consumption is complex, involving, for example, extracting use and symbolic value? Here the EV already faces difficulties in the consumer market. Electric vehicles have higher acquisition costs than ICE cars, making it difficult for them to compete with traditional vehicles (Cherubini et al. 2015). The high purchase cost of EVs, coupled with steep depreciation and the cost of battery pack replacements do not map well onto existing models of car purchase and use patterns. Establishing EVs within ICE car consumption institutions and culture is a fundamental challenge. However, while the technical aspects of the million-mile electric car have attracted considerable attention, there is scant research on their consumption and on strategies to stimulate and manage it. With a car designed for ultra-long product life, consumer issues are likely to be even greater than those faced now by EVs. The million-mile EV would have a life of at least 50 years and needs to be designed for refurbishment, modernisation and restyling. Such a vehicle would probably be best provided under a lease or service package and not outright purchase. Although there may be some market segments for new high priced EVs and then post-refurbished/modernised cars, such a vehicle lends itself to a lease/service package model (Cherubini et al. 2015). To some extent the car market, with the use of personal leases for new cars, has such a model but rolling this out across the 50-year life of the million-mile car is something novel for consumers.

Research indicates that whether a product is suitable for recycling, refurbishment or remanufacture or not greatly depends upon decisions made during the design process. There are specific product properties that may have a positive or negative effect upon particular life extension measures, such as disassembly or cleaning (Hatcher et al 2011). Until recently, product life extension (through longer product life, refurbishment and remanufacturing) was not routinely dealt with in most design practices (Bakker et al 2013; Hatcher et al., 2011). In the case of cars, particularly, the general assumption was that the vehicles would largely be recycled as scrap metal after reaching their end of life. However, owing to current trends in material substitution for fuel efficiency and safety in vehicular design, the percentage of electronics, plastics, composites and other non-metallic parts that cannot be recycled through traditional processes is increasing (Despeisse et al., 2015). With the growth in the complexity and embedded value of vehicles, designers increasingly take into account the disassembly, remanufacture and recycling processes and there is a growing case for radical lifecycle extensions. Consequently, there is growing interest in the development of a variety of strategies for resisting or postponing obsolescence (making a product easy to maintain) or reverse it (making products easy to upgrade and refurbish). There are several socio-technical design challenges for designing long-life products. Design considerations for product-life extension include reuse of the product itself, maintenance, repair, technical upgrading and a combination of these. Emotional and cultural dimensions must also be taken into account. For example, designing for attachment and trust can support product life extension by creating products that will be loved, liked or trusted longer (Bocken et al., 2016, den Hollander et al 2017). In addition to product innovation, companies must develop innovative circular business models to capture financial benefits from increased product longevity, which they would not be able to achieve in a linear model (Bocken et al., 2016).

With a diverse consumer market for vehicles, business models could take a number of forms depending on nature of the consumers themselves. *Product Service Systems* (PSS) could be particularly valuable (Cherubini et al. 2015) to explore the types of consumer access appropriate for the technical and financial characteristics of the million-mile car. A PSS is a system of products and services supported by networks and infrastructure designed to be resource efficient (Mont 2002). For example, the Million Mile EV could be made available through a rented or leased vehicle package or could also form part of a more comprehensive Mobility as a Service (MaaS) offering.

The manufacturer (OEM) would then be responsible for maintenance and disposal of the vehicle. In the case of EVs, a manufacturer acting also as PSS provider would have incentives to enhance remanufacturability through design, as a means of extending a physical product's life cycle (Hatcher et al 2011). PSS offer the advantage of making service providers (rather than users) responsible for monitoring resource use, controlling parts and materials for EVs on the road and organizing end-of-life treatment and resource reclamation (Saidani et al 2018). A number of PSS-style models are possible (Cherubini et al. 2015) and probably a range of such options could be developed to suit the variegated and changing needs of different consumers (Cook 2014; Catulli, 2019). Indeed, there may be various opportunities to develop new leasing models, for example extending the present personal lease package for new cars to older cars throughout their lifetime, for flexible city car lease. In some instances, such offers could be integrated within transport systems using smart city technologies (cf. Valdez et al, 2017; Cook, 2018).

A review of trade literature suggests that the industry is already developing the required capabilities. Accenture (2018) claims that by 2030, revenues from manufacturing and selling vehicles (around €2 trillion) will be only marginally higher than they are. By contrast, revenues from mobility services are projected to soar to almost €1.2 trillion. Consequently, automakers are expected to evolve their value propositions from "hardware provider" to "integrated mobility service provider" (McKinsey 2016). The transition is not necessarily inspired by ecological concerns but rather by awareness of the rapid pace of technology: "*The increasing speed of innovation, especially in software-based systems, will require cars to be upgradable. As shared mobility solutions … with shorter lifecycles will become more common, consumers will be constantly aware of technological advances, which will further increase demand for upgradability in privately used cars as well*" (McKinsey 2016).

The Modular EV – A potential Million-Mile Solution

One approach to make it easier for 50-year old vehicles to remain technically and stylistically functional is modular design. The concept of upgradeable cars was explored by EV makers such as Tesla as a way to address the rapid obsolescence that can be caused by rapid developments in battery capacity (Forbes 2014). On a whole-vehicle-level, some players in the automotive market have already presented scalable and modular vehicle concepts (Figure 1). These vehicle concepts are generally associated with MaaS to address urban traffic issues (Ulrich et al 2018). Several major automakers have delivered prototypes exploring variations of that concept. The Urbanetic concept by Mercedes Benz, for instance, is based on a self-driving, electrically powered chassis that can take different switchable bodies depending on the intended use (Fig 2). The modules are designed so they can be switched automatically or manually in a matter of minutes and the autonomous chassis can make its way to its next location without any body attached. While the company explains that the rationale for the modular design is flexibility, a modular design would also support longevity. One major problem that could be expected from a million-mire car with a 50-year lifespan is that it would be easy for it to become aesthetically obsolete, losing symbolic value for consumers and requiring replacement even if the mechanical components remain sound. A modular design, combined with PSS, would make it easy for manufacturers to refurbish and update the passenger module in response to the latest stylistic trends, without compromising the longevity of the "platform" with motor, batteries and other components with high embedded environmental costs. If the social and even emotional dimensions of consumption are not taken into account, however, such offering might face implementation challenges (Li and Voege 2017) because consumers might see such PSS as less able to enable their everyday activities and project their identities (Catulli 2019).

Conclusions

We have discussed a number of issues associated with consuming the million-mile electric car and suggested one approach in which a PSS would be combined with flexible, modular vehicle design to provide such offering. Several major manufacturers (Fig. 1) are already exploring modular designs largely under the assumption that they will be used to provide MaaS. While this is only one of the many potential approaches that would make the million-mile car work, it illustrates the importance of a design where technical and social aspects support each other. The long-life car is more than a technical challenge and technical design needs to allow for unforeseeable changes in behavioural, symbolic, stylistic and lifestyle factors. An exploration of industry trends suggests that many elements of the million-mile EV are emerging – but a key set of consumer factors have received limited attention. Unless they become the focus of the million-mile car design, then it may fail to become the central business model of the automotive industry. If business models and socio-technical consumption aspects are overlooked when designing both vehicles and systems in which they are embedded, then even if the million-mile car is technically viable it is unlikely to be adopted and the environmental benefits they may yield will be lost.

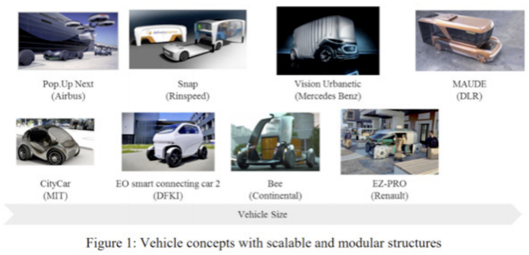

Figure 1. Concept vehicles by major manufacturers exploring modular approaches (Ulrich et al. 2018).

Figure 2. Vision Urbanetic concept © Daimler.

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Product Lifetimes And The Environment

The Economic Implications of Increased Product Longevity

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Keywords: Economics; Market Failure; Competition; Resource Productivity; Employment.

Abstract: Interest in product longevity has increased across Europe in recent years. To date, however, little attention has been paid to the implications for national economies if a higher proportion of consumer durables were to be designed and manufactured for longer lifetimes, average lifetimes increased, and product replacement cycles slowed. This lack of knowledge is problematic for several reasons. First, it is important that the implications of increased product longevity for traditional economic goals such as growth, low unemployment and a satisfactory balance of trade are understood. Second, if public policy support is required for such a strategy on environmental grounds, the economic implications need to be understood in order to leverage support from governments' finance and economics departments. This paper reviews the current state of knowledge on product lifetimes from the perspective of economics, drawing upon literature from academia, public bodies and policy organisations, and including recent studies on the circular economy. It concludes that the evidence base on the macroeconomic implications of increased product lifetimes is inadequate, while noting that studies have identified potential growth, employment and trade benefits. There is also inadequate understanding of how microeconomics might be applied to product lifetimes. Too few economists have engaged with this topic; a research agenda is urgently required.

Introduction

Within a growing body of research on product longevity, scholars from many disciplines have explored consumer attitudes, behaviour and expectations towards product lifetimes, design approaches and tools, planned obsolescence, lifetime optimisation and metrics, business models and product-service systems (Cooper et al., 2015; Bakker and Mugge, 2017). By contrast, there has been negligible engagement from economists, which is problematic because if policies are put in place to encourage increased product lifetimes, the implications for traditional economic goals such as growth, low unemployment and a satisfactory balance of trade need to be understood to enable appropriate management of the economy.

The circular economy provides a suitable starting point to explore the economic implications of increased product longevity. The concept can be traced to economists Boulding (1966) and Daly (1977), who argued that the Earth should be regarded as a closed system and that this should be reflected in economic policy. By the 1990s links had been made between the circular economy and product lifetimes (Stahel and Jackson, 1993; Cooper, 1994, 1999). In subsequent discussion, prompted by the European Union's Action Plan for the Circular Economy, the initial focus was on 'closing the loop' (i.e. recyclability), although a need to 'slow the flow' (i.e. longevity) is now recognised (Cooper, *forthcoming*). The transition to a circular economy is understood to demand structural change in the economy, involving lower output in some industry sectors and more in others, but little research on it has been undertaken from the perspective of economics; most journal papers on the circular economy have been written by academics from other disciplines.

Aim, method and structure

The aim of this paper is to review the current state of knowledge on product lifetimes from the perspective of economics. It draws upon the burgeoning literature relating to product longevity from academia, public bodies and policy organisations in order to explore how our understanding of product lifetimes could be informed by economic theory and practice.

The flaws in mainstream economics, some of them identified in this paper, have long been criticised by heterodox economists. The primary purpose of the paper, however, is to explore the potential value to be gained from engagement with the economics discipline rather than the need to transform it.

The method used was a systematic literature review (Tranfield et al., 2003). Appropriate key words were identified and applied to Google Scholar. For instance, to trace theoretical studies search terms such as 'market structure, product durability' were used. For empirical studies, terms such as 'economic impacts, circular economy' were used. Abstracts were read and grouped according to their theoretical and empirical content.

The next section considers the use of macroeconomic models to explore the economic implications of increased product lifetimes and how they relate to economic policy goals. This is followed by some examples of how microeconomic theory might be applied to product lifetimes.

Product lifetimes and the economy

Recent studies on the potential macroeconomic implications of circular economy strategies, some of which incorporate longer lasting products, have used both product-based analysis and quantitative modelling.

Product-based analysis (alternatively termed accounting modelling) provides insights into the likely costs and benefits of increased material or product circularity in one or more sectors. Such analysis does not, however, incorporate economy feedback processes such as those associated with changing prices. Quantitative modelling, by contrast, enables the effect of changing prices on supply and demand to be taken into account, and, likewise, interactions and spill-overs of policy on sectors and agents other than the ones initially affected. Product life extension activities are not well represented in such models, however, typically being aggregated with other activities (McCarthy et al., 2018).

Product-based analysis

One of the earliest government studies on product longevity used interviews and stock and sales modelling to identify and assess the potential impact on the economy of measures to extend product lifetimes and concluded that, overall, they were 'mixed'. The impact on manufacturing was "broadly negative but limited" (Environmental Resources Management, 2011, p. 18). The impacts on retail and distribution varied, some being negative and relatively deep. By contrast, the impacts on repair, refurbishment and maintenance (and, to a lesser extent, the second-hand market) were positive. Some measures offered substantial benefits to businesses and consumers but lower turnover for retailers and lower VAT receipts for government.

A subsequent report on the circular economy considered reuse and better design to determine whether producing, selling and consuming less material might prove more attractive to businesses and consumers than mass produced goods based on low labour costs and economies of scale (Ellen MacArthur Foundation (2013). The inputs needed to make a new product in a linear economy were compared with those needed in a circular economy. For example, the cost of materials used in reverse-cycle processes were compared with the cost of virgin inputs saved through materials recovery. The potential for net material cost savings in European manufacturing was calculated as up to $630bn annually, equivalent to 3.9% of the EU Gross Domestic Product (GDP).

A third study used a detailed sector-based analysis to estimate the impact of an expanding circular economy on the Netherlands economy as a whole (Bastein et al., 2013). Insights from literature, interviews and a workshop were used to estimate the current value of the circular economy in the metal and electrical sectors and its potential for expansion. The number of new products entering circulation each year was compared with the number repaired, reused and recycled, and a similar comparison was performed for the value of new products and of repaired goods, reused items and recycled material. The value of the circular economy in the two sectors was estimated at €3.3bn and the potential for expansion €573m per year. The impacts on the economy as a whole were then calculated by extrapolating the findings to comparable industry sectors; the study estimated the overall market value presented by circular economy opportunities to be €7.3bn annually, equivalent to 1.4% of GDP.

Quantitative modelling

A second macroeconomic approach is to use economy-wide models. A recent review of the use of such models to explore the macroeconomic consequences of transition to a circular economy identified 24 studies that used either computable general equilibrium models (CGE) or macro-econometrics models (ME) (McCarthy et al., 2018). It noted, however, that although longer lasting products are often identified as a key element of the transition, they are not explicitly represented in such studies because "CGE and ME models are based on representations of economic flows … (and) … include very little stock accounting" (McCarthy et al., 2018, p.27).

The authors concluded that, in principle, longer product lifetimes could be modelled through an exogenous decrease in demand for more robustly designed products, thus lowering total sales revenue - although such products might fetch higher prices, which would reduce or even negate this. Alternatively, the models could assume that increased longevity is captured in the price of products and total sales remains unchanged, in which case the total demand in value terms would be unaffected. The report warned of the current limitations of macroeconomic models: there is, for example, considerable uncertainty over the effects of changes in product lifetimes on consumption and investment, and thus on national income.

Two macroeconomic studies that use input-output models to address product lifetimes merit attention here, although the first only considers 'first order' effects and the second uses a static model; both recommend the use of CGE models to extend their work.

The first study, prepared for a European Parliament committee, developed an analytical framework and set of definitions in order to consider how the benefits and costs of longer product lifetimes would be distributed across society (Montalvo et al., 2016). The five sectors most likely to benefit from (or be affected by) longer product lifetimes were identified - repair, design, (material) science, waste treatment and rental - and, using the EU-28 aggregated input-output table, sectoral and geographical effects of an increase in value-added in these sectors were explored. The report concluded that longer product lifetimes would improve competitiveness in Europe (as a result of an increase in the value added to products), have a positive effect on the European Union's trade balance, and generate low- and medium-skilled jobs.

The second study used input-output models to explore the impact on carbon emissions and employment of measures aimed at decoupling economic growth from resource use in five European countries (Wijkman and Skånberg, 2017). One of its three scenarios involved doubling the life-span of consumer goods, a 25% increase in material efficiency and replacing 50% of virgin materials by secondary materials; the others addressed renewable energy and energy efficiency. The research found that the material efficiency scenario led to the largest increase in employment; it also reduced carbon emissions, though not by as much as the other two scenarios.

Impacts on economic goals

The impact of circular economy strategies on the traditional macroeconomic goals of growth in GDP, low unemployment and a satisfactory balance of trade has been estimated in several studies.

Despite longstanding criticism, economic growth remains a key indicator in public policy. In a linear economy the continual updating of products fuels GDP, whereas in a circular economy the likely shift in economic activity from manufacturing to the service sector (as goods are maintained for longer) has uncertain implications for GDP. There is tension between innovation and product longevity: Fishman et al. (1993, p. 361) warned that "if products are too durable, potential innovators may lack the incentives to invest in the development of a new technology and the economy may stagnate as a result."

Several studies modelling a circular economy transition have addressed economic growth. A study on measures to increase resource productivity concluded that improvements of 2%-2.5% p.a. could be achieved with net positive impacts on GDP but, beyond this rate, added costs would outweigh the benefits (Cambridge Econometrics and Bio Intelligence Service, 2014). Another study concluded that resource productivity could grow by up to 3% p.a., generating a 'primary resource benefit' to Europe's economies of around €1.8 trillion and leading to an increase in GDP of up to 7% by 2030 (Ellen MacArthur Foundation, 2015).

Transition to a circular economy might increase employment because of the labour-intensive nature of maintenance and repair activities associated with longer product lifetimes, although there could be a negative effect on employment in manufacturing and retailing. Overall, the studies cited above have indicated positive employment effects. The €7.3 billion added value generated by expanding the circular economy in the Netherlands was predicted to generate around 54,000 jobs (Bastein et al., 2013). An improvement of 2% p.a. in resource productivity was expected to create around two million additional jobs in the EU (Cambridge Econometrics and Bio Intelligence Service, 2014). A material efficiency decoupling scenario in five countries suggested employment gains ranging from 50,000 in Finland and Sweden to 300,000 in France (Wijkman and Skånberg, 2017).

Another study, on employment and resource efficiency, explored the impact of 'preparation for reuse' targets for municipal solid waste: 20%-30% for textiles and 35%-45% for furniture. Based on a literature review and an assessment of established practice, it concluded that up to 269,000 jobs in furniture reuse and 30,000 jobs in textiles reuse could be created (European Environmental Bureau (2014). Lastly, a UK study based on an econometric model concluded that fiscal reform such as switching taxes from labour to resource use would create 455,000 jobs (Green Fiscal Commission, 2010).

A few studies have considered the potential effect of increased product longevity on the balance of trade. One concluded that longer product lifetimes would have a positive effect because they would "reduce dependency on non-EU imports to meet European demand" (Montalvo et al., 2016, p. 41). The effect would be greatest for electric and electronic equipment, textiles, transport equipment and furniture, as the proportion of such goods that are imported is relatively high. A Club of Rome study also drew a positive conclusion about the effect of decoupling on the trade balance; it found that a materially efficient strategy would result in a trade surplus improvement equivalent to 1-2% of GDP (Wijkman and Skånberg (2017).

Product lifetimes and markets

This section explores how microeconomic theory could inform understanding of product longevity with reference to market mechanisms and, specifically, market failure. The topics addressed are necessarily selective due to limitations of space; the potential range of topics is substantial.

Market mechanisms

Production and consumption are explained in economics through the concept of markets, where prospective buyers and sellers make decisions that determine the demand for, and supply of, goods and services.

The determinants of demand identified in economic theory include price, tastes and preferences, necessity, the price of other goods (either substitutes or complementary), and the level and distribution of income. Such relationships could be used to explore, for example, the effect of an increase in incomes on the demand for longer lasting products (which are liable to be relatively expensive).

Economics textbooks rarely address product lifetimes and often even fail to distinguish between consumer durables (e.g. vehicles, appliances, furniture), semi-durables (e.g. clothing) and non-durables (e.g. food, energy), even though markets may operate differently in each case. This is significant: as the lifetime of consumer durables is variable (being determined by inherent durability and consumers' disposal decisions) replacement cycles vary, making future demand harder to predict. In addition, demand may be affected by higher transaction costs (because consumer durables are not bought frequently) (Parks, 1974) and second-hand markets (Miller, 1961).

Price is a key economic variable. In the specific case of a durable good, consumers need to know its anticipated lifetime, in addition to its 'point of sale' price, in order to assess the cost of ownership over the period of use.

When addressing tastes and preferences economists typically use ordinal utility (i.e. ranking levels of consumer satisfaction from different products) in order to create indifference curves. This is a rather narrow approach to consumer behaviour compared with theories in marketing, which address factors such as people's values, attitudes, intention, habits and social norms, and the purchasing context. Such theories have informed studies on consumer behaviour relating to product lifetimes, notably research on user attachment and disposal behaviour (Cooper et al., 2015; Bakker and Mugge, 2017).

Other determinants of demand include the level and distribution of income. In theory, the historic increase in GDP should make longer lasting products more affordable. Indeed, a recent study indicated a trend towards increased product lifetimes (Oguchi and Diago, 2017), although other studies (cited in Bakker et al., 2014 and German Environment Agency, 2017) have identified a decline, at least for electrical and electronic goods. As longer lasting products are liable to be less affordable to poorer households, in particular, the distribution of income is highly significant (Cooper, 1998). Policy measures aimed at product lifetimes, such as minimum quality standards, might disproportionately benefit higher and middle income households (Environmental Resources Management, 2011).

The supply of goods is primarily determined by price in relation to the costs of production, notably raw materials and labour. In industrialised countries the relative cost of different factors of production has led to an excessive use of primary raw materials and a tendency to minimise the use of labour (von Weizsacker and Jesinghaus, 1992; Cooper, 1999), with obvious implications for product lifetimes: as repair and maintenance tends to be labour-intensive, high labour costs make replacement relatively cost-effective.

Another determinant of supply is the profitability of other goods (i.e. substitutes). In the case of consumer durables, the supply of relatively cheap, low quality goods represents an alternative to goods designed for longevity. The supply of longer lasting goods thus depends on their production costs, relative to those of shorter-lived alternatives, and the price premium that consumers are willing to pay.

Markets for consumer durables interact with markets for second-hand items, the supply of which depends on repair costs, people's willingness to bear the risk of breakdown, their evaluation of 'newness', and personal circumstances (Miller, 1961). Although reuse is often advocated in environmental grounds, Thomas (2003) notes a long tradition of economists who concluded that second-hand markets may increase demand for new goods. For example, Scitovsky (1994, p. 37) argued that second-hand markets "stimulate the economy partly by enabling the well-to-do the sooner to replace their worn out or obsolescing durable goods with new ones and thereby increasing the total demand for them." A recent empirical study concluded that only 27% of second-hand purchases displaced the purchase of a new item (WRAP, 2013).

Market failure

Inadequate product lifetimes may arise from different forms of market failure, as described in the following three examples.

First, in the ideal situation of perfect competition buyers need to be fully informed about goods, including their anticipated lifetimes. Consumers need to be able to make choices that will maximise their utility (i.e. satisfaction) if markets are to operate efficiently, and this requires that they know how long consumer durables are intended to last. They cannot assume that price is a reliable indicator of quality: marketing researchers have found the evidence ambiguous (Rao, 2005) and the relationship has attracted little interest from economists (Bowbrick, 1992). Lifespan labels have been advocated by the European Economic and Social Committee (2016) as means to inform consumers.

Consumers' decisions are even harder in second-hand markets. Akerlof (1970) gave the example of used car markets in which sellers have information on the quality of used cars that buyers lack (i.e. information is 'asymmetric'). If buyers are only willing to pay a price reflecting the average quality of the cars offered for sale, a supplier of a good quality used car might choose to keep it rather than sell it. As the average quality of used cars would consequently fall, buyers might become less willing to pay the prevailing price, prompting more sellers to withdraw from the market. Uncertainty about quality has led to a flaw in the market mechanism.

Second, individuals and households may face costs arising from economic transactions for which they are not responsible (i.e. externalities). This is relevant to product lifetimes because the cost of managing waste is typically not paid directly by the consumers responsible but through collective charges to households. 'Pay as you throw' charges have been proposed to address this. Theoretical studies that have addressed the relationship between product durability and waste management suggest that policies which internalise the costs of waste disposal should result in increased product durability (Runkel, 2003).

Third, competition may not merely be imperfect but constrained by a monopoly or oligopoly situation, in which sellers are able to influence the supply or price of goods. There is a longstanding debate among economists on the relationship between market structure and product durability, stimulated by concern about cartels in certain product sectors (e.g. light bulbs, razor blades) (Avinger, 1981). Its origins have been traced to an article which, noting that "durability is an aspect of products which is exceedingly variable" (Chamberlin, 1953, p. 23), raised the question of how durable producers should make goods in order to maximise their profits, and whether this would be affected by the extent of competition.

In a series of theoretical papers some economists argued that a monopolist chooses an inefficiently low level of durability compared with a producer in a competitive situation (e.g. Martin, 1962; Kleiman and Ophir, 1966; Levhari and Srinivasan, 1969; Schmalensee, 1970), while others refuted this and argued that monopolists exploit their market power through prices rather than product durability (e.g. Swan, 1970). Later papers (Stokey, 1981; Bulow, 1986) used different argumentation to conclude that the earlier papers had, in fact, drawn the correct conclusion, albeit using flawed reasoning (Snelgrove and Saleh, 2016). A review of these earlier papers criticized the use of "simplified models that gave very incomplete pictures of actual durable goods markets" (Waldman, 2003, p. 132) and noted that "most of the literature assumes either monopoly or perfect competition, while clearly most real world markets are either oligopolistic or monopolistically competitive" (Waldman, 2003, p. 150). The author described subsequent advances in microeconomic theory on durability choice and issues associated with new product introductions but concluded that further research is required.

Conclusions

This review of literature relating economics to product lifetimes has found that there is potential for significant insights from the discipline that could inform future, multidisciplinary academic discourse.

Until the emergence of a series of studies on the transition to a circular economy, economists paid little attention to product lifetimes from a macroeconomic perspective. These studies have mostly addressed resource efficiency or decoupling strategies, however; only one has specifically focussed on product lifetimes. Overall, they conclude that the transition to a circular economy would have a positive effect on growth, employment and the balance of trade (BITC, 2018), although product life extension activities are currently not well represented in quantitative models.

Similarly, aside from theoretical studies on durability choice and market structures, there has been little research on product lifetimes from a microeconomic perspective. Even in studies that have addressed topics such as information asymmetry and second-hand markets product longevity has not been the main focus. More research is needed in these areas and others, such as how economies of scale and depreciation rates influence product lifetimes. More generally, while there is an apparent consensus that the circular economy concept is useful, economists need to contribute to greater understanding of the interface between material flows and economic flows.

Finally, all economies are influenced by government policy. Policymakers have an important role to play in the transition to a circular economy. Economic policies to increase product longevity may take the form of green fiscal reform but a wide range of market-based, regulatory and voluntary instruments are available (Cooper, 2010).

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Trialling the Preparation for Reuse of B2C ICT WEEE in Ireland

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Keywords: Preparation for Reuse; Reuse; B2C; WEEE, ICT.

Abstract: The TriREUSE project investigated the potential of collecting B2C ICT WEEE for preparation for reuse in workplaces in Ireland. TriREUSE ran a series of WEEE to Work events where employees were incentivised to return their data-bearing devices (Laptops, Tablets & Smartphones) at these events where free data wiping and destruction were offered on all devices. The collected devices were returned to a certified Preparation for Reuse organisation where the devices were tested and assessed for their suitability for reuse using both technical and economic criteria. 283 kg of laptops, smartphones and tablets was collected from 10 events of which 60 kg (28%) was suitable for preparation for reuse. 64 (29%) of the data-bearing devices that were collected were successfully prepared for reuse. A further 308 kg of WEEE outside of the scope of the project was also collected during the events.

Introduction

The proper treatment of Waste Electrical and Electronic Equipment (WEEE) is high on the global agenda in concerns regarding resource efficiency and climate change (Baldé *et al.*, 2017). Promoting the lifetime extension of EEE is also considered of importance due to the use of numerous critical raw materials which do not emerge from recycling streams (European Commission, 2014). In addition, very high manufacturing energy inputs are required for these products, particularly for low entropy components (Zero Waste Europe, 2017).

Research has demonstrated that the scope for future improvements in efficiency of material production is limited (Allwood *et al.*, 2012; Gutowski *et al.*, 2013). Therefore, for a reduction in industrial emissions to contribute to the mitigation of climate change, a reduction in material production through strategies such as reuse and preparation for reuse that offset new production will be necessary. EEE reuse has been prioritised by a wide range of global policies and regulations as a prudent approach for conserving resources and reducing environmental pollution. Most of the legislation that regulates movement and disposal of equipment containing potentially hazardous materials recommends reuse. The European Commission have also commissioned research on the feasibility of including preparation for reuse targets in the WEEE Directive (European Commission, 2017). This study concludes that a universal target across all member states is not recommended but it encourages individual member states to pursue actions which support preparation for reuse of WEEE including targets (McMahon, Johnson and Fitzpatrick, 2019).

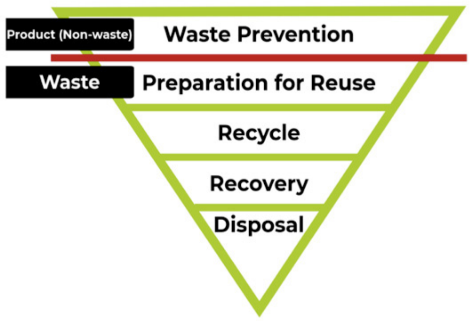

Figure 1. Waste Hierarchy.

Preparation for Reuse is a waste treatment option at the end of life of WEEE. ICT WEEE such as Laptops, Tablets and Smartphones can have a high intrinsic value and often do not present as WEEE (Angouria-Tsorochidou, Cimpan and Parajuly, 2018). Preparing for reuse refers to checking, cleaning or repairing and recovery operations, by which products or their components that would have become waste are prepared in a way so that they will be reused without any other pre-processing (Gharfalkar *et al.*, 2015). The time taken from end of use to disposal is a growing problem with EEE. The reluctance of consumers to dispose of EEE as WEEE is claimed to be rooted in frugality, altruism and cleanliness (Casey, Lichrou and Fitzpatrick, 2018). Casey et al identified key stages in the WEEE divestment process in figure 2.

Figure 2. Critical Moment of Disposal (Casey, Lichrou and Fitzpatrick, 2018).

The potential for preparing for reuse and reuse has been highlighted in several studies. One study in Bavaria found that between 13% and 16% of WEEE was suitable for reuse and a further potential of 13% to 29% could be created through changes in collection, storage and treatment at collection points in the region (Messmann *et al.*, 2019). Another study in Denmark found that 22% of small appliances and 7% of monitors were fully functional and had the potential for resale (Parajuly, 2017). A study in Spain investigated the potential for preparing for reuse of small WEEE (sWEEE) and found that 67.7% of collected devices had the potential to be prepared for reuse through refurbishment and repair (Bovea *et al.*, 2016). All studies highlight the potential for increased revenue from a better preparation for reuse system.

Preparation for Reuse in Ireland

The process of becoming a "preparing for reuse" organisation in Ireland requires several steps to gain access to WEEE. Firstly the organisation must be approved and registered with the WEEE Register Society Ltd. The approval and registration requires waste collection and waste license/facility permits from the local authority, Preparation for reuse certification, at the moment the BSI PAS141 standard is required with the intention to migrate to EN 50614 in due course. The confirmation of working arrangements with compliance schemes and proof of indemnity insurance for preparing for reuse activities and a warranty policy is required for registration. An administration fee of €250 is also payable.

The TriREUSE Project

The TriREUSE project was created to trial the "Preparation for Reuse" of ICT WEEE throughout the Republic of Ireland. The trial was conducted using a series of collection events with a mix of public and private organisations. The collection events were undertaken in various workplaces from local government authorities, third level educational institutions, government departments and agencies and private companies. These workplaces were selected as a testbed to assess the willingness of employees to hand over their old ICT devices with a view to being reused after secure data destruction.
TriREUSE used these events to gather a mix of data-bearing devices (laptops, tablets and smartphones) to be "prepared for reuse". TriREUSE aims to facilitate and encourage consumers to dispose of EEE as WEEE by providing a work-based collection event in tandem with free data erasure and destruction.
The results from the TriREUSE project will enhance the understanding of how preparation for reuse of B2C WEEE can operate in Ireland.

Collections

Collections took place as "WEEE to Work" events which have been used previously to encourage people to dispose of their old or unused electronic devices. The TriREUSE project used the same methods to collect devices for reuse. The project undertook two public and eight private collection events from October 2018 to May 2019. They were run in collaboration with a mix of organisations, from Compliance schemes, Local Government Authorities, Educational Institutions, Government Departments and Multinational companies.
The object of the collection was to gather data-bearing devices. The decision was made between the project partner to focus our efforts on collecting Laptops, Tablets and Smartphones as they can have a higher resale value, contain many critical raw materials and traditionally suffer from low collection rates.

Data Protection

The implementation of the General Data Protection Regulation (GDPR) throughout Europe in May 2018 provided a point of reference to help leverage the incentive of free data erasure & destruction as part of the collection system. From speaking with employees and staff, it was evident that GDPR coverage provided a focus on what was happening to their data. All devices were issued with an identification number and the user could email our preparation for reuse partner if there was a requirement for a data destruction certificate.

WEEE to work

The collection events were promoted in several ways and were conducted over two day or one day events. The two day events comprised of an awareness day followed by a collection day. The one day events comprised solely of a collection day. The events were promoted using TriREUSE branded materials for posters and e-flyers in tandem with targeted Facebook and Twitter campaigns. A website was developed to disseminate the preparation for reuse message and its benefits. Video templates were used to personalise and publicise events for companies and organisations.

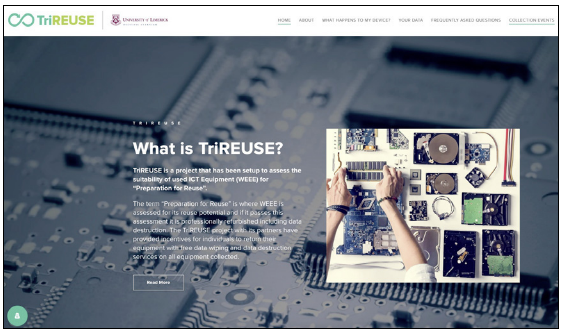

Figure 3. TriREUSE website screenshot.

Figure 4. TriREUSE YouTube video screenshot.

Results

The devices that were collected were prepared for reuse at PhoenixRM, an authorised preparation for reuse organisation. Figure 5. presents the process flow for the collected devices.

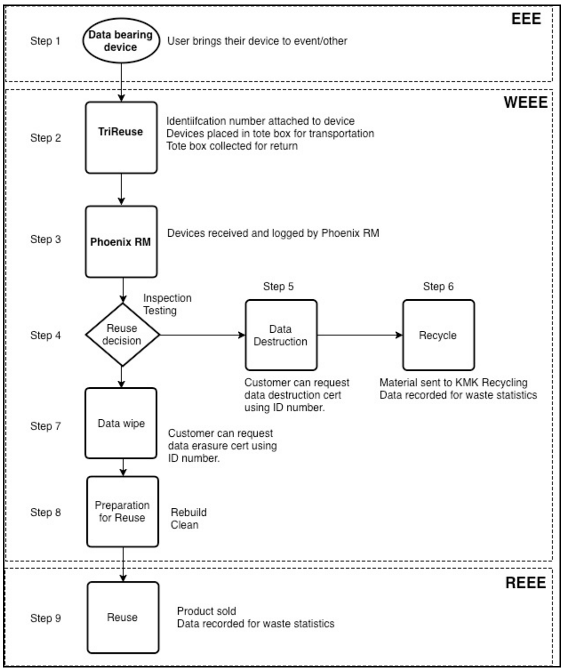

Figure 5. Process flow for TriREUSE.

As part of this preparation process, devices that were not suitable for direct reuse (minimal intervention) would be assessed for parts reuse as supply feedstock.

Device	Total	REUSE		RECYCLE		Total Weight (kg)
		No.	Weight (kg)	No.	Weight (kg)	
Laptop	93	18	38.34	75	159.75	198.09
Tablet	36	9	19.17	27	57.51	76.68
Smartphone	91	37	3.33	54	4.86	8.19
Total	220	64	60.84	156	222.12	282.96

Table 1. Devices collected, count and weights (UNU-keys, 2010).

Table 1. presents the devices collected by the number collected and weight. United Nations Univeristy (UNU) keys are used to assign an average weight to each device. UNU keys from 2010 and the corresponding weight values were assigned to each device type.

Figure 6, presents the number of devices collected with laptops representing 42% of devices collected with Smartphones representing 41% and Tablets accounting for 16%.

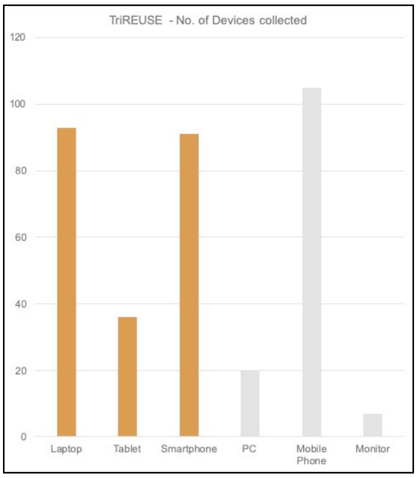

Figure 6. Number of devices collected.

Other data-bearing devices were received as part of the collection but have been omitted as they are not in the scope of the project. A total of 590.38 kg of WEEE was recorded from the collection. 282.96 kg of WEEE was within the scope of the project i.e. Laptops, Tablets and Smartphones. 60.84 kg of this WEEE was recorded as being prepared for reuse while the remaining 222.12 kg went for recycling. Devices that were outside the scope of the project went for recycling (307.42 kg). Figure 7 presents the total weight collected per site. Site E had the largest amount of WEEE collected by weight.

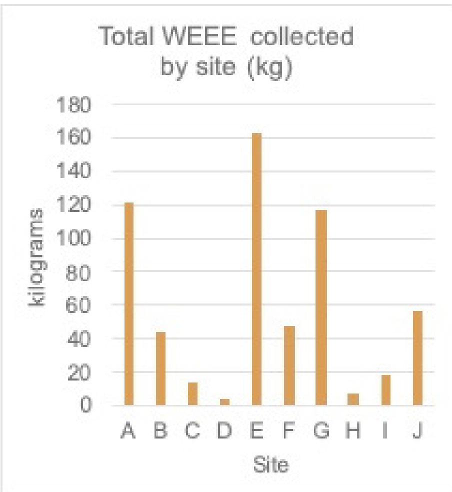

Figure 7. Total WEEE collected by site (kg).

Figures 8, 9 and 10 present the reuse and recycle device quantities collected per site.

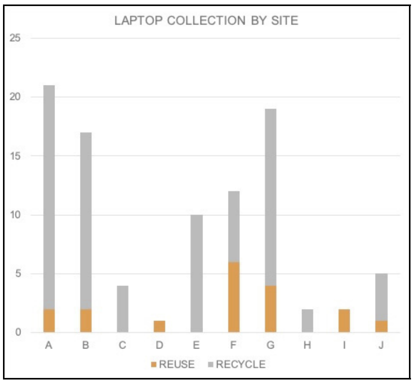

Figure 8. Laptop Reuse/Recycle per site.

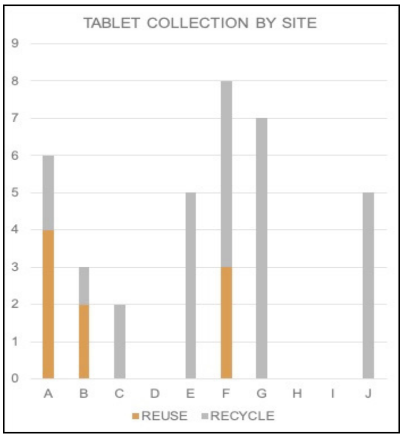

Figure 9. Tablet Reuse/Recycle per site.

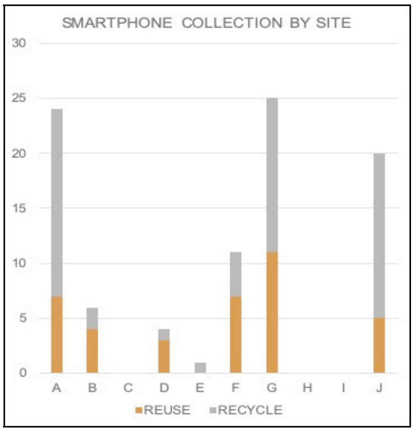

Figure 10. Smartphone Reuse/Recycle per site.

29% (64) of the data-bearing devices (laptops, tablets and smartphones were prepared for reuse. An analysis was carried out on the kilograms collected per person (8 private collections) in Figure 10.
Site E had the best return of WEEE with 0.09kg with a workforce of 400 approx. An average of 0.03kg was collected from staff at all events. These results can help to inform the basis of a benchmark for targets for future events,

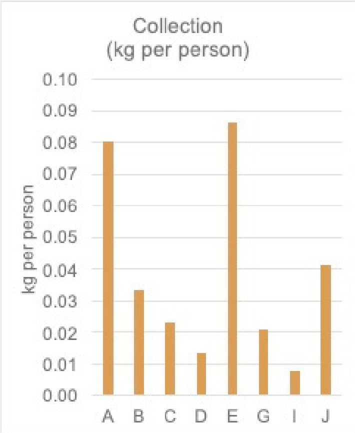

Figure 10. Collection kg per person.

Findings & Discussion

The objective of the TriREUSE project was to trial the preparation for reuse of B2C ICT WEEE in Ireland. The trial consisted of operating a series of collection events at public and private organisations. The project employed incentives to encourage and create awareness around the concept of reuse and preparing for reuse. The trial allowed people to dispose of their devices safe in the knowledge that their data was being securely destroyed/erased as per industry standards. The findings from the project are summed up below;

1. Higher reuse rates were achieved than from regular WEEE collections (29%).
2. On-site promotion from CSR, IT, Facilities and Employee Volunteer Programs (EVP) of awareness and collections days improves collection rates.
3. High returns of typically difficult to collect devices. Providing a free data destruction & erasure service increased takeback.

There were several outcomes from trialling the reuse of B2C ICT WEEE in Ireland and these are listed below;

1. Secure data destruction/erasure provides an incentive to owners to return devices.
2. It created and raised awareness of the concept of "reuse".
3. It promoted reuse before recycling for IT equipment.
4. Idenitifed potential source of feedstock for reuse.
5. All devices will contribute to targets either through reuse or recycling.
6. Potential for Preparation for Reuse certified organisations to continue collection events.
7. Collaboration with all stakeholders yielded the best return of devices.

The outcomes of this project indicate that there is a potentially a large and untapped resource which should be managed by certified "preparation for reuse" providers. We would recommend that IT Asset Disposition (ITAD) become Preparation for Reuse organisations to enable them to conduct B2C WEEE to Work collections in tandem with existing B2B collections. This could increase takeback of B2C WEEE and have benefits for greater returns for future targets for reuse and recycling. The TriREUSE trial provided evidence of how a preparation for reuse collection of B2C ICT WEEE might work. A regular collection service would encourage users to dispose of unused and unwanted data bearing devices sooner.

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Designing Useful Fashion: A New Conceptual Model of the Garment Lifetime

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Keywords: Sustainable Fashion; Design for Longevity; Garment Lifetime; Clothing Practices.

Abstract: This paper considers how research into clothing lifetimes and consumer practices can be integrated into a garment lifecycle assessment model, to facilitate a reorientation of fashion design from design for sustainable products to design for the conditions of sustainability (after Fry, 1994). Drawing on the research of Payne (2011a) and Klepp (2001), a revised Garment Lifetime Diagram is proposed that segments the use phase to provide a more holistic understanding of the garment lifecycle. By making visible the detail within the phase of use, the aim is to show how designers might foster sustainable clothing use practices through the design decisions they make. In particular, how design might encourage extended garment use. The resulting diagram of a single garment lifetime challenges the popular approach to sustainability through extended use that describes garments with multiple lives (Fletcher, 2008). Arguably, defining the garment lifetime as ownership, reinforces what has been criticised as the inherently anthropocentric viewpoint of sustainable development (Fry, 2009). Instead, the notion of 'custody' emerges to describe temporary possession of a living garment.

Introduction

Life-cycle assessment is a quantitative measure used to assess the environmental impacts of materials and products, fundamental to the implementation of sustainability (McDonough & Braungart, 2002) and the transition to a circular economy (Ellen MacArthur Ellen MacArthur Foundation, 2013). A number of researchers have referenced garment lifecycle assessment as a framework to discuss how design decisions can influence each phase of the garment lifecycle to transform conventional design practices from a linear to circular model (Fletcher, 2008; Gwilt, 2011; Payne, 2011a). It is at the point of design that materials are gathered and manufactured into garment form, comprising decisions on which fabrics and trims to use and where and how to produce it. These decisions affect how the garment can be cared for (dry clean, machine or hand wash), how long it will last (durability of components and construction) and what end-of-life scenarios are possible (reuse, recycling and disposal).

Lifecycle Assessment as a Design Tool in Fashion

A diagram of the garment lifecycle is particularly useful to designers to visualise the relationship between the design phase and the other phases of the garment lifecycle. Diagrams and infographics are popular methods of communicating complex information, especially within the design disciplines. Leading examples are the Ellen MacArthur Foundation's diagram of the Circular Economy System (2017), and the TED 10 Sustainable Design Strategies (TED, n.d.). A literature review of sustainable fashion design research identified Payne's *Garment Lifecycle Assessment* diagram as one of the earliest of its kind to map the typical, linear garment lifecycle of single use and discard with the alternatives: extended use prior to disposal and a closed loop of material recovery following disposal (Figure 1). The diagram demarcates the phases of product development as the production of the fibre, garment design and manufacture, distribution and retail sale, followed by consumer use and end-of-life scenarios. This provides a logical structure within which to discuss the harmful environmental and social impacts of each stage within the linear system and to promote the benefit of the alternatives.

A garment lifecycle assessment diagram serves as a design tool by prompting examination of where positive intervention might mitigate unintentionally harmful consequences. Payne illustrates this process with a number of questions that might be asked at each stage. For example, what are the impacts of fibre production? Can we design a service system rather than a product? Who makes the garment? (Payne, 2011b) Fashion brands at all levels of the market have used lifecycle assessment tools to transform their business models towards sustainability and produce products with reduced negative environmental and social impacts (for example, Hoffman; Holm, 2017).

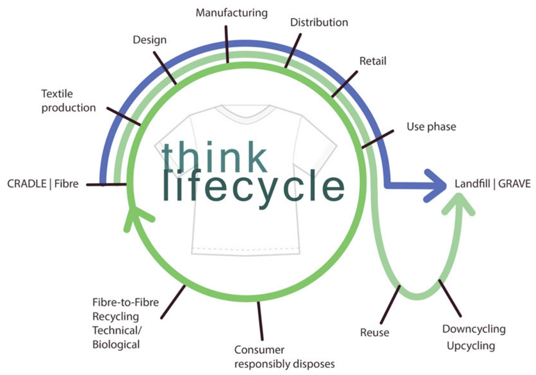

Figure 1. Garment Lifecycle Assessment Diagram (Source: Payne, 2011b).

Extending the Use Phase of Clothing by Design

Alongside improvements to the supply chain, leading researchers within the field have advocated for greater consideration of the use of garments in fashion design for sustainability strategies (Fletcher, 2008; Gwilt, 2013). Garment design that supports extended use is one strategy with the potential to mitigate the harmful environmental consequences of disposable fashion. Lifecycle assessment studies of clothing conducted in the UK, have shown that even a modest extension to the use phase of clothing can significantly reduce the carbon, water and waste footprint (WRAP, 2012).

An interrogation of a typical garment lifecycle model undertaken within a practice-led doctoral study, identified such models as problematic for designers seeking to reference lifecycle assessment to inform strategies for sustainable garment use practices. Firstly, the equal division of all phases within the lifecycle disguises the fact that the longest phase of the garment's lifecycle is the use phase. Therefore, the imperative to design for sustainable garment use practices is diminished. Secondly, while the production of a garment is segmented into phases, its use is not similarly segmented. Therefore, opportunities to design for particular use practices are concealed. Each of these limitations is discussed below and a revised model of the garment lifetime presented in response. Further, it will be discussed that garment lifecycle diagrams represent a single garment lifetime, yet popular approaches to sustainability through extended use, describe giving garments multiple lives (for example, Fletcher, 2008). Arguably, defining the garment lifetime as ownership, reinforces what has been criticised as the inherently anthropocentric viewpoint of sustainable development (Fry, 2009). Instead, the notion of 'custody' to replace ownership is discussed.

Clothing Use

There is a lack of research into consumer use of garments, but that field is growing. The available data goes some way to detailing the use phase of the garment within the lifetime by explaining reasons that garments are either kept and worn or discarded (Laitala & Klepp, 2015; Woodward, 2007). Different garment types, and garments for different occasions, are worn by people of different demographic profiles, are used with varying intensity and have different life expectancies (Langley, Durkacz, & Tanase, 2013). The nature and duration of use have environmental impacts that might be mitigated through a design process that includes greater consideration of garment use.

Clothing Lifespans

The duration of the garment's use phase varies considerably but is generally longer than all phases of production combined. Following a review of the literature, Laitala and colleagues discuss the wide difference in the reported average lifespan of clothing. A general range from 1 to 7 years is cited, with exceptions noted for specific garments like skirts and dresses that may be worn for 15 years. This variation they attribute to the differing methods of data collection. (Laitala, Hårvik, & Klepp, 2014). While fashion trends may pass quickly, garments are not typically replaced at the same rate. Instead, a fashionable appearance is maintained by styling existing garments with new acquisitions (Woodward, 2015).

In contrast to its duration of use, a garment typically takes less time to produce. While the manufacture of the textile may take over twelve months (in the case of some natural fibres), a garment may be designed, manufactured, distributed to market and sold to the consumer in a matter of weeks (Cline, 2012). However, within a garment lifecycle assessment diagram, all phases within production are represented equally to that of use. Adjusting the segmentation of the phases of the garment lifetime within a lifecycle assessment model to better reflect the comparatively shorter duration of production compared to use, would indicate to the designer the significance of the use phase within the garment lifecycle. So amended, the diagram becomes a tool through which existing strategies for sustainable product development might be extended to design for sustainable use.

Extended Clothing Lifespans

Design to extend the lifespan of clothing is one design strategy for sustainability that follows from analysing garment use. Research has shown that extending the life of a garment by as little as three months leads to a 5-10% reduction in each of the carbon, water and waste footprints (WRAP, 2012). This saving occurs through the conservation of energy and materials where the need for new clothing is reduced and by withholding garments from landfill. WRAP suggests that only modest changes across the clothing lifecycle are needed to reach this figure: production and fibre choices, life extension, laundry practices, re-use and recycling. They argue that the technology to implement these changes already exists and from a production perspective, need not dramatically increase costs or retail prices (WRAP, 2013).

However, industry-led sustainable fashion design strategies tend to focus on the phases of production and end-of-life-scenarios (for example, see H&M Group, 2017). Indeed, some sustainable fashion design resources position design for sustainable use practices beyond the direct influence of the producer (Brismar, 2015). Yet the inclusion of spare buttons with a shirt makes its repair possible, and trousers with an elastic waistband accommodate a changing waistline. A limitation of lifecycle assessment as a framework for sustainable design intervention across the entire garment life cycle is that it does not elaborate on the sub-phases of use with the same detail as it does for production. To successfully design for an extended use phase, fashion designers need more information about how fashion garments are worn.

Patterns of Clothing Use

In a study undertaken in 2001, Klepp identified a common pattern in clothing use despite the complex differences between garment types and the occasions for wear. Between acquisition and discard, the garment is typically worn and rested for periods before it is put aside for potential disposal (Figure 2).

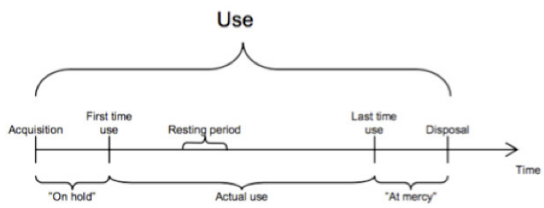

Figure 2. Diagram of The Lifetime of Clothes (Source: Klepp, 2001).

The division of the use phase of the garment lifetime provides critical information to fashion design for sustainability not captured in a typical lifecycle assessment diagram. That garments are used and rested is important to design in relation to both function and fashion: Where garments are rested because they need dry cleaning or ironing, might they be designed for less labour-intensive care practices? Where garments reflect the very latest fashion taste, might they be designed to be modular so that components can be removed and interchanged once the trend has passed? Particularly, when a garment is ‘at mercy’ of disposal, what design strategies might enable tired garments to become fashionable again and return to active use? Integration of the sub-phases of use into a lifecycle assessment model would better enable designers to connect decisions made within the phases of production to outcomes that manifest in use.

A New Garment Lifetime Diagram

The Garment Lifetime Diagram proposed in Figure number 3, integrates Klepp’s Lifetime of Clothes Diagram (Figure 2) and Payne’s Lifecycle Assessment diagram (Figure 1). The use phase of the garment lifecycle is divided into four sub-phases: first time use, resting period, last time use, at mercy. The subsequent phase of reuse and recycling is elongated to indicate the potential to extend the lifetime of the garment by these measures.

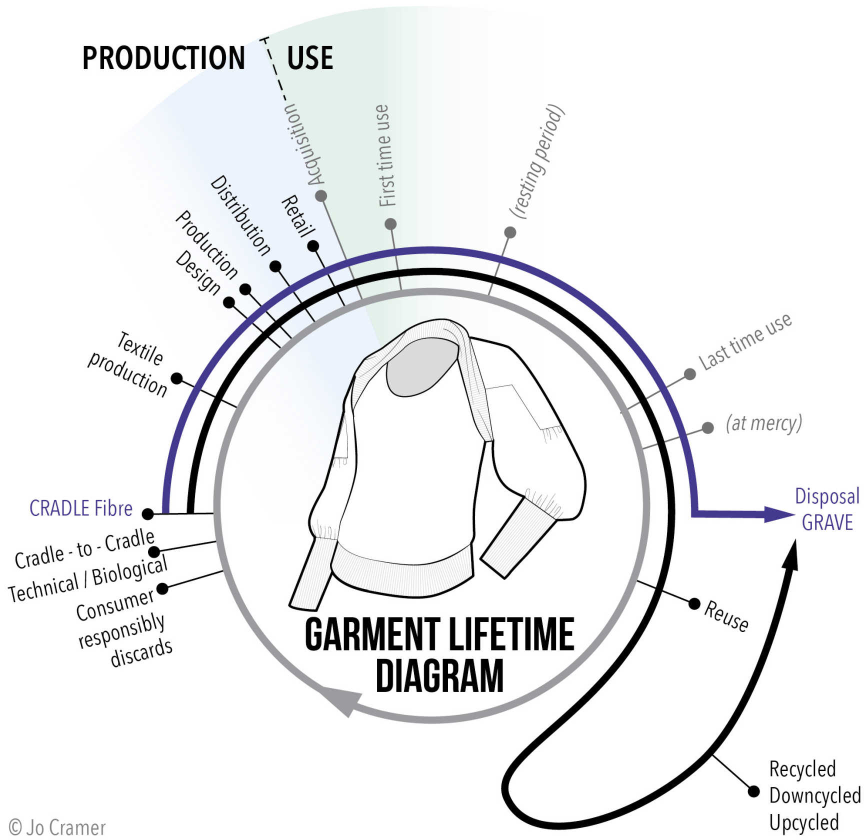

Figure 3. The Garment Lifetime Diagram Includes Sub-Phases of Use Within the Lifecycle (Source: Author).

The introduction of a time scale within the diagram changes the title from a lifecycle assessment diagram to a lifetime diagram. Further, the revised title acknowledges that this is not a scientifically derived model, but rather a theoretical one (at least so far).

Single or multiple lives?

Clothing that is worn by a subsequent owner is popularly described as having a second life (Figure 4). However, as the Garment Lifetime Diagram shows, describing an extended life as a subsequent life, mis-represents the actual garment lifecycle that is, in fact, a single lifetime inclusive of the garment being remodelled, repurposed or changing hands, before final disposal. The assumption that the garment life is synonymous with ownership is anthropocentric and therefore undermines the value of the garment artefact beyond its role in the formation of the purchaser's individual identity. Instead, reconceiving garment ownership as temporary custody, may encourage fashion design strategies for sustainability that look beyond the initial use phase to design for the possibility of subsequent use phases.

Figure 4. On this clothing donation bin, one-time ownership of a garment is synonymous with a garment lifetime (Source: Author).

In the following section, the application of the Garment Lifetime Diagram to a conventional fashion design process is discussed, for its potential to inflect existing practice to design for the extended use of fashion garments.

Fashion Design for Extended Use

Existing Extended Clothing Use Practices

Consumers have embraced garment re-use and recycling as methods of practicing fashion sustainability, yet frequently garment qualities inhibit rather than enable what action might be taken. For example, a narrow, densely overlocked seam provides no scope to let out a tight waistband. Similarly, while it is common for garments to be passed on through second-hand channels, fashion garments are not typically designed for extended use by different wearers. However research shows that fashion garments are more likely to be donated to charity than other types of clothing (Laitala, Boks, & Klepp, 2015; Weber, Lynes, & Young, 2017). Thus, the extended lifetime of a fashion garment describes both the purchaser wearing the garment for longer, and/or the garment changing hands from one wearer to another. This leads to the question, how might garment custody be facilitated by design?

Consideration of the Garment Lifetime Diagram in relation to a specific garment type, target customer and market level, can inform a design process that predicts the likely wear of the garment, and designs in the capacity for future adaptations that may be necessary or desirable. Including a capacity for change may help the garment keep pace with the changing needs of the wearer, therefore postponing obsolescence and disposal. In addition, those strategies that may extend first time use, may facilitate re-use by a second or third wearer. The final sub-phase of use when the garment is 'at mercy' of disposal is especially ripe for design intervention. At this stage, various actions of repair, repurposing and remodelling can reinstate the garment to active use. In Figure number 5, a number of alternatives to disposal are shown for a garment that is at mercy of divestment from the wardrobe.

A Living Wardrobe

After-sales services in garment repair and remodelling are experiencing a resurgence in popularity (for example, Eileen Fisher; Nudie Jeans Co.). However, the design of fashion garments with provisions for future remodelling has not yet been explored in any depth by fashion brands. The doctoral, practice-led research project within which the Garment Lifetime Diagram was produced, explored how garment remodelling as a practice of fashion design can enable both designers and wearers to act on their shared responsibility for the sustainability of the garment lifetime. Having identified the single garment lifetime, the project focused on designing for the various needs of changing custodians across its lifetime.

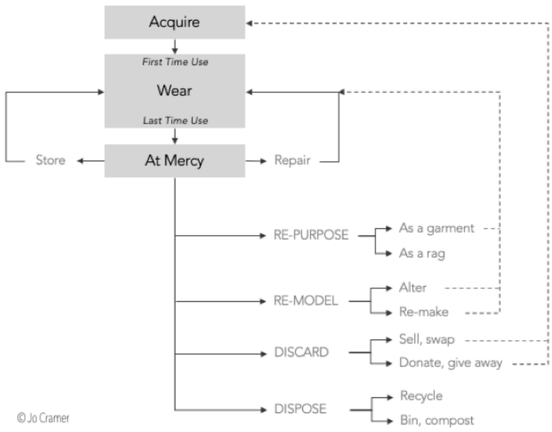

Figure 5. Garment Use with Divestment Options Including Methods of Extended Use (Source: The Author).

The outcomes include a series of prototype garments with capacities for repair and alteration to transform both the fit and visual appeal of the garments (Figure 6). Development of this *Living Wardrobe* further explored a redirection of the conventional fashion design process to predict and design for likely use (Fry, 2009). The findings highlight unrealised potential for the physical garment artefact to support sustainable use practices (Cramer, 2019 forthcoming).

Use Forecasting

Extending the conventional fashion design process to include consideration of garment use might be approached as a type of 'use forecasting'. Just as a designer researches trend forecasts to inform the visual appeal of the design in development, so too might they forecast the likely future use of the garment and design accordingly. A range of lifecycle assessment tools now exist to assist designers to evaluate the potential impacts of products in development (for example, Ecoinvent). As research into clothing use patterns deepens, it is feasible that in the future, quantitative measures may be developed to assist designers predict likely garment use also.

Conclusions

The Garment Lifetime Diagram (Figure 3) evolved through my doctoral research project that investigated ways of designing for extended use and found existing models of the garment lifetime lacking. Despite detail of the phases of production and end-of-life scenarios, the possibilities for intervention for sustainability in the phase of use are concealed.

Figure 6. Detail of an Outfit Comprising a Modular Top and Adjustable Culottes from The Living Wardrobe (Source: The Author).

This is consistent with the limited and widely variable information available on clothing use practices. Nevertheless, useful information exists about general patterns of clothing use that when referenced alongside LCA, provides a more holistic perspective of the garment lifecycle. Further, the Garment Lifetime Diagram makes visible the opportunities a designer has to direct design for sustainability in both production *and* use.

The Garment Lifetime Diagram is in its first iteration. By sharing it here, the author seeks to initiate a conversation with peers both within and beyond the discipline of fashion design that will hopefully see the diagram revised and improved. For example, the phases within the lifecycle may be more accurately distributed and the subphases of use defined alternately and in more detail. Application of the diagram to a specific market context for which LCA and user data exist, could result in a scientifically proportionate model. These are exciting areas for future research.

In the short term, the author is interested to develop a 'use-forecasting' resource to assist designers embed consideration of future use into their existing fashion design practice. Designing garments to be worn, repaired and altered by a series of wearers can shift the focus of design practice from a short linear lifecycle to an extended circular lifecycle, investing in those garments value beyond the seasonal trend for which they were created.

Acknowledgments

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Product Lifetimes And The Environment

What Businesses Might Benefit from Product Repair? Insight from Different Stakeholders

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Keywords: Business Innovation, Commercial Repair, Repairable Products, Repair Services, DIY Repair.

Abstract: Repair represents a more sustainable alternative to disposal as it maintains the functionality of products, whilst improving resource security and material efficiency. However, consumers may face a wide range of difficulties when making repair decisions due to uncertain residual life, the inconvenience and high cost of repair, concerns about access to information in repair manuals and service quality. Businesses are often considered responsible for these problems. This paper presents preliminary findings on how innovative business activities could resolve these issues and how business might benefit from these activities. Opportunities for, and challenges to, the adoption and execution of the activities are also discussed based on the practices of five businesses interviewed from three industries: furniture, textiles, electrical and electronic goods. The findings offer an insightful base for an upcoming study, with a larger sample, which will provide evidence for business stakeholders interested in developing commercial activities with a greater focus on product repairability and repair services as a form of business model innovation, and for policymakers to regulate and support commercial repair.

Introduction

The current linear economic model has been successful in creating low-priced and on-trend products but at the cost of shaping lifestyles that demand fast and unsustainable consumption. The benefits of product repair have recently generated interest among the general public in initiatives and political discussion with regard to transforming the throwaway culture (Cooper & Salvia, 2018). In particular, the Repair Café Foundation has witnessed an extraordinary increase in the number of worldwide registered repair cafes: 1,040 in 2016 and 1,800 currently. Over 25 community repair groups across the UK stood up for more repairable products in The Manchester Declaration hosted by The Restart Project (2018). The latest report of the Committee on Climate Change (CCC, 2019) recommended households to purchase good quality products, use them for longer and try to repair rather than replace them as influential means to achieve the 2050 carbon emissions target.

Indeed, nearly 20 states of the USA had introduced Right to Repair legislation by 2018, and more will be considering it this year. VAT reduction on repair work and tax allowance for households were introduced by Swedish Government in 2017 and Czech Government in 2019 to encourage both consumers and businesses to repair broken items. However, these financial initiatives are conditionally applied to several types of products. Two protests, in December 2018 and January 2019 in Brussels, called for EU member states to defend the right to repair. As a result, manufacturers would be encouraged to produce more easily repairable and longer-lasting products from April 2021 (EEB, 2019). Nevertheless, this rule only considers a specific set of electronics products, including lighting, TVs, washing machines, dishwashers and fridges. Furthermore, only repair professionals will be licensed to access spare parts and repair manuals. In other words, these initiatives will not benefit independent repairers, repair cafés and users and facilitate their repair work. In the same vein, a mixed-methods behavioural study on consumers' engagement in the circular economy, funded by European Commission (2018), reported that the inconvenience of repair is one of the most dominant barriers, just after the cost factor. In addition, the European Commission's Joint Research Centre (JRC, 2019) has developed both generic and product-specific scoring systems for repair which would incentivise innovative changes in product design, repair facilities, information and other forms of support.

These transformations appear to require a comprehensive engagement of business stakeholders, including material suppliers, manufacturers, retailers and repair service providers. However, each stakeholder seems to have a distinct business strategy towards keeping up with - and gaining competitive advantage from - improvements in technology, changes in fashion, consumer demand and cost efficiency. Business model innovation, in theory, is an important lever to create/ sustainable strategies. Lüdeke-Freund (2010) argued that a sustainable business should generate ‘superior value’ to customers and be instrumental in the sustainable development of the company and society as a whole. Similarly, an innovative business model for sustainability should seek to create considerable positive benefits for the environment and society (Bocken et al., 2014). In other words, providing repairable products and commercial repair services should be beneficial not only to consumers but also product and service providers.

This paper presents preliminary findings of opportunities for, and challenges to, the business alignment of sustainability, profitability and competitive gain through a greater focus on product repairability and repair service development.

Research methods

A literature review was conducted to identify current and potential business activities that are expected to improve the repairability of products and promote repair services. Figure 1, below, shows nine cards of business activities that emerged from this review.

Figure 1. Cards showing business activities promoting product repairability and repair services.

Each card presented a business activity, its description and potential narratives. The first card addressed product features and design strategies, whilst the next two were related to the provision, availability and accessibility of information. The remaining cards included services offered during the use of products.

A qualitative approach was adopted. Initially it helped to investigate the complexity of views of different business stakeholders in the three industries. The businesses were chosen for this research as their products account for the highest proportion of annual bulky waste in the UK, although more than 50% of discarded items can be reused directly or after slight repair, reported by the UK Waste and Resources Action Programme (WRAP, 2012). Second, qualitative methods provide rich data with deeper insights into business practices than a quantitative approach and explain them in detail. In particular, tailoring interview questions with the use of 'business activity cards' was beneficial to exploit their full stories of conducting one or more of the nine proposed activities, as each business has its own strategy, constraints and opportunities.

Five semi-structured interviews were undertaken with different business stakeholders. Table 1 lists the companies' code, description and related information. Convenience sampling method was employed; however, the variety of industry sector, company size and business stakeholder were taken into consideration. The interviews were conducted between 40-60 minutes and focused on these two questions:

i. What are actual and potential benefits of the proposed activities to the focal business and its stakeholders?
ii. What are actual and potential challenges to the adoption or execution of the proposed activities?

Business code	Description	Interviewee's position	Products studied
BU1	• Swedish-founded multinational group • Retailer of ready-to-assemble furniture, kitchen appliances and home products	Sustainability Developer	Wardrobes, chest of drawers, sofas and armchairs, tables and desks, chairs, cabinets and bookcases
BU2	• British brand of electrical appliances • Target markets in the UK, Australia, Israel, India, China and other Asian countries	Director of Product Development and Chief Strategy Officer	Kettles, toasters, cookers, blenders, irons and vacuum cleaners
BU3	• Swedish fashion company, focusing on denim products • Target markets in Sweden, the UK, Austria, Japan and the US	Environmental Manager and Sustainability Coordinator	Jeans
BU4	• Family run firm with over 30-years' experience of restoring furniture in Nottingham, including French polishing, hand stripping, lacquer and wax finishing, spray painting, colour matching and general repairs • Certified by The Guild of Master Craftsmen	Owner-repairer and 12-year experienced repairer	Dining tables and chairs, cabinets, bookcases and wardrobes
BU5	• Local electronics repair business • Family run electronics repair firm with two branches in Nottingham	Owner-repairer	Phones, tablets, laptops and computers

Table 1. Description of sample.

Key findings and discussion

This section reveals practices relating to the proposed repair activities that emerged from the interviews.

Repairable products and co-design

A focus on design characteristics is a vital solution for product repairability and the possibility of the other proposed activities at grassroots level. However, repairability may vary for different products. For example, denim fabrics are so durable that company BU3 can repair jeans five times or more during the products' lifetime. Even when they are severely worn, repairers can add several layers or stitch decorative frames to necessary places. An online platform is used to collect and keep diaries of repair jobs done at stores in different parts of the world, aimed at the continuous improvement of product design and customer service. The gathering of feedback from repairers and customers is expected to support the co-design process for future products. The firm believe that efforts to make repairable products and repair them help to improve customers' satisfaction and brand loyalty.

When it comes to flat-packed furniture, company BU1 expected to design products not only for assembly and disassembly, but for repairability. The organisation correspondingly developed a co-design guide for a circular economy that requests product designers, developers and engineers to go through a set of criteria, including repairability. Nevertheless, a new supply chain model must be established and piloted to proactively provide spare parts and tools for repair services for products out of warranty and consumers' self-repair. Not all of these investments would be worthwhile if consumers prefer to purchase cheap or the latest products rather than repair outdated or antique ones. This has led to a gradual decrease in customers coming to BU4 and the closure of similar local businesses.

In contrast to clothing and furniture products, designing repairable electrical items can appear more complex. The representative of company BU2 explained the situation of independent repairers and consumers being prevented from disassembling components of small kitchen appliances due to safety concerns. For instance, these processes and repair work may require breaking seals between parts, which may lead to water or food leaking, damage the machine and cause electric shocks. Likewise, when certain components are glued or sealed, mobile phone design hinders disassembly and repair work by consumers and local repairers such as BU5.

Design for 'safe-to-repair' is likely to be opposed on grounds of the manufacturing cost. As most products of company BU2 are produced in the Far East by third parties, on an enormous scale, any customised change of design could generate unexpected costs for the brand. Moreover, one of the organisation's studies reported that energy efficiency is preferable to durability. Their current product design and marketing tactics have been influenced by this finding. Furthermore, the company also asserts that there is a dearth of evidence of a reduced carbon footprint arising from repair compared with replacement by energy-efficient products. For these reasons, repairability is currently not a priority in the company's strategy and that of its business partners. A top-down intervention from government is essential to foster collaboration between stakeholders to enable product design for repairability.

Diagnostic and repair manuals, and instructional support

Diagnostic and repair manuals have potential to save time, ensure the ease and safety of repair work, and increase the confidence of fixers. Company BU3 provides repair booklets, attached to repair kits, for free distribution by post. They also claim to be very responsive to customers' emails and comments via social media regarding instructional support for repairs. However, these instructions appear to be flexible and require creative decisions. For instance, they depend on users' preferences, the size, position of holes, and the colour of the garment. Likewise, the promising role of repair manuals in furniture longevity was indicated by company BU1. Its representative believes that repair manuals for furniture do not need complicated instructions, particularly on fault diagnostics unlike electrical and electronics items. However, according to BU4 these manuals need to be visual to encourage customers to try DIY repairs because these may be time-consuming and challenging to inexperienced individuals.

By contrast, manufacturers of electrical and electronic products seem to encourage consumers to conduct frequent maintenance to prevent faults. For example, company BU2 includes product care information in users' manuals, to instruct them to remove vacuum cleaners' filters for cleaning or to descale kettles for maintenance. Due to safety concerns, their customers are recommended not to self-repair broken products. Repairability is not considered in the businesses' interest, and currently they are not willing to put effort and resources into redesigning products for repair and related activities.

Promotion of repair benefits and repairable products

Product repairability and the benefits of repair can be customised to marketing strategies and tactics to increase brand awareness. Company BU3 successfully applies both offline and online communication methods, including paper booklets available at stores, social media and website content, to share tips and hints on product maintenance, repair and reuse. Moreover, the interviewees stated that fabric materials shown in display windows and sewing machines' noise at stores efficiently promote free repair services in their own way. The brand is also differentiated due to an attractive new marketing model - Mobile Repair Station on Tour - which brings repairs to high street shoppers to raise their awareness of repair benefits in the UK and overseas.

Company BU1, for a similar purpose, has piloted learning spaces and workshops on how users can take care of, repair and upgrade products. Visitors are instructed and allowed to fix their broken items at no cost. On the other hand, the upscaling and multiplying of these initiatives may be problematic due to the substantial requirements of workshop spaces, the availability of spare parts and machines, and the need for competent staff. The inclusion of repairability information on the product label is unlikely to be the first criterion that company BU1's customers consider when making purchase decisions. They often prioritise their needs and the price, followed by durability. However, consumers' preferences could change with the emerging wave of the circular economy, as evidenced by a recent growth in customers asking for replaceable covers for sofas. Furthermore, the attractive display of repairable products, in-store and online, and the use of everyday language for repairability information for consumers need to be considered, especially for technical concerns.

Repair over replacement within warranties

Encouraging and attracting both businesses and consumers to choose repair over replacement as a remedy in warranty claims may cause controversy for two reasons. Firstly, a straightforward replacement or refund is assumed to be an essential courtesy of the manufacturer or retailer. Secondly, there would be considerable costs for repairers, and reverse and forward logistics issues. As a result, both company BU1 and BU2 collect faulty products under warranty claims but choose distinctly different resolutions for these items. Although product repairability is currently not considered as a 'must-have' purchase criterion by company BU1's customers, they appear to be increasingly interested in how products are made. It also reported by the interviewee that there has been a remarkable increase in customers' enquiries about the repair work of returned products. Despite offering free repair services, in line with customers' predilection, company BU3 does not offer a commitment to return faulty items to their original condition.

Reuse and repair integration

The integration of repair and reuse aims to extend the lifetimes of unwanted parts and broken items by giving them a second life. As mentioned above, companies BU1 and BU2 offer a prompt replacement or refund for any warranty claim. At company BU1 recovery departments are responsible for the assessment of the faulty products' condition and whether they are to be repaired and resold as new or put in a 'bargain area'. At company BU2, by contrast, pallets of returned products are transferred to a third party, which independently decides either to repair and resell the items or dispose of them. Before disposal, parts may be harvested for future repair work. This service provider profits from the products sold in the second-hand market and recompenses company BU2 accordingly. Even so, many small domestic appliances brands appear to regard repair work as uneconomical for products priced under £40. Company BU3, conversely, themselves deal with old jeans collected from 'exchange schemes' in which customers can swap unwanted jeans for a 20% discount voucher for their next purchase. Traded-in pairs are either repaired for resale, repurposed into shorts and caps, or cut into patches to use in future repairs.

Exchange model and temporary replacement model

A temporary replacement may be occasionally offered for customers' use during repair work by companies BU1, BU3 and BU5, which helps to improve customer satisfaction with their repair services. Nonetheless, the interviewees from these three companies raised a concern about substantial investments in the supply chain and logistics to facilitate this activity if it is offered to every customer. Another factor reported by company BU2 was that consumer behaviour towards receiving refurbished products for rental might vary across different products. In particular, most participants in its research tended to be against refurbished food processors but would accept refurbished irons. The company thus assumes that hygiene concern would be one of the most notable barriers to both the temporary replacement model and exchange model. In the latter, a repaired or refurbished product of an equivalent age, quality or condition is exchanged for the broken item. For electronics products, in the context of these two models, BU5 emphasised data protection issues, especially in phones, tablets and laptops. They occasionally provide only basic phones (serving calls and messages), rather than smartphones, for consumers to use while waiting for the return of repaired phones.

Fixed-cost model and fixed lead-time return model

The two models in this activity are expected to ensure the transparency of repair costs and duration. In other words, the cost and return time for repairs are fixed and independent of the nature of the fault. Moreover, the service quality and post-repair warranty also need to be taken into account by service providers. Nevertheless, this activity was not practiced by the interviewed companies.

Localised repair service network and shared data

Localisation of repair services may contribute to improvement of the service network, its responsiveness and quality assurance. Consumers can easily access repair services at all of company BU3's stores and repair partners. The store locator tool on its website eases customers' need to do research by pinpointing nearest stores. Moreover, the company is planning to accept repair requests by post to enhance the accessibility of the service. However, constraints on skilled staff and warehouses for materials and parts limit the upscaling of their repair services. From their viewpoint, repair service teams are the face of the entire organisation; thus, an online portal has been launched to collect information on each repair case, including a diary of product faults, customers' contact and feedback. Despite the richness of the data gathered, their analysis has not been utilised due to lack of human resources. Customer satisfaction data revealed that the lead time of repair services and work standard of new employees are current major concerns. Understandably, adding more staff and training would increase the operational costs of stores.

In contrast to company BU3, company BU1 does not currently provide any repair service for customers. However, it is in the process of mapping the necessary capabilities to apply this service logic and expects to gain value from it. In other words, a bigger scale of repair services for 'out of warranty' claims would need the comprehensive development of resources and competencies, including proficient repairers, an efficient spare parts and customer management system. Recently, the company bought an online platform that would have potential for outsourcing repair services by connecting local independent repairers and consumers. Consumers, nonetheless, may not want to spend time and money on repairs. BU4 witnessed unreasonable bargaining over repair costs and situations in which people came to dump broken furniture instead of getting it repaired.

In general, financial incentives from government, such as tax cuts in labour, parts and materials for repair activities and more supportive business rates relief, would be expected to maintain the repair market and attract more participants.

Transparent spare parts and tools supply chain

Problems with accessibility to spare parts and tools to facilitate repair work can be solved if they are either offered for free or sold either online or at local retailers. For instance, on company BU3's website customers can easily order a free repair kit, which will also be posted to their home at no cost. This ready-to-repair kit includes patches, a needle, a belt loop, threads and a repair kit booklet. Similarly, screws and joints are available in company BU1's stores for free or donation to charity, although major components, such as chair legs, are not provided to the public. The organisation is seeking a better solution for the logistics of these parts, i.e. transportation and warehouse management. A close partnership between third-party warehouses and company BU3 enables the storage and delivery of repair kits and patches for repair work.

Limited ranges of outer parts of company BU2's products, such as filters for coffee makers, kettles and vacuum cleaners, and lids and blades of food processors, are sold on its website. The brand's representative explained that accessibility to inner components of electrical products is risky to untrained repairers and consumers. He also doubted whether consumers would be willing to pay more for a 'safe-to-repair' product than a cheap one and to spend time on the repair work. In addition to improved access to spare parts, transparency of the supply chain would benefit independent repairers and consumers, enabling more reasonable costs for the parts. To demonstrate this, BU5 commented on unexpected price differences between Samsung's and Apple's phone components noting that the former has launched hundreds of models, compared to less than twenty of the latter, which leads to higher costs due to the smaller batch of each model's components. Lower and more transparent prices for parts may influence consumers' purchase decisions.

Conclusions

This paper presents preliminary findings on innovative business activities that could increase the availability and accessibility of repairability information and related services and improve product features and design strategies. Due to resource constraints, collaboration between different stakeholders (i.e. suppliers, manufacturers, retailers, repair service providers and consumers) is vital to ensure the sustainable supply of, and demand for, repairable products and repair services.

The principal motive for the adoption of both business innovation and collaboration would be the efficient alignment of sustainability, profitability and other competitive advantages. Potential benefits to stakeholders could be a sustainable revenue stream from business activities and enhancement of brand awareness and loyalty. Capturing these advantages could generate the rationale for investment in collaboration. Moreover, government legislation and financial incentives are essential to reshape the economy, change business practices and achieve sustainable consumption.

Further work is necessary to confirm these preliminary conclusions and explore more business practices.

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Circular Economy Business Requirements

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Abstract: In 2016 Philips launched its sustainability program Healthy People Sustainable Planet, and set the ambitious target to generate 15% of its total revenue from circular propositions by 2020. In order to achieve this target Philips not only defined to what extend existing revenues met circular criteria, but also defined on what steps would be required to improve the performance in the years to come. Additionally, Philips embarked on a broader journey of business transformation and capability building to sustain future growth after 2020. This paper explains how the concept of circular economy is being translated by Philips into actionable circular revenues and business requirements.

Philips Sustainability Strategy

Philips has a long sustainability history, stretching all the way back to its founding fathers; already early in the 20th century Philips employees benefited from schools, housing and pension schemes. Since the 1970s Philips focused on environmental sustainability and has since then constantly been looking for opportunities to improve its performance. In 1994 Philips launched its first Ecovision sustainability program including targets for its own operations and green products (Philips 2016). In subsequent programs the scope of the sustainability programs broadened and also the supply chain became in scope.

One of the first external commitments from Philips on circular economy was made in the Ecovision V program (2012-2015) by contributing to closing the materials loop via doubling the amount of recycled materials in their products. In its current sustainability program ‘Healthy People, Sustainable Planet’ (HPSP) (Philips 2016) launched in 2016, Philips addresses both the social and environmental challenges and including associated targets to be achieved by 2020. One of the targets is to have 15% of its total revenue generated by circular propositions by 2020, starting at a baseline of 7% achieved in 2015. In addition, through innovation across the health continuum Philips has the ambition to improve the lives of

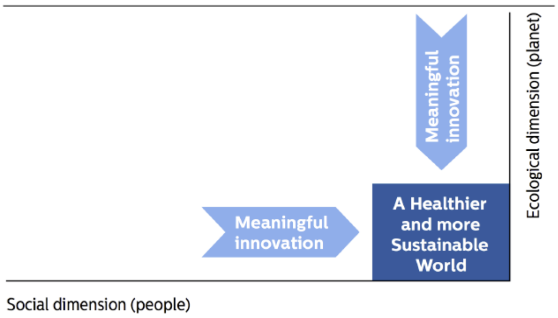

Figure 1. Program ‘Healthy People, Sustainable Planet’.

3 billion people annually by the year 2030 (Philips 2019a).

In 2013 Philips became a Global Partner of the Ellen MacArthur Foundation, a leading organization on the concept of circular economy (Philips 2017). Support from top management in the ambition to a circular economy is pivotal for success but also requires to make public commitments for action. Philips CEO Frans van Houten co-chairs the World Economic Forums Platform for Accelerating the Circular Economy (PACE). At the PACE capital pledge in January 2018 the Philips CEO publically committed that *“By 2020, Philips will fully close the loop on all large medical systems equipment that becomes available to us, and that we will continue to expand these practices until we have covered all professional equipment”* (PACE 2019).

To support the strategy and ambition on sustainability Philips employs over 30 dedicated sustainability professionals including a circular economy program team.

> *"At Philips, we fully embrace sustainability because of the benefits for societies, and because we believe that it is a driver for economic growth. That's why we have sustainability incorporated in our company strategy."*
>
> **Frans van Houten, CEO Philips**

Circular Economy as innovation driver

In Philips, innovation and sustainability are closely interlinked and circular economy is one of the innovation drivers. The corporate strategy is cascaded to business group sustainability dashboards with the following key performance indicators for target setting and measuring the transition towards circular economy

- Circular Economy project to drive exploration of new business (model) opportunities;
- Circular Economy revenue to drive the revenue from current propositions
- Circular Economy readiness by driving design and architectural change.

Philips has defined different circular revenues categories that can be applied to both the B2B health systems business as well as B2C consumer business, and allows to combine information from different businesses and customer relations into one single metric (€). These circular revenues are divided into three main categories; software revenues, service revenues and hardware revenues (figure 2). Although most of them have elements of service, hardware and software, this has been done to make them easier to understand and distinguish from one another. The revenue categories itself are defined using the Ellen McArthur circular economy framework and tailoring it to the Philips organization. Product- or service revenues that meet at least one of the defined circular revenue categories are included in the circular revenue calculation. The circular revenue can be expressed as percentage (%) of the total Philips revenue, resulting in the circular revenue percentage.

The application of recycled plastic in products is an example of circular revenue that support to close the materials loop. Philips launched its first products containing recycled plastic in 2010. By proactively partnering with suppliers, compounders and recyclers the organization has been able to gain more knowledge on how recycled content can be applied in product components, and stepwise improving its overall performance by adding new products with recycled plastic to its portfolio over the years. Early 2019 Philips pledged to apply 7600 tons of recycled plastic annually by the year 2025 (European Commission 2019). In the circular revenue metric only revenues from products are considered that have a minimum amount of recycled plastics content of >25% by total weight of eligible plastics. The recycled content from steel and aluminum is not considered as it is perceived an existing practice, and to ensure focus on application of recycled plastic. The Philips Performer Ultimate FC8955 is an example of a product containing recycled plastic. In this specific case the recycled plastic is sourced from a closed material loop recycling

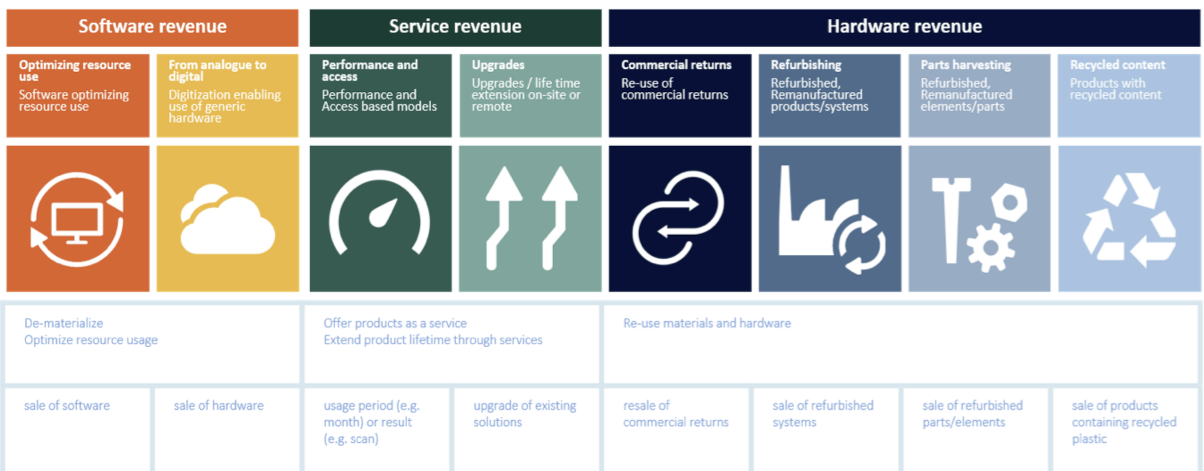

Figure 2. Circular revenue categories applied within Philips.

system where old Philips vacuum cleaners were collected in western Europe and recycled.

Figure 3. Refurbishment at Philips.

An example of refurbishment is the Philips Diamond Select program. This program offers refurbished healthcare systems where customers can benefit from state-of-the-art technology at a more affordable price (Philips 2019b). The refurbishment program of used Philips medical equipment started in the 1990s and has grown significantly over the years. By refurbishing, used products are upgraded to current high quality systems, and also allows to reuse vital components like magnets and x-ray tubes. As a result of the refurbishment program, the design changed over the years improving upgradeability. In order to be considered as circular revenue the refurbished products are required to consists at least of 30% reused materials; in practice most often the percentage reused accounts for 80%-95% of the product weigh.

The Philips PerformanceBridge is an example of how software can support in optimizing resource use. The Bridge is a flexible secure cloud based suite of services that provides analyst access to departmental performance including utilization rate, enabling efficiency in use of resource intensive hardware. Application of the Bridge results in a 20% reduction in time per exam (Philips 2019c).

Figure 4. Philips PerformanceBridge.

The long term strategic partnership between Philips and Jackson Health System is based on an Enterprise Monitoring as a Service (EMaaS) model where state of the art patient monitoring systems is provided for a per-patient fee (Philips 2018). This is an example of a performance and access based business model. A comparable partnership agreement has been made between Philips and Augusta

Figure 5. Performance and Access based model.

Health hospital in 2013 for a 15 year strategic managed services alliance to help transform care (2019d).

As part of the internal capability building each revenue category is explained including further detailing of the category specific requirements, typical stakeholders, enabling conditions and risk factors. An example for the Performance and Access based model is provided in figure 5
In the Performance and Access based model the revenue from contracts that include the condition that Philips has individual end-of-life responsibility for the product.

An example is the Philips Lumify, a flexible subscription service providing access to transducers, app and online ecosystem (2019e). The subscription service reduces upfront costs to help clinicians improve patient care. The ownership of the product remains with Philips or an affiliated financing company, who will repurpose it in a responsible way across its lifetime.

Figure 6. Philips Lumify.

If we further look into this example, the following steps are important for this circular category (figure 7):

- Step 1 Legal contract: Drafting appropriate contract with terms and conditions defining that ownership either resides with the manufacturer (Philips) or an affiliated financing organization)
- Step 2 First customer: The customer pays for the performance or the access to Lumify
- Step 3 Reverse logistics: Hardware take-back triggered at end of contract
- Step 4 Sorting and triage: Assessing quality of the returned Lumify, determining next cycle
- Step 5 Value restoration: Processing and cleaning the Lumify for following customer
- Step 6. Sales and next customer: The next use cycle begins

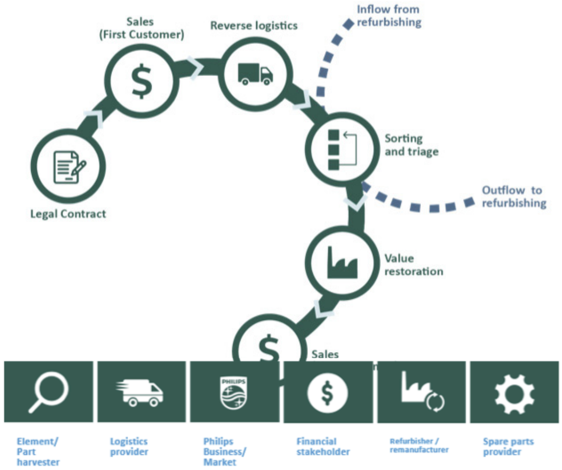

Figure 7. Visualization steps in Performance and Access based model.

The important stakeholders in this situation are:

- Financial stakeholder to help finance the transition from capital expenditure (CapEx) to operational expenditure (OpEx)
- Refurbisher & remanufacturer to process returned goods (used Lumify) for re-use
- Spare parts provider who provides parts for the installed base management
- Element/part harvester retrieving Lumify parts from installed base
- Logistics provider to deliver the Lumify to and back from customer
- Philips Business/Market Internal stakeholders operating this business model

Circular readiness

Circular readiness addresses how design and architectural changes can support the (future) generation of new circular revenues by e.g. enabling product take back and refurbishment of hardware or virtualizing software. So in practice by including circular readiness already at the design stage the costs for operation or costs when products are returned can be lowered, improving the overall business case for repurposing.

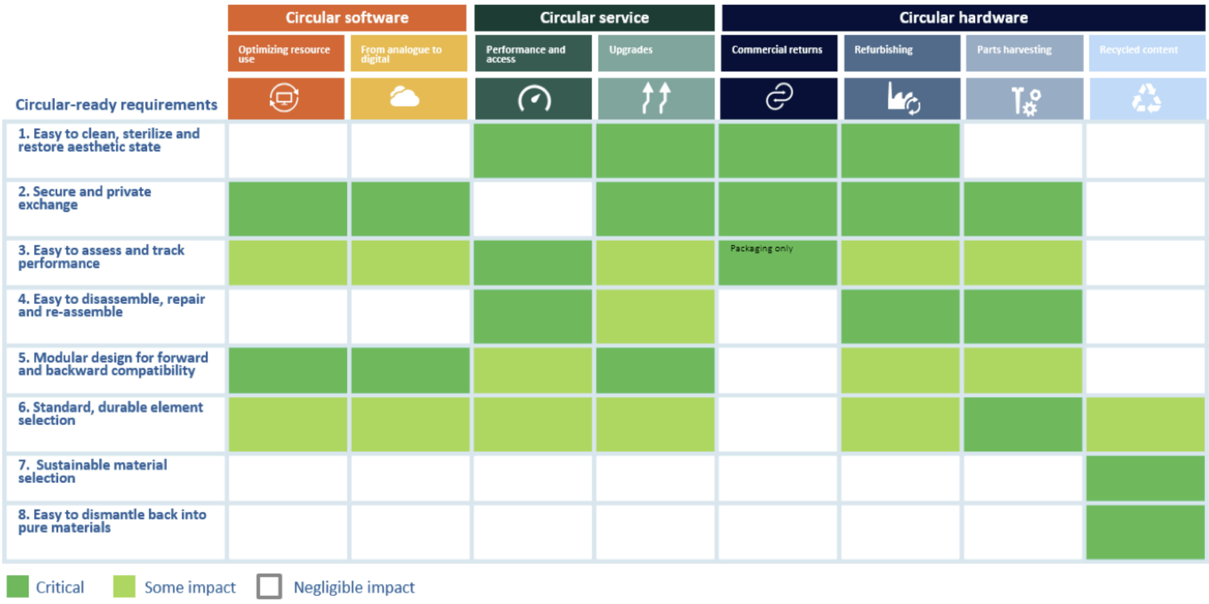

Figure 8. Interlinkage circular revenue and circular readiness.

A product that is designed for easy disassembling will ultimately reduce the cost for refurbishment, and positively impact the business case for bringing the product back to the market. Including circular ready requirements already at design stage enables growth of the circular revenues.

Figure 8 demonstrates how circular readiness and circular revenue categories are interlinked. The dark green color indicates the critical requirements for each circular revenue. The light green requirements are recommended. In this situation the business case for a product in 'performance and access based' will benefit if during design stage the easiness to clean, asses and track performance and repair & disassembly has been considered. Furthermore, modular design and a more durable component selection positively contributes as well. Further detailing of the exact requirements occurs at product (group) specific level. This detailing includes an analysis of the specific benefits for the company and customers, important enabling conditions and risk factors.

In the specific case of the Lumify the following circular ready requirements are perceived essential (figure 8):

- **Requirement 1: Easy to clean, sterilize and restore aesthetic state**: This requirement is critical to safe product sharing. When a Lumify user no longer needs it, Philips will rent it to a new user. Before doing so, it is critical that the transducer has been properly cleaned and that potential scratches have been fixed. This will help generate the needed trust of the user that the product is of a good quality.
- **Requirement 3. Easy to assess and track performance:** This requirement is critical to management of products, so-called fleet management. In this model Philips remains the owner of the Lumify and therefore has an interest in keeping it in use and in a good state for as long as possible. This can be done by keeping track of it, monitoring if it is due for servicing, if it is used correctly and according to what the user is paying for.
- **Requirement 4. Easy to disassemble, repair and re-assemble***:* This requirement is critical for optimal fleet performance. If a Lumify needs repair or when it needs refurbishment, is has to happen in an efficient way, keeping costs low and ensuring it can quickly return to the user, preventing usage downtime.

Each requirement is further detailed in so-called design factors. The relevant design factors for requirement 1 Easy to clean, sterilize and restore aesthetic state includes the following design factors:

1.1 Will the end user be confident that the products have a high quality of hygiene?
1.2 Will the product withstand many cycles of cleaning and sterilization?
1.3 Will the dismantler be protected from contagious or hazardous content?
1.4 Will the dismantler be able to disinfect the product with standard tools and methods
1.5 Is the product designed so it maximizes cleaning efficiency? Is a long life cycle ensured by 'age with grace' materials?

Altogether the selected circular revenues define the circular ready requirements and the design factors. The Lumify would at least have to be modular designed with forward and backward compatibility, and standard durable element selection to decrease the operation costs (requirement 5 and 6).

Circular Economy design constraints

During the development of a circular ready product the designer and product architect will have to deal with constraints. A product designed for improved durability is designed to withstand typical use cycles for a longer period of time than normal other similar products available in the market. Objective of creating a more durable product is to decrease the average field call rates for the durable product. Designing a more durable product might entail cost implications making the product more expensive. In order to achieve durability, the product might have been designed using less connections, or maybe the opposite using more connections to secure stability, influencing the reparability of the device. Also the opposite might occur; a product designed for reparability might be less durable. The product might also have been designed using more or less sustainable materials to ensure durability. For product segments with fast moving technology (extra) durable designs might have no or very limited benefit since technology will outdate quickly.

Another example of constraints is the application of chemical substances. At end of the first use cycle or total product life, the presence of certain chemical substances might hamper placing the product on the market after refurbishment when these substances have become subject to new regulations.

Product specific requirements can also be a constraint, like for magnetic resonance (MR) scanners. The magnetism influences the material options available, metals cannot be applied. The MR signal can also not be negatively influenced by impurities.

Another example is related to X-ray solutions like computed tomography (CT), mammography, where the application of lead is required to shield of the x-rays, yet lead is a toxic material and not desired in circular solutions.

Circular Economy business transformation

Transforming towards circular economy requires capacity building in the functions and roles that contribute to the overall product and market proposition. Awareness creation is often not sufficient; a dedicated (online) training per function and role is required to ensure the circular economy concept and potential is fully understood.

To ensure the concept of circular economy and readiness is fully understood, Philips created several trainings including full day workshops for the design and architectural community and relevant business functions who define the business strategy and -model. In a physical interactive workshop setting the concept is explained including how circular economy can be applied in daily work. The training addresses both Value Proposition Creation (VPC) and Advanced Development (AD)/Explorative (EXP) projects. The VPC part focusses on the circular revenue business model aspects, while the AD/EXP focusses on translating this into an actual circular designs. As a follow up of the workshop design specifications are created for embedding in the (future) product roadmap(s).

Conclusion/recommendations

Circular economy is an umbrella term that can be associated with countless aspects of sustainability. In order to ensure circular economy can support the organization in their ambition, the concept requires translation in the organization specific 'language'. In this case Philips choose for the different circular revenues buckets allowing to measure the performance of separate businesses. It has to be noted that in larger organizations the different businesses might apply their own 'language'' and tendency to work and think in silos hampering effective transformation at an equal pace. Applying Circular Economy principles will challenge the organization to break through these silos. As an example marketing teams for new medical equipment have to team up the with marketing teams that work with refurbished medical equipment to avoid cannibalism in the same market segment. This requires to translate the concept into the language that different roles speak and turn this into stepwise actionable requirements.

Circular Economy demands a holistic organizational approach including design, innovation and development team, marketing and business leaders, but also external partners who e.g. handle logistics. The concept of circular economy product design cannot be separated from business model explorations. A business model without a circular economy ready solution is doomed to fail. And a circular economy ready device that is not combined with business model exploration likely ends up in a third party having the advantages/benefits from the circular economy product improvement.

Organizations that tend to use life cycle assessments as the single guidance for setting design priorities in the environmental performance improvement might also struggle with the circular economy concept. Typically, energy consumption is the key environmental impact accounting for 2/3 or more of the total impact. Energy improvements that can be achieved in a next product outweigh the benefit that can achieved from more circular designed products. As an example the benefits of applying recycled plastics might be negligible when looking purely at the environmental impact, but has a significant impact on the closing the materials loop.

Acceptance of trade-offs is crucial, and also the fact the circular economy does not exclusively entail long lasting products that never go the waste. Extending the life time of components can be more useful than repair and refurbishment. Re-use of components can result in significant cost and use of resource to clean and prepare the component for a new cycle. In specific case a linear business model with good product recyclability might be the best circular economy solution for the moment

It should also be accepted that pending the angle on how the product is approached different circular economy business requirements prevail. The hygienic aspect of a medical device is different from a vacuum cleaner. Tailoring requirements per business and product group requires some effort but pays off by ensuring the requirements can be practically applied.

When reaching out to the different design and architect communities it is interesting to observe the positive vibe that brings the concept of circular economy and willingness to learn and seek for opportunities how to apply the concept. The transformation is not an onetime effort. A follow up plan, creating internal (online) centers of competence or expertise where problems and solutions can be shared inspires the community.

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Data-driven Decision-making Instruments to Support Circular Product Design

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Keywords: Circular Product Design; Product Lifecycle Management; Data-driven Decision Making; Sustainable Product Development; Digitalization.

Abstract: The accelerated population growth and the economic activity boost experienced within the second half of the 20th century has put human activities in the spotlight as principal agent of change for many biophysical indicators on the functioning of the planet. Circular economy (CE) has been proposed as an enabler of sustainable development, allowing humans to thrive economically without overshooting the planet's carrying capacity. Strategies embedding circularity into product design hold a lot of potential, especially the decisions made during the early phases: it is estimated that 80% of a products environmental impact is determined during its design phase. At the same time, circular product design can benefit from the growth of digital connectivity in manufacturing environments, making it possible to foster data-driven decision-making. To integrate a circular vision for middle-of-life and end-of-life product phases into the design phase of products, the data captured by Product Lifecycle Management (PLM), the main companies' strategy to manage products' lifecycle information from cradle-to-grave, could be leveraged. Regardless of the promising synergies between circular product design and PLM systems, some barriers still need to be overcome in order to unlock its potential. The study aims at identifying suitable decision-making instruments able to use PLM data to inform circular product design through a literature review and feedback from practitioners.

Introduction

The consumption of resources by humanity has historically followed a linear sequence based on taking-making-using-disposing. The pressures emerging from exponential population growth combined with linear consumption patterns threaten the planet's carrying capacity by overshooting the critical thresholds established for key biophysical indicators (Rockström, 2009). Circular economy (CE) is an emerging economic model that aims at decoupling economic growth from resource consumption by keeping materials at their highest value form in a closed-loop flow within economic systems (Haupt & Zschokke, 2017). CE has often been operationalized as a hierarchy of several value retention strategies (Rs) to be implemented at different stages along the value chain of products. Models have evolved from identifying 3 Rs (Lieder & Rashid, 2016) to distinguishing up to 10 different Rs (Reike, Vermeulen, & Witjes, 2018). Considering the model proposed by Reike et al., (2018), consumers and businesses can decide among 10 different options in order to turn their products' lifecycle from linear into a circular one. The hierarchy of strategies includes, from shorter to longer material loops, *reduce, refuse, resell/reuse, repair, refurbish, remanufacture, re-purpose, recycle materials, recover energy and re-mine*. The hierarchical ranking of these strategies implies that preferable options are those that originate shorter material loops. However, consideration of impacts of different Rs are scarce in the practice (Reike et al., 2018). This might lead to product designs that fit into the definition of circularity but provide limited sustainability outcomes. Even more so, sustainability rebound effects linked to applying the definition of circularity might emerge too (Zink & Geyer, 2017). In order to prevent this, this paper argues that designers interested in embedding circularity principles in products should make design decisions based on actual product data considering the entire lifecycle. Because it has consisted of the main companies' strategy to streamline information flows between all the stages of the product lifecycle, this research aims at exploring the role Product Lifecycle Management systems (PLM) have played to date to guide decisions on sustainability performance during the design phase of products. In addition to that, the scope of this research includes the identification of existing decision-making tools developed in the context of sustainable product development literature. These two aspects have been explored through a literature review on decision-making tools (the 'data needs') and PLM applications (the 'data sources') and the results have been contrasted with the input collected from a set of six sustainable product development practitioners.

Methods

The approach of this research consisted in combining the insights collected by means of a literature review and six semi-structured interviews. For the literature review, two different query strings were built by surveying the keywords of 30 relevant papers exploring the intersection of sustainable product development and PLM. Synonyms were added to these strings and Scopus was chosen as the search engine for being considered one of the largest abstracts and citation databases of peer-reviewed literature, including scientific journals, books and conference proceedings. The two resulting subsets of literature (the first, identifying decision-making tools in sustainable product development, n_1=53; the second, identifying PLM use-cases for sustainable product development practices, n_2=131) underwent practical and content screen and were enriched by means of snowballing technique. Finally, qualitative content analysis was conducted to n_1=45 and n_2=65 papers, focusing on the literature proposing methods and frameworks that had been applied in the sustainable product development context. In n_1, the identified decision-making tools were clustered according to core method and source of sustainability data. In n_2, PLM use-cases coupled to sustainable product development were clustered according to lifecycle phase addressed and PLM dimension involved. A pool of six experts working for at least three years in sustainable product development in manufacturing companies for built environment, automotive, telecommunications and utilities sectors was interviewed through semi-structured interviews. Interviewees' role consisted of design engineers or eco-design experts working in engineering teams to assure they had hands-on experience with managing data required on environmental impacts of products' materials and components. The insights from interviews were analyzed through theoretical thematic analysis (Braun & Clarke, 2013) and generated initial themes around decision-making methods and tools used, data sources and PLM.

Results

Decision-making methods in sustainable product development and sustainability data sources

From all the papers reviewed, 44% of the tools used methods based on Life-Cycle Assessment (LCA) indicators. The second most mentioned types of methods were those based on Multi-Criteria Decision Making (MCDM) (22%) (i.e. Buchert et al., 2015; Chandrakumar & Kulatunga, 2017). The third most mentioned type of method consisted on various Design optimization tools (15%) (i.e. Kwak et al., (2009), based on mathematical programming, allowing to favor certain end-of-life pathways at early design stages); and Knowledge-based Systems (11%) allowing the preliminary filtering of design alternatives (i.e. Zarandi, Mansour, Hosseinijou, & Avazbeigi, 2011). Finally, Quality Function Deployment methods adapted to environmental performance accounted for 4% of the publications. A last group accounting for the 4% of publications used other methods, not matching any cluster nor forming any cluster among themselves. The prevalence of these results is aligned with the answers collected from experts, who mentioned LCA as a common assessment tool under which decisions are made, even though simplified and streamlined versions were applied in many cases. MCDM approaches were mentioned as a common practice in two cases, providing the advantage of streamlining the inputs from cross-functional teams. The majority of interviewees noted that even though environmental and social performance criteria are gaining weight in design decision-making, economic aspects usually unlocked trade-off decisions towards the most profitable one.

As for the sources of sustainability data, it was often not made entirely explicit in the literature what data the used methods needed nor the source it was collected from and papers very often referred to generic terms such as "experts", "the department database" among others. Nevertheless, the identified data sources were clustered among four different types according to the degree of structure and whether the data was generic or specific to the company processes. The first group (structured-generic) considered the use of data coming from specialized impact data databases for creating life cycle inventories and input/output tables, which was mentioned as the main source of data 37% of times. The second group (unstructured-generic) was composed by various publicly available regulatory organizations databases, which was mentioned as main data source in 4% of cases. The third group (structured-specific) included the publications that mentioned product data management applications as main sources of data (20% of cases) and the fourth group (unstructured-specific), 22% of cases, mentioned various internal sources such as reports, portfolios, and internal staff. Notably, 17% of the publications did not mention where the data was collected from. The answers from experts were aligned with these results, pointing at generic lifecycle inventory databases as data source of their design decision-making tools.

Product lifecycle management as a data source for sustainable product development

From all the reviewed papers, it is worth to note the fact that most predominant sources of sustainability-related data internal to companies have been the Bill of Materials (BOM), accounting for the input of materials at the product level and Enterprise Resource Planning (ERP), detailing the input of materials at the company level. Notably, the role PLM plays in this context has been not only as a data source but as integration framework for different types of information. The case that has been mentioned more frequently has been the link between mechanical properties of products with environmental impact data, combining the interfaces of Computer Aided Design (CAD) applications, that are frequently used by designers when choosing product configurations. The respondents' acquaintance with the existence of a PLM culture in their companies varied across sectors, being mostly mature in the case of automotive industries. When asked about product data exchanges, experts mostly referred to actors belonging to the pre-consumption phases of products, and very often admitted there was an insufficient or non-existent feedback on their products´ fate during middle-of-life and end-of-life.

Discussion

The review has revealed some patterns that are important to consider prior to identifying or developing a tool to systematically support design teams in the decision-making around products for a sustainable CE. In the literature it has been difficult to identify a method that could match designer's routines because it had been found that many of the methods reviewed had hardly ever been applied, an aspect already pointed out by Baumann, Boons, & Bragd (2002). Through the literature review, it has been possible to confirm some of the factors that have been pointed as causes for this, such as the lack of consideration of the design phase in which the method needs to be applied (Deutz, Mcguire, & Neighbour, 2013) or the consideration of the potential user of the method, including skillset and working culture (Lindahl, 2006). In addition to this, it can be argued that relatively little attention is paid in describing valid sources of data to be used as input for these tools, which is an important aspect to consider since data collection and preparation consists of a highly time-intensive phase of a sustainable product development project (Pagoropoulos, Pigosso, & McAloone, 2017). With regards to data, experts also acknowledged the uncertainty around whether impact data contained in generic databases is representative of their in-house processes. This research suggests that applicability considerations should be addressed in further tool development. Besides a lack of focus on the applicability of the tools, it should also be further explored whether existing tools are able to capture all dimensions of circularity. This is a challenging aspect because there is little consensus on what circular economy means for different societal groups (Kirchherr, Reike, & Hekkert, 2017). The most prevalent method to measure the sustainability performance of products has been found to be LCA, even though it remains unclear how to account for multiple material uses with changing material qualities (Haupt & Zschokke, 2017), a critical issue for cascading. An additional aspect that should be further captured in the context of CE is durability of products – not only physical, but also emotional – as CE takes as underling guide the Inertia principle formulated by Stahel (2010), aiming at keeping the product in a state as close as possible to the original product for as long as possible, thus minimizing and ideally eliminating environmental costs when performing interventions to preserve or restore the product's added economic value over time (den Hollander, Bakker, & Hultink, 2017). Finally, it is also worth to note that most prevailing methods and tools found are product- and process- centric, while it should also be assessed the extent to which the products are driving large scale system level changes.

The review has also depicted that the role PLM has played so far in sustainable product development has been mainly two-fold: as product data management platform, but also as an interface in which different types of information flowing from different company processes are coupled together. As for the data exchanges, it has been observed both in literature and practitioners' answers a very strong focus on the use of upstream information, while many of the value-retention strategies considered in the CE model target the middle-of life and the end-of-life. For this, we argue there is room for further contribution of PLM to CE if the systems are further used to track information across different lifecycles including actors in downstream phases of the value chain. Interviews with experts indicate a different degree of PLM maturity and thus, intersectoral variability should be noted as well.

Conclusion

The purpose behind this exploration has been to identify suitable methods to assess the sustainability implications of circular product design in practice. This literature review has identified most prevailing methods supporting decision-making in sustainable product development during the last three decades, the most relevant sources of data and existing synergies with PLM. Because of theory-practice gaps and inter-sectoral differences, further exploration is needed in order to identify which specific method is appropriate for a certain industrial context but has provided critical aspects that need to be addressed in order to increase the future applicability of methods, additional circularity aspects that current methods fall short in addressing and the further role PLM should play in informing design decisions.

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The Legend of the Circular Tire: Creating a Vision for a more Resource Productive Tire Business Ecosystem

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Keywords: Reuse; Business Ecosystem; Component-level; Environmental Impact; Utilization Data.

Abstract: While the topic of circular economy (CE) has become more popular, tires are one example in which the market appears to be going in a more linear, less circular direction. In fact, the prevalence of tire retreading has decreased in Europe over the past decade. This paper presents a vision for a more circular tire business ecosystem and show that while there are resource and environmental gains to be had, achieving them will require significant changes to the system including both implementation of technical solutions and new ways of working. Moreover, these changes require efforts that may not seem motivated given the magnitude of gains considered in context with vehicle-level priorities. The case illustrates the conflict between norms of product longevity, achieving circularity and a circular economy tomorrow and those of achieving measurable improvements of environmental performance based on rules governing the linear economy today.

Introduction

Product lifetimes are known to be results of not only product design, technical specifications and material durability, but based on how the product is used and the system in which it operates (van Nes 2010, Chapman 2010). While the realized product lifetime of a product can be influenced (or increased) by addressing individual aspects of the product, i.e. material composition, aesthetics, reparability, and ease of use, understanding and addressing the product system with all its complexities could yield even more substantial improvements (Rai & Terpenny 2008; Diener et al 2019). As difficult as this may be, such an approach is supported by theories of systems science which suggest that 'engineering' approaches, which often take a mechanical view of systems, are severely limited in their success in changing complex systems (Checkland 2010), in which actions of and interactions between people and organizations, not mechanical workings, govern outcomes (Ingelstam 2002).

A systems-view could be especially relevant for products that are mere components of other products, potentially not prioritized as such, and that are potentially controlled by not one actor, but multiple actors during their lifetime (Diener et al 2019). This is exactly the type of situation described in this paper in which we describe a component that seems to be going towards less longevity.

While the topic of circular economy (CE) has become more popular, tires are one example in which the market appears to be going in a more linear, less circular direction. The prevalence of tire retreading has decreased in Europe over the past decade (EY 2016). Besides a lingering question of retreaded tire quality and safety, the availability of low-cost tires appears to have displaced some of the market for retreaded tires. It was hypothesized that monitoring, collecting and utilizing key tire health metrics (e.g. pressure, temperature, vibration) could reinvigorate tire retreading and reuse in a tire ecosystem. To assess the tire system and possibilities, we studied a truck tire business ecosystem, collaborated with actors in it and used multi-disciplinary approach to understand the system and resulting tire longevity. In doing so, we (1) develop a vision for a circular tire business ecosystem, (2) provide suggestions of how it could be achieved with data cultivation and sharing and (3) assess the magnitude of potential environmental impact reductions and resource benefits in the tire ecosystem. The works provide guidance specific to the system studied while the study itself provides an example of how combining a variety of assessments of a complex system can facilitate system-level learning and ultimately, to understanding how to achieve increased product longevity and how difficult that may be.

Method

Researchers studied an incumbent business ecosystem[1] of a long-haul truck tire, including key actors: a truck manufacturer, truck fleet operator, truck tire retreading company, and tire material recyclers. To study these actors and the ecosystem as a whole, we first assess the environmental impact of a product (tire) and create a list of opportunities to reduce it. We then assess information sharing as a key enabler to achieving better resource productivity. We utilize many methods including: interviews and collaboration with key actors in the business ecosystem, and life cycle assessment to estimate the magnitude of possible improvements. Tests of sensor technology on truck tires were also conducted, although they are not explained here.

Quantifying magnitude of potential benefits: Life cycle assessment and complementary assessments

For this study, we focused on the gains that can be made with the types of tires that are currently used in the system studied, the ones that fulfil the function demanded by the users. The functional unit is thus km of use of tire type demanded by users in the system in Sweden. Tires are used on a heavy-duty truck with diesel or electric drivetrain, which is assumed to have an energy efficiency that is between two and three times that of a diesel engine. After a tire is used it can either be recycled or retreaded and reused. According to the tire retreading company in the project, a tire core, or "casing", can be retreaded up to three times. Questions addressed are the following: To what extent can the environmental impact be reduced by: (1) retreading tires up to three times?, (2) using sensors ensuring optimal tire pressure and temperature.

[1] An economic community produces goods and services of value for customers, who themselves are members of the ecosystem (Moore 1996).

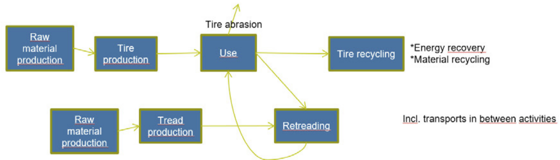

Figure 1. The simplified tire life cycle as modelled.

Data collection was performed during 2018 and 2019. Generally, the LCA is using primary data for the processes which are represented by a partner in the project (e.g. retreading), and secondary data for remaining processes (e.g. tyre production). Modelling of the product system was made in the LCA software GaBi.
Environmental impact measures from LCA were complemented with three other assessments: (1) a qualitative overview of toxicological aspects of the tire life cycle, (2) material per service unit-MIPS (Schmidt-Bleek 1998), calculating the amount of tire material use per amount of function delivered by a tire for different treading outcomes, and (3) economic circularity (Linder et al 2017), measuring how much value of virgin tires is retained when retreaded, using new and retreaded tire pricing among other statistics from project partners to determine percentage value retained.

Describing the business ecosystem and identifying possibilities of data cultivation and sharing

The process of investigating the needs of information and information sharing consisted of an initial set of onsite interviews with the participating companies regarding their current way of working with sourcing of tires, selling tires and tire related services, as functional sales, maintenance and repairs, retreading, collecting and end of life treatment. These interviews formed the input for making a functional analysis (lie et al., 2011), listing tire related data functions described as needed. The functional analysis was presented during a workshop with the participating companies where they prioritized the list of functions.
Based on prioritized functions, images of the current value flows were developed depicting the amount of tire material, information, money, immaterial values in the current tire system (den Ouden 2011). As well as for desirable, future value flows for amore circular business ecosystem. To isolate and explore how the tire related health data could be shared among the actors, a further visualization was made based

on the so-called living lab methodology (Ståhlbröst & Holst 2013). This methodology provided a clear visual representation of the various data flows over a tire's various life cycle phases and with touch points between the actors and tire related data in a "Metro map" (based on the analogy of the London subway map), which was further used as a mediating object to explore actors' actual willingness and capabilities to share, receive and use the tire-related data.

Results from individual works

First, opportunities identified from LCA are presented focused primarily on the potential magnitude of assessed "inefficiencies" in the system. Next, opportunities related to achieving these gains via data cultivation and utilization are presented.

Potential environmental impact reductions and resource productivity gains

The use phase of a tire is where the environmental impact is highest for most environmental impact categories including toxicity; the energy required to overcome a tire's rolling resistance as well as its weight and wind resistance is substantial, and this requires a lot of fuel combustion for internal combustion engine vehicles (ICEVs) or electricity for electric vehicles (EVs). As such, the biggest influence one can have on tire function's environmental burden is by choosing a light tire with low rolling resistance (Of course, this choice can conflict with other basic requirements such as safety and tire longevity, which has an influence on overall operation and standstill cost). Nonetheless, retreading can result in some reduction to a tire's lifecycle environmental impact, from 1% (CO2-eq) for trucks with combustion engines to 25% for trucks with electric drivetrains with low carbon electricity (Sweden). Depending on existing tire maintenance procedures, large CO2-eq reductions (up to around 15%) could also be gained by maintaining optimal tire pressure, which has a large impact on fuel efficiency. These results (summarized in the Table) are rather similar for other environmental impact categories.

Action	**Potential CO_2-eq reductions in total life cycle**
Tire monitoring implemented	Up to 15%, less than 1% for already thorough maintenance, to 15% for "bad" tire maintenance
Retreading 1-3 times (for use in electric truck, low carbon electricity)	Up to 25%
Retreading 1-3 times (for use in diesel truck)	<=1%

Table 1. Comparing tire life cycle improvement opportunities.

Measures focused solely on tire material and economic value (and not demands of energy during use) are more convincing. Approximately 55% of tire material sent to retreading is reused in retreaded tires. Retreading increases the material per service unit from 1 material unit per 1 service unit to around 0.6 material units per 1 service unit for multiple retreadings. From an economic perspective of the tires themselves, the circularity metric shows roughly that currently 30% of the value of tires is recirculated when retreaded in today's system. This is based on assessed value (price) of retreaded tires, which are sold for less than new. This is estimated to be able to be increased to over 50% for three retreadings.

A vision of how a more resource productive tire business ecosystem could be facilitated with data cultivation and utilization

Embedded sensors can help monitor tire pressure, which is critical to vehicle efficiency and tire wear and can identify damage due to jolts and impacts, improper air pressure, and increased heat, can provide the tire service providers, haulers, retreading companies, vehicle manufacturers and recyclers with valuable information for preserving economic value. There is also a potential for generating valuable information for other actors, e.g. road authorities and actors involved in road maintenance. The information is naturally valuable to individual actors as well as the ecosystem as a whole as it can be used to inform: (1) maintenance or tire change-out, (2) estimates of remaining tire lifetime, (3) retreading activities, and (4) assessments for fitness for reuse and repurposing. The data can hypothetically be shared among actors in the ecosystem but sharing such valuable information is not a natural function of the current system, a limitation that could be resolved with incentives and alternative business models. For example, data can be shared via alternative pricing, sold as an extra service or can be contained as part of a function-based or circular business model (Linder & Williander, 2015; Altmann & Linder 2019). Potential solutions are to be considered with the possibility (and likelihood) that tensions will arise between individual firms, who each have their own ideas and interests in commercializing the data (Altmann & Linder (2019). Figure 2 (on the next page) provides an illustration of the tire business ecosystem and key data nodes.

Synthesis: Vision for a circular tire ecosystem and key lessons learned

Putting lessons learned from separate assessments together provides lessons learned about the business ecosystem. With this new knowledge, a vision of a circular tire business ecosystem was created (Figure 3, next page).
The vision builds on the following findings:
1) The theoretical mileage of a heavy tire casings is rarely realized for applications in most developed countries.
2) There are unrealized environmental and economic values in a tire system. Hypothetically, there is economic value in monitoring tire condition and use for reasons of reducing risks for premature tire casing disposal, fuel efficiency, and to avoid costly vehicle stand-still by tire failures. Tire use data that can be collected during use can also be valuable for facilitating reuse, for example by informing retreading (or remarketing) processes. In addition, retreaded tires are less expensive than replacing with new (conventional) tires. Use of sensor-generated data can facilitate the potential to help realize something closer to the theoretical lifetime.
3) Retreading increases the material per service unit from 1 material unit per 1 service unit to around 0.6 material units per 1 service unit for multiple retreadings. Currently, 30% of the value of tires is recirculated when retreaded in today's system. Multiple retreadings could allow the system to achieve over 50% economic value circulated.
4) Tires are already repurposed and reused in different positions (e.g. drive vs roll) for long-haul trucks. In fact, for certain applications, retreaded tires are apparently considered to be "better than new". Thus, comparing these tires with new tires used in other positions may not be a sound approach as the function delivered is not the same. This represents one of many complexities in determining a single tire's share of the burden for a truck and trailer that could have 18 up to 46 tires.
5) Repurposing of tire casings from long-haul trucks to short-distance vehicles such as forklifts is allegedly suitable.
6) Electrification of the vehicle fleet will make the potential environmental improvements of retreading more significant as the ratio of use phase to production phases will be less.
7) Retreaded tires must be of similar quality and rolling resistance as new tires (for that same application). From a resource and environmental perspective, this is especially important for ICEV cases.
8) Today's main end of life treatments of disposed tires are granulation and incineration in cement production. While recycling outcomes such as use in cement kilns do offset use of fossil fuels in those applications (and are calculated that way in LCA), they are a result of today's fossil-based economy and result in environmental impacts themselves. The vision presented here suggests a delay to end-of-life treatment, and ultimately, a reduction to tire material throughput.
9) Even without vehicle and production emissions, toxicity via tire road particle emissions during use –which have been identified to have adverse effects on humans and other organisms – will still exist with tires as they are designed today. The vision presented here does not address this issue.

Conclusions

Assessments of the tire business ecosystem and its resource productivity reveal inefficiencies in the physical system and therefore, room for improvement. These potentials may be numerous but achieving them requires not just technical enhancements or interventions but changes in traditional use and reuse patterns, and modifying established data and value sharing practices in the business ecosystem. These types of changes imply changes both internal and external to all organizations involved. Given the complexity of the system including its actors and their individual interests (as illustrated for this study), it can be concluded that such engagement may not seem motivated given the magnitude of gains, especially when considered in context with higher-level (vehicle and fleet-level) priorities and when carbon reductions are in-

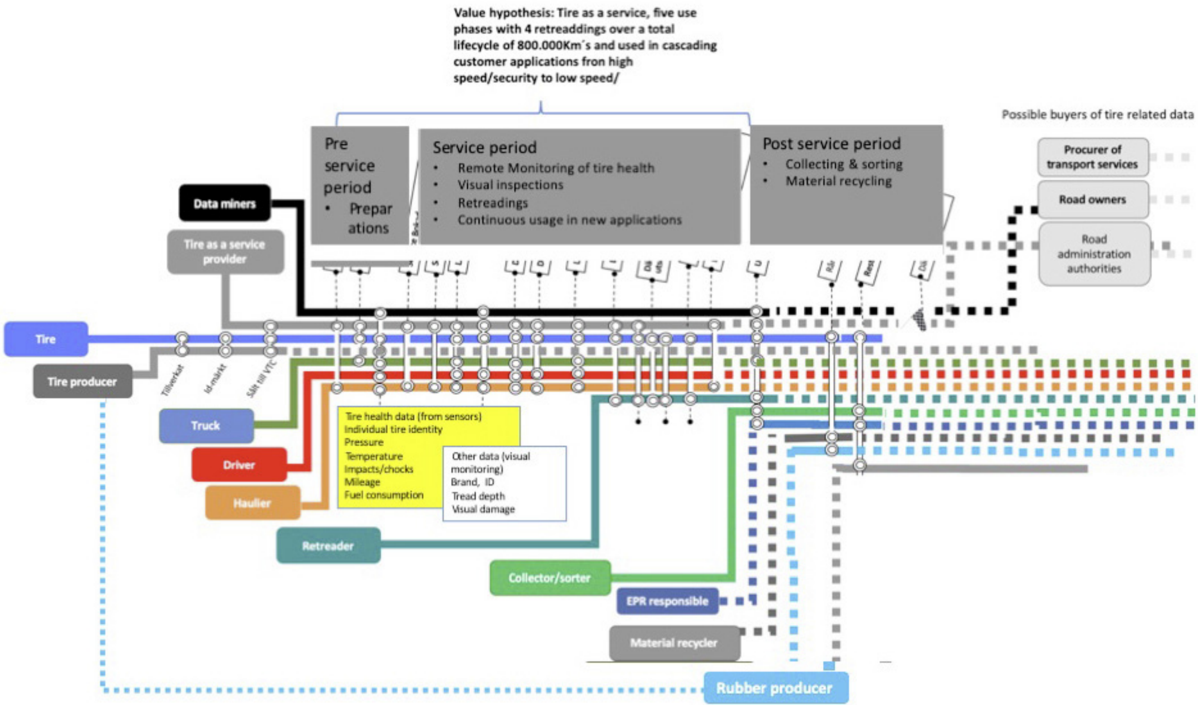

Figure 2. This map from the project illustrates the opportunities but also the complexity of the tire business ecosystem and possible difficulties of making change. Ultimately, identifying and visualizing key data and who values it helps determine what potentials there are for actors in the business ecosystem to share or monetize this data and lead to increased productivity for the business ecosystem as a whole.

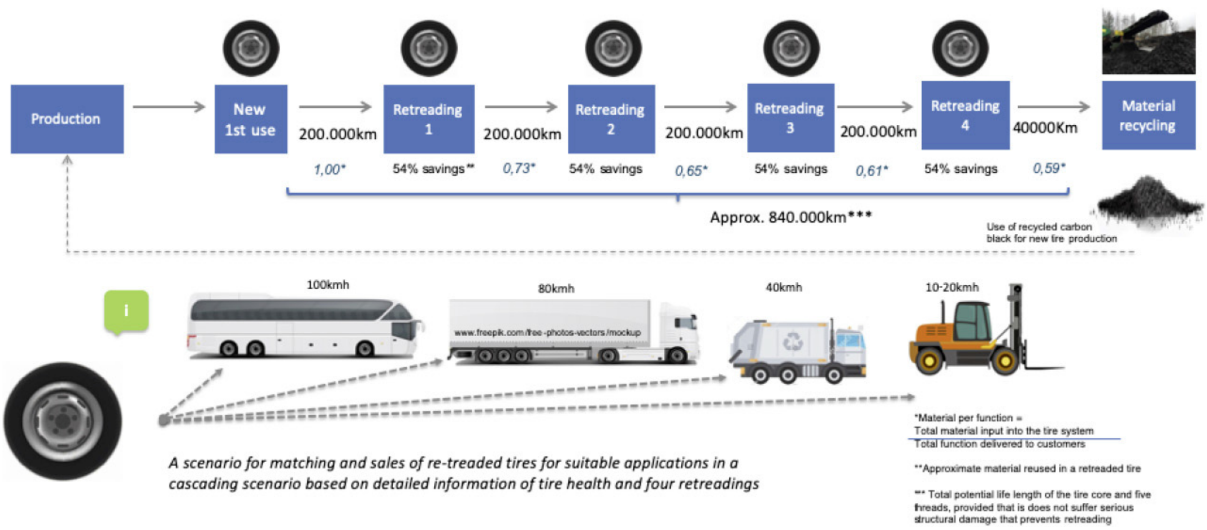

Figure 3. Depicting increased resource productivity via tire life extension and cascading use. Material per function delivered is reduced for every retreading and reuse as approximately 55% (including discards) of tire material is saved after each use. Tires could be used in a planned cascade in which the function delivered is not less but slightly different for each application. Considering material efficiency gains and the costs of new tires for each of these applications, there are potentially huge gains to be had for the system. However, risk for individual actors builds up and can dissuade later reuses. A circular business ecosystem in which data about tire use and health is monitored and collected could help mitigate this risk and result in greater economic and environmental productivity.

focus. For example, the tire's rolling resistance during use is the most determinant factor in the tire's resulting life cycle impact (for most impact categories). Does a 1-25% reduction in tire GHG impact of tires justify the efforts needed to achieve three retreadings in the tire business ecosystem? This question can be posed in context in which choosing an ultra-low resistance tire that has a shorter longevity could potentially achieve a larger reduction, without the efforts to realize three retreadings and without the fear of increased rolling resistance and perceived risk. Of course, this is not an either-or proposition – both actions could be taken – and other measures such as potential improvements in tire material efficiency and economic circularity are quite large (greater than 30%) and suggest there is great improvement to be had.

Moreover, all measured resource and environmental gains are assessed in a tire business ecosystem that is entrenched in a fossil-based world. Tires are made partially from fossil-based material, are used in fossil-based transportation system, and recycled as substitutes for other fossil fuel (oil) use (e.g. cement kilns).

Nonetheless, cases like this illustrate the conflicts that exist between striving according to norms of product longevity, achieving circularity and a circular economy tomorrow and those norms focused on achieving measurable improvements of environmental performance based on rules governing the linear economy today.

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Co-creation – a Facilitator for Circular Economy Implementation? A Case Study in the Kitchen Industry

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Keywords: Circular Economy; Circular Design; Circular Business Model; Co-creation.

Abstract: Although the concept of Circular Economy (CE) has gained significant attention in business and academia, knowledge and strategies on how to bring circularity into practice still remains limited. Most research efforts are theoretical and focus on waste handling, resource use and environmental impact. Only few studies focus on the practical implementation of CE. There is a lack of research on practical cases, where both the design process and involved stakeholders are considered. This paper reports on a case study carried out in collaboration with a Scandinavian kitchen manufacturer, to increase the understanding on how co-creation strategies can contribute to the implementation of circular economy in the kitchen industry. Based on three workshops followed by five interviews with workshop participants, insights have been gained regarding barriers and opportunities for implementation of circular economy in small manufacturing firms. Results indicate that the co-creation workshops have led to an increased understanding of CE and change of attitude towards CE among the participants.

Background

In order to minimize pressure on the environment and overcome the linearity in the lifecycle of products, Circular Economy (CE) is increasingly considered as a promising solution. CE is defined as 'an industrial system that is restorative or regenerative by intention and design (Ellen MacArthur Foundation, 2013), which aims to eliminate waste, by keeping products, components and materials at their highest utility and value.

Only recently, industry has gained more interest in CE as the competitive and economic advantages of circular business models have become more recognized (Lewandowski, 2016). But for companies, the transition from a linear to a circular business model is a complex process that requires fundamental changes to an organization. These changes might mean that the current capabilities and networks of a company lose its usefulness (Aminoff, Valkokari, Antikainen, & Kettunen, 2017)

Especially for small and medium-sized enterprises (SMEs), barriers such as financial resources, knowledge of CE, technical and innovative capabilities, lack of support from supply and demand network and government, and company culture are factors that might prohibit becoming circular (Rizos et al., 2015, 2016). The transition to a CE will not succeed if companies attempt to overcome barriers individually, but rather by establishing new ways of working, new business partners, new roles of existing partners and new kinds of collaboration between stakeholders (Aminoff, Valkokari, & Kettunen, 2016). The transition requires collaboration between all stakeholders in the supply chain (Leising, Quist, & Bocken, 2018).

To achieve new ways of working and collaborating, co-creation processes could play a role. Co-creation refers to an act of collective creativity (Sanders & Stappers, 2008) and research by (Setchi, Howlett, Liu, & Theobald, 2016) highlights how co-creation of value with partners, other stakeholders as well as consumers is a crucial and strategic element in maintaining competitive advantage. However, thus far there has been limited studies focusing on the relation between co-creation and CE, especially on practical cases where both the design process and involved stakeholders are considered.

The research presented in this paper is a case study in the kitchen industry. Previous studies have shown that premature alterations and replacements of the kitchen and its appliances lead to unnecessary material flows and climate impact (Femenías, Holmström, Jonsdotter, & Thuvander, 2016). In the EU, 80% to 90% of disposed wooden furniture, of which kitchen furniture represents a significant percentage, is incinerated or sent to landfill (European Environmental Bureau, 2017). Hence, it is worthwhile to investigate how kitchens can be developed in a more resource efficient direction by applying CE principles.

Therefore, this paper aims to explore the role of co-creation strategies in practical settings as a way to understand and overcome barriers for CE and enable CE implementation in SMEs.

Methods

As a part of the case study, three co-creation workshops were carried out with a medium sized Swedish kitchen manufacturer. The company has not formerly been active in developments for a CE but has a sustainability agenda. The workshops were followed up by interviews with different employees of the company, to evaluate attitudes and interpretations towards the circular economy and the collaborative workshops.

Workshops

A series of three co-creation workshops were carried out with the aim to 1) develop an understanding of CE principles 2) explore the potential for circularity in the kitchen industry and for the involved kitchen manufacturer and 3) co-create circular kitchen concepts and business models that would lead to the development of a circular kitchen prototype. The workshops were conducted at the company and lasted between a half and a full day. Each workshop featured a team of five researchers and several representatives from different departments of the company such as management, product development, marketing, IT and customer service, up to ten participants in total. Table 1 gives an overview of the different workshops with their purpose, activities, participants and outcomes.

All workshops were prepared, led and documented by the research team. Between the different workshops, ideas were further iterated to be presented and evaluated in the following workshops. Data was collected in the form of audio recordings, photos, written notes, observations and generated workshop material. A qualitative content analysis was performed and focused on revealing how attitudes towards CE were formed and changed throughout the workshops and how ideas were generated, selected and further developed. A critical perspective was applied on how roles, relationships, and the collaboration affected the outcomes of the workshops.

Interviews

Qualitative, semi-structured interviews were carried out with five workshop participants from the company by three of the researchers that were also involved in the workshops. The participants for the interviews played an active role in at least one of the co-creation workshops and had varying positions within the company. Three of the interviews were carried out face to face at the company, lasting between 25 and 55 minutes and two of the interviews were performed textually through email. They concerned the participants experiences from the workshops as well as their understanding and attitudes towards CE and the vision of the project. To guide the interview, workshop material and a diagram of the CE system (Ellen MacArthur Foundation, 2013) was used. The interviews were audio recorded with permission from the participants and later transcribed. The transcripts were then coded and analyzed in parallel by the two first authors, using the software NVivo 12 in parallel. The coding was then compared between the two researchers to evaluate the degree of agreement.

Workshop	Purpose	Activities	Participants	Outcomes
#1 Jul-2018	Introduce project and members Build mutual trust Analyze market Identify stakeholders Generate ideas	Company presentation & factory tour SWOT analysis Stakeholder analysis Innovation workshop Idea generation for kitchens different user groups	CEO (owner) Product range manager Product coordinator Product manager Constructors (2) Concept marketeer Researchers (5)	Stakeholder map Analysis of company and market Ideas for further development of circular kitchen
#2 Sep-2018	Evaluate concepts Circular business model ideation Identify relevant collaboration stakeholders	Concept presentation Concept evaluation Circular business model canvas Stakeholder mapping (continued)	CEO (owner) Product coordinator Product manager Constructors (2) Researchers (5)	Concept evaluation and selection of ideas Circular business model ideas
#3 Oct-2018	Agree on goal/vision for project/company Further development of selected concept	Define circular vision for project & company Discussion selected concept Opportunities & challenges for selected concept based on different scenario	CEO (owner) Product coordinator Marketing manager IT manager Customer service manager Researchers (5)	Circular vision ideas for 2022/2030 Concept evaluation Prototype plan

Table 1. Description of workshops.

Findings

The analysis resulted in different findings related to changes in understanding and attitudes towards CE as well as barriers and potential for implementing circularity in the company.

Changes in understanding and attitudes towards the circular economy after the co-creative collaboration

All interviewees mentioned an increased understanding of the circular economy after the co-creation workshops compared to before, four interviewees also mentioned an increased awareness about it during daily work. The definitions of CE varied between interviewees, some emphasized product-specific parameters like lifetime extension and re-use of products while others focused more on the business aspects.

'We need to find business models where a growing share of the companies' turnover consists of service-based revenues so that one finds a balance between production and services'

Interestingly, only one of the interviewees described the CE as a way of solving environmental problems, such as reducing the overconsumption of the earth's natural resources.

'If you look at the bigger picture, I understand that we live in a very manufacturing-driven society. We need to stop consuming so much of our planet.

Overall, the interviewees mention that aside from their increased understanding of CE, they are incorporating more circular thinking in their daily work. One interviewee mentioned that by working actively with circularity in the workshops, you start to think more in such tracks on a daily basis. The same person explained that the collaboration has indirectly influenced ongoing product development in the company and that the increased awareness has led to scaling down functionalities and material use in a new range of products.

'It has indirectly become an awareness that is taken into consideration when developing the new products for the upcoming product launches'

Another interviewee mentioned that sustainability aspects are now considered earlier in the process, e.g. more communication with suppliers about the impact of their products before they are purchased.

Barriers for implementing circularity

Throughout the workshops and interviews, several barriers for implementing circularity within the company were identified, such as the costs of changing the current capabilities, (reverse) logistics, potential increased prices of products, lack of support from supply and demand network, complexity of the supply network, lack of policies and regulations for the entire industry and lack of capacity in the company to focus on circularity.

One of the main strengths of the company is to deliver highly customized, ready-assembled components and kitchens through a structured logistical process to building projects. This expertise is strongly appreciated by their customers, as it greatly reduces installation time and complexity. However, this high level of specification and customization towards the customers has led to a wide product range with different components, dimensions, styles and colors. This makes circularity more difficult to achieve, as a narrower product range, standardization and modularity generally simplifies repairing, remanufacturing and recycling of products.

'From experience, I know that the company listens very much to our customers' demands and is very customer-oriented, and of course that has helped us grow, since we often introduce the solutions that customers demand. But introducing such a solution [based on circular economy principles] should in that case be demanded by our customers.'

During the second workshop, an idea was presented to the company regarding a modular kitchen concept consisting of a frame structure, which would allow for maintenance and repairs as well as easy disassembly to improve recirculation of components and materials. The idea was overall received with minor enthusiasm as a modular kitchen design would imply major investments to change the current production capabilities and was associated with 'flat packaging' which opposes the company's ideology of delivering ready assembled kitchens.

'If you are talking about a circular kitchen which means large volumetric products in the end, which one best solves with flat packaging or alternatively demountable frame structures to develop these solutions. I see this as the biggest obstacle, that it will be a big change for the company to launch large product ranges like this'

Processes are very optimized and specialized, changes to manufacturing processes would require big investments. The risk of investing in innovation without knowing if it pays off, is a big barrier. Furthermore, one interviewee mentioned that it is hard to establish circularity alone, it should be more industry wide thinking.

'It should be more for the whole industry, because then it is more that everyone must follow the same rules and so. It is not easy to be alone in starting with something like this, it must be industry-wide thinking.'

Two interviewees mentioned (reverse) logistics as a barrier, of which one interviewee associated circularity with increased logistics for the company, which might not prove to be a sustainable direction either. Furthermore, two interviewees mentioned a lack of support from the (complex) supply and demand network. Customers do not demand circularity and uncertainty exist whether to involve and collaborate with suppliers to recirculate components and materials, partly due to the complexity and length of the supply chain.

'We buy all the materials. We can't grind them down and do something with that ourselves currently. How to look at it, should one involve their suppliers? There's a lot of steps in between for those things to get back. Should we take back our own products? There is not much we can do with them here.'

Potential for implementing circularity

The use of more renewable materials such as solid wood and bio-composite were discussed as a potential direction instead of currently used materials like chipboard and MDF (Medium Density Fibreboard), which have a relatively short lifespan and limited possibilities for recycling. Many benefits could be seen in the use of more renewable materials, as long as these materials could be processed with the current manufacturing capabilities and would not results in significantly higher prices of the products.

One idea developed during the workshops which received most appreciation by the company, was that of a service solution that would enable tracking and recirculation of kitchens and materials and streamline maintenance and repairs of kitchens (see figure 1). This could avoid premature disposal and extensive renovations of kitchens, and was identified as a potential direction for more circularity, which was also emphasized by one of the interviewees:

'If one could simplify the replacement of fronts and such things, there I don't see any large barriers – that one could get maybe new materials that are based on the current cabinet frames. It is those that wear out most often, the fronts and the outer shell.'

Kitchen owners would be able to, through the service, identify their kitchen or components of their kitchen to order repairs and upgrades. This would extend the lifetime of their products and promote sustainable choices, rather than premature disposal of kitchens and extensive renovations. If renewable materials are used, the service could facilitate remanufacturing and recycling through reverse logistics of components and materials. Furthermore, it would give the kitchen manufacturer insights in the parts that are replaced most often, which is feedback that can be used for further development.

Through the developed idea's, great potential was identified for further iterations by collaborating with stakeholders and include them in a co-creative process, such as housing and recycling companies and material producers.

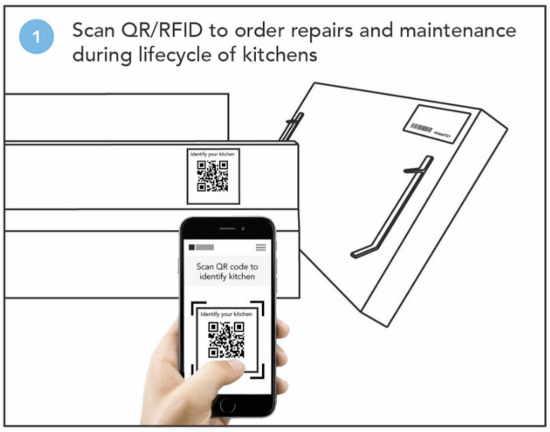

Figure 1. An appreciated idea was the service solution for tracking and recirculation of materials, components and kitchens.

Conclusions

Based on three workshops and five interviews with a kitchen manufacturer, this study shows what role co-creation strategies can play when collaborating with SMEs in developing an understanding and awareness about circular economy and finding barriers and potential for circular economy implementation. The results indicate that the co-creative collaboration has led to an increased understanding of the circular economy and an increase in circular thinking amongst the participants of the workshops. It also gives valuable insights into barriers and potential for circularity that should be taken into consideration when co-creating with SMEs.

The company indicated a variety of barriers for circularity, the biggest one being the costs of changing the current production capabilities. Furthermore, the company is dependent on a complex network of suppliers and feels a lack of support from the supply and demand network, contributing to the feeling that the company has to 'close the loop' themselves. Although some of these stakeholders were invited to the workshops, they did not manage to participate in the end. Including some of

these stakeholders into the co-creative process could have led to better results and more potential for collaboration and closing the loop.
Instead, a potential was seen in a smaller step towards circularity such as launching a service that enables lifetime extension of the current products, which could also form a stepping stone to the implementation of more renewable materials. This service solution would not imply major changes to the current capabilities and could be developed as a side-track. Implementation of renewable materials could then also create an incentive to retrieve materials to remanufacture kitchens.
The research is limited by the fact that it was a single case study with a small sample of interviewees and that not all interviewees participated in all of the workshops. Another point is to what extent the researchers should actively partake in the co-creative collaboration, as it might lead to counterproductive situations if they account for the majority of the generated ideas.
It could be beneficial to study the effects of co-creation in more cases and evaluate the impact on circularity in companies over a longer period of time. Future research will further develop three concepts that were generated in the workshops, study the effects of including more stakeholders in the process, and perform a comparative study between circular development for a Swedish and Dutch kitchen manufacturer.

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Fun for Life – Designerly Opportunities for Lifetime Extension in Toys

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Keywords: Product Lifetime Extension; Toys; Design Education.

Abstract: In order to broaden our understanding of product lifetimes in support of a circular economy, within this research, we focused on toys, which unfortunately often have a relative short lifetime of 3-4 years according to several studies. In addition to the huge amounts of toys that are discarded, another reason for focusing on toys is that while using toys, i.e. playing, children are influenced, generate certain behaviors and retrieve many values and norms. Consequently, toys with short lifetime might teach kids that it is normal that things are frequently replaced without questioning the value. Being in the transition towards a circular economy it is crucial to change people's behavior, so it is of large importance to consider children's environment as well. The aim of the research was to define designerly opportunities for extending the lifetime of toys. The research was done by means of an education-oriented approach in which an exploration was done to investigate and evaluate potentials for design-driven innovation to increase product lifetimes of toys. The resulting concepts that were generated by the students were categorized through a survey based on various criteria as well as semantically organized in categories. Next the results were discussed with a selection of experts. The concluding concepts were mostly tackling lifetime shortness by focusing on emotional value and the opportunity to grow, in addition to the technical maintenance and repair possibilities. To enlarge or convey values and norms, most concepts focused on the connectability of different types of toys as well as concepts that aim to inspire children related to understanding nature, and taking care of the environment.

Introduction

Investigating existing literature, we found that toys often have a relative short lifetime. Reliable data is however hard to find, and only limited studies are done to retrieve accurate data, for instance (Murakami, Oguchi, Tasaki, Daigo, & Hashimoto, 2010),and (Conny Bakker & Schuit, 2017). According to (Wang, Huisman, Stevels, & Baldé, 2013) toys have an average lifetime of 3-4 years. Yet, 95% of all plastic toys currently will get a second life (de Graaff & de Graaf, 2015). The main reasons found to discard toys were fast growing and change of interest (Cooper, 2004). Research on consumer satisfaction of product lifetime (Gnanapragasam, Cooper, Cole, & Oguchi, 2017) indicates that satisfaction is relatively high for toys. Exploring this study in depth, we notice that both price and longevity are both indicated as very important purchasing factors. Yet, these are often contradictorily factors. Obviously, there will be a large variance between different toys and it is not clear in each of the investigated studies which toys were included.

Another reason for focusing on toys is that they not only contribute to children’s cognitive and emotional growth, but also play a crucial role in passing on cultural knowledge and values (Allison J. Pugh, 2005). While playing with toys, children are influenced, generate certain behaviors and retrieve many values and norms. We also note that while educational toys for motoric and cognitive skill development have clearly defined criteria for design (such as providing fun, keeping the child safe, offering challenge, being adaptable, ease of use and providing interaction (Hinske, Langheinrich, & Lampe, 2008), research does not offer such criteria for the design of toys that aim to instill or convey values to children. This lack reflects the relative novelty of value-centric design processes (Barreto et al., 2013). Consequently, toys with short lifetime might teach kids that it is normal that things are frequently replaced without questioning the value. Being in the transition towards a circular economy it is crucial to change people's behavior and to consider children's environments as well (Ellen MacArthur Foundation, 2012).

Exploring the existing design strategies for lifetime extension. (van Nes & Cramer, 2006) and (Guiltinan, 2010) mapped the factors that influence the replacement decision. In sum, four general motives for replacement were detailed: Wear and tear, Improved utility, improved expression, and new desires. In order to prolong or extend product lifetime, the existing design approaches are mainly studied by (den Hollander, Bakker, & Hultink, 2017). The first approach focuses on longer use of a product, the second on extended viability of a product (through maintenance and repair), and the third on product/component recovery.
Designing products with an intrinsically long life can be achieved through (i) creating emotionally (attachment and trust) and/or (ii) physically durable products. This is also referred to as 'resisting obsolescence'. Keeping a product from becoming obsolete (called 'postponing obsolescence'), can be achieved through (iii) designing for maintenance and repair, and (iv) upgradability and adaptability. The third design approach is to return an obsolete product to a non-obsolete state (also called 'reversing obsolescence'), for instance through design for repair or remanufacturing by allowing (v) design for dis- and reassembly and (vi) design for standardization and compatibility (den Hollander et al., 2017). From a design perspective, in (Conny. Bakker, Hollander, Hinte, & Zijlstra, 2014) these six strategies are discussed to design for longevity.

Method and materials

The aim of the research was to investigate and evaluate potential for design-driven innovation to increase product lifetimes of toys. Within the research, we included all types of toys and without any age limitation as one of our research questions was to identify the largest potential for increasing lifetime. The research was done in a nexus research – education context, which means that by handling an education-oriented approach, new knowledge was generated as well as existing knowledge was given to students.

At first, an exploratory study was done to investigate the state of the art. Next, 120 design students took part in an experiment within the educational setting of the bachelor program of Product Development, Faculty of Design Sciences at University of Antwerp. The research was set up in a context of the science education nexus. The design task was given by OVAM (i.e. Flemish waste management institution) and formulated as: "How would you as a designer extend the lifetime of toys?"
At first, in a pretest, they were asked to think about what type of toys (i) they played with over a long period, (ii) they cherished; (iii) quickly broke, (iv) they get but did not play (much) with. Furthermore, they had to motivate this in order to find a relation between the type of toy and the play experience (in the motivation). Next, each student took part in a 2days deep dive in small groups, supported by various experts from toy companies (such as Smart Games, Cartamundi, Pars Pro Toto, and Technopolis) and experts in ecodesign and circular economy (Vlaanderen Circulair, OVAM) as well as by the teaching staff. At the end of these 2day event, they had to pitch their ideas for an external jury (including the former experts and people from toy retail such as Colruyt Group and De Banier). After this event, the students had to work for five more weeks on an individual project to design one specific concept of a new toy with elongated lifetime or other concept that elongates lifetime of existing toys. The Products That Last -model (Conny. Bakker et al., 2014) was used to structure the strategies for lifetime extension.

In order to process the results, the 120 resulting concepts that were generated by the students were categorized through a survey based on following criteria: Strategies, Type of toy, Avoided reason for discard, Motivator for lifetime extension, Place of toy usage, Usage age, estimated lifetime extension, and Engagement. Moreover, the resulting concepts as well as the semantically organizing categorization was discussed by a selection of the experts in group.

Results

Results of pretest

At the start of the project, four questions were asked to the participants plus for each question, the argumentation for the answer was asked. The questions were related to their memories of (i) which toy was quickly broken, (ii) the toy he/she did not played with, (iii) which toy was played with a lot, and (iv) which toy was/is cherished most. All eight questions were asked as open questions. Based on the answers categories were identified by means of a qualitative content analysis.
The what-questions that are related to a specific toy were categorized based upon a standard classification of toys, i.e. fantasy toys, creativity toys, board games, sensory toys,

movement or activity toys, puzzles, construction toys (EXPOO - Expertisecentrum Opvoedingsondersteuning, 2002). In addition to these seven categories, an additional three categories (i.e. cheap toys, vehicles and electric or electronic toys) plus an others category was identified to assure sufficient differentiation.
Based upon the results of toys that break quickly, electronic toys are mentioned most. Argumentation is related to the failure of electronics and the depletion of the battery. In addition, also fantasy toys are mentioned to break quickly because of loose limbs. Lastly, activity toys were mentioned as often parts break of do not fit anymore.
Next, identified toys that were not (much) played with appeared to be similar to those that brake quickly. Toys that were not played (much) were argued mostly because they were not interesting, not within interest of child, did not fulfil expectations, were tedious, boring or monotonous. Plus an additional category of cheap toys, that often are related to a hype or fad and are only interesting for a short period of time.
In contrast, toys that the respondents played with a lot are construction toys and also fantasy toys. Argumentation is related to the amount of variations or stimulation of creativity or imagination, as well as because the focus was on creating an experience and telling stories. Besides, also board games were mentioned because of the competition and teambuilding.
Lastly, the identified precious and memorable toys are mostly in the category of construction material as well as fantasy toys. The manner for the timeless character and opportunity to keep them for the next generation, and the latter for the memory and emotional value.

We must note that the participants were all design students, consequently the conclusions should not be generalized as their choice of toys might be related to their choice of studying design.

Resulting concepts

In total 120 concepts were generated, focusing on different types of toys and using different strategies to elongate the lifetime. Out of the 120 concepts generated by students a selection is shown in Figure 1-10, to illustrate the different strategies that can be applied. Within the strategy of Design for maintenance and repair, Figure 1 shows a concept of a completely modular doll from which components can be detached to be upgraded or repaired. Figure 2 shows a concept for a new way of working with markers. By providing a refilling service one would be able to maintain markers for an extended period of time.

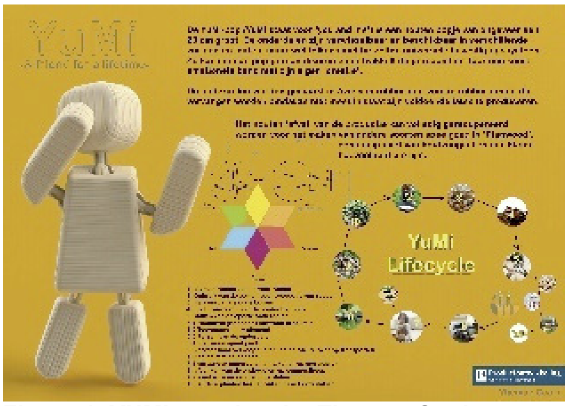

Figure 1. YUMI a project by Thomas Cools.

Figure 2. Concept of Emiel Goffin.

Within the strategy of Design for adaptability and upgradability, the concept in Figure 3 modular building kit concept, whose elements can be used to build a playhouse for children, afterwards, to stay relevant, they can be transformed to serve as everyday household furniture like chairs and tables.
Within the strategy of Design for standardization and compatibility, the Mr Bamboo concept (Figure 4) is a toy set which uses regular bamboo to let children build their own toys. Comparable, the Tik-Tak-concept (Figure 5) gives kids a new way of building with branches and Ecoscrew (Figure 6) uses standard pet-bottles to construct a building game.
Within the strategy of Design for durability, the Concept Drop (Figure 7) is a marble track set which can also serve as a puzzle game. It reduces the possible points of failure by

designing with limited components and minimal connection system.

Within the strategy of Design for dis- and reassembly Babo (Figure 8) suggest a modular approach to bike design. Components can be upgraded and returned to better suit the needs of the growing child. The design of the bike is centred on the ability of the user to disassemble and reassemble the different parts.

Based on the Design for attachment & trust-strategy, Yume (Figure 9) is a toy which initially serves as a simple doll for the kid, besides, it has a special memorabilia compartment build in to foster memories and has sentimental value. Figure 10 show a concept of a doll which, when watered, will grow into a plant. This way the kid has to care for the doll and foster a more involved relationship.

Figure 3. Concept of Maite Dillen.

Figure 4. Mr Bamboo of Nicolas Vanheusden.

Figure 5. TIK-TAK-Kit by Egon De Bruyne.

Figure 6. Ecoscrew of Bruno de Selva-Dewint.

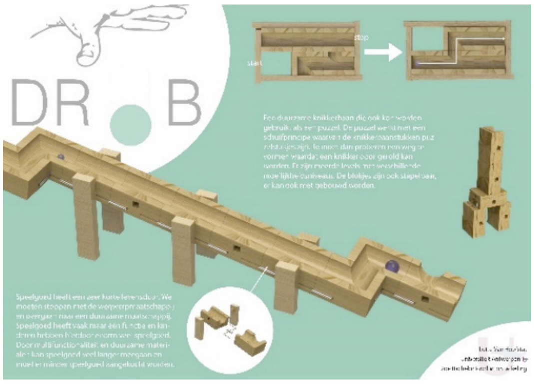

Figure 7. Drob" by Lotte Van Hoofstat.

Figure 8. Babo by Margot Fonteyn.

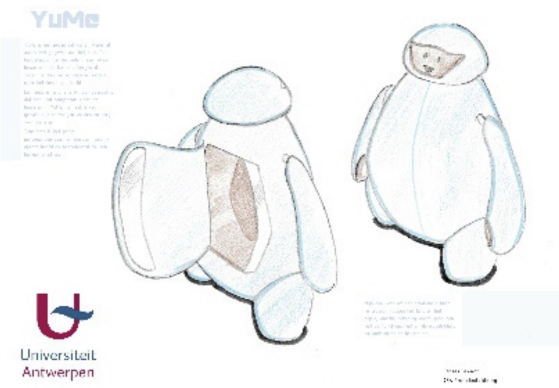

Figure 9. "Yume" a project by Thomas Bekaert.

Figure 10. "I'm loving our planet" of Brent De Nef.

Results of the concepts evaluation

In conclusion of the design assignment, students were asked to participate in a survey that evaluates their designed concepts. First of all, they were asked what type of toy they had developed (one of seven categories mentioned in previous Section). Second, they were asked to indicate which one(s) of the strategies that their concept responds to, and third, for what reasons the life time of their concepts was extended (i.e. avoided disposal). Answers were gathered in cross tabulations in order to interpret the results of this design course.

As shown in Table 1, the strategies that were used to design the concepts Design for Durability was most applied, followed by Design for Adaptability and Upgradability (47,5%), and Design for Attachment and Trust (41,7%). Moreover, as multiple strategies could be applied in a single concept design, this top three strategies were also most often combined.

When we plot the chosen strategies (see Table 1) across the seven discussed product categories, we find that Design for Durability is the most prominent design driver in all categories, especially in the case of Board games, but except for Fantasy toys that rather integrate Design for Adaptability and Upgradability, and Design for Attachment and Trust. In addition to Durability, Creativity toys focus on Design for Attachment and Trust as well. Sensory toys can be considered to comprise the most equal combination of all strategies and are mainly found within Design for Standardization and Compatibility. Movement games also include the highest focus on Design for Dis- and Reassembly. Puzzle toys also incorporate Design for Attachment and Trust, while Construction toys focus on Design for Adaptability and Upgradability too.

When investigating the specific reasons for life time extension (reason for avoided disposal) – which are related to the strategies, Fantasy and

	Design for attachment & trust	Design for durability	Design for standardization and compatibility	Design for ease of maintenance and repair	Design for adaptability and upgradability	Design for dis- and reassembly	Total
Fantasy	25,6%	16,3%	7,0%	4,7%	**34,9%**	11,6%	100%
Creativity	**30,3%**	30,3%	6,1%	**15,2%**	6,1%	12,1%	100%
Board games	13,0%	**39,1%**	8,7%	**17,4%**	17,4%	4,3%	100%
Sensory games	11,1%	27,8%	**16,7%**	11,1%	16,7%	16,7%	100%
Movement games	10,0%	27,5%	7,5%	**17,5%**	17,5%	**20,0%**	**100%**
Puzzle	22,2%	**33,3%**	3,7%	11,1%	18,5%	11,1%	100%
Construction	15,4%	26,4%	9,9%	9,9%	**23,1%**	15,4%	100%
Applied by % of students	41,7%	**62,5%**	19,2%	26,7%	**47,5%**	31,7%	

Table 1. Linking strategies with types of toy concepts.

Puzzle toys focus on "growing" with the child, Creativity toys clearly aim at the creation of an emotional bond (which complies with the strategy of Design for Attachment and Trust), Sensory games focus on simple repair, Movement and Construction toys avoid technological obsolescence, while Board games combine varied (other) reasons.

Results of the expert discussion

Based on the experts' discussion, in addition to lifetime extension, we could conclude that many students were, focusing on the connectability of different types of toys as well as concepts that aim to inspire or convey values and norms to children related to sustainability, understanding nature, and taking care of the environment.
The added value of this connectability of different types of toys allows to connect unconnectable parts and offers consequently a whole new level of opportunities to experience the game.
In addition, toys that support in the understanding of how nature works also enrich their value of taking care for the environment.
The experts concluded that especially those products that focus on creating values strengthen the transition towards and understanding of the importance of a circular economy. This is mainly because they stimulate lifecycle thinking in various manners. A few concepts took another step further and focus on combining social interactions with care for nature in for example a board game to initiate the concept of a circular economy.
Lastly, experts also concluded that aesthetic aspects and integration of toys in their environment also have an important impact on the manner of how people deal with objects. Higher aesthetic experience will increase the product lifetime.

Conclusions

This paper is reporting upon an education-driven experiment to identify design opportunities for lifetime extension of toys. Based upon the research, the following propositions can be made out of the evaluation of 120 designed concepts:
Proposition 1: Design for durability was the most applied strategy in combination with design for attachment and trust and design for adaptability.
Proposition 2: toys that bring values and norms have higher chance of changing behavior and supporting the transition towards a circular economy. Students achieved this mainly through connecting with nature and values of taking care.
Proposition 3: toys that offer many opportunities for playing are more appreciated by children
Elongation is additionally possibly by allowing to connect and combine various types of toys.
Proposition 4: aesthetic aspects also have an important impact on the longevity as they influence how people appreciate toys.

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Designing for and with Garment Repair: an Exploration of Future Possibilities

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Keywords: Mending; Design; Sustainability; Breakdown.

Abstract: Over the years, the increasingly domineering heavy hand of the fashion industry's 'take-make-waste' production paradigm has contributed to the creation of systems that support fast production, easy purchases and frequent disposal of inexpensive, poorly designed and often low-quality garments. Prior research has slowly but steadily been working towards highlighting the fundamental role that garment mending can play in supporting product longevity. While addressing clothing breakages through mending has been considerably explored as a user practice, how it can inform the process of garment design has remained under-researched. Therefore, this paper takes its theoretical inspiration from 'broken-world thinking' with a repair-centred sensibility as its point of departure. Here we take malfunction, as opposed to innovation or design, as the starting point of change and garment design. Through this paper we then explore the opportunities to introduce and weave a repair ethos into every stage of the garment design process. In this way, we highlight the inseparability of repair from design and the importance that basic design decisions can have for facilitating cultures of mending. We also identify the challenges and opportunities that such an approach entail. This paper presents findings from three student workshops in three design universities in different geographical locations. By exploring the preliminary results of this work we open up a discussion on re-evaluating present-day fashion design approaches by initiating a move towards a design sensibility for repair which is fundamental to the process of fashion design, particularly in the context of sustainability.

Introduction

"Repair is about space and function – the extension or safeguarding of capabilities in danger of decay" (Jackson, 2014).

Over the years, the increasingly domineering heavy hand of the fashion industry's 'take-make-waste' production paradigm has contributed to the creation of systems that support fast production, easy purchases and frequent disposal of inexpensive, poorly designed and often low-quality garments. The alarming and ever-increasing rates at which textiles are disposed of has therefore ushered academic research to explore various ways of encouraging and extending the use-time of garments (Fletcher, 2008; Birtwistle & Moore, 2007; WRAP, 2012). Prior research has slowly but steadily been working towards highlighting the fundamental role that garment mending can play in supporting this endeavour (Mc Laren et al., 2015; WRAP, 2012; Fletcher, 2015; Durrani, 2018a; Laitala and Klepp, 2018). While mending is acknowledged as crucial for saving garments destined for the bin, research also notes that a lack of awareness, time and mending skills stand as barriers to garment repair in Western countries (Laitala, 2015; Fletcher, 2015; Twigger, 2016; McLaren et al., 2015; Lapolla and Sanders, 2015; Norum, 2013; Gwilt, 2014). In order to overcome these issues, various recommendations have been proposed, such as 'educating' users in how to mend by introducing sewing classes at schools, launching media campaigns on the benefits of laundering less and maintaining garments through mending, or offering repair services as part of fashion designers' businesses (Laitala, 2015; Norum, 2013; Gwilt, 2014). Alternatively, design-led solutions such as modular garments (Gwilt, 2014) or the use of robust materials for future garment production (Fletcher, 2008) have also been suggested as means to ensure the long-term use of clothing.
However, these recommendations have primarily been presented through a focus on

only user perspectives of mending (see Norum, 2013; Gwilt, 2014; Mc Laren et al., 2015; WRAP, 2012). Such an emphasis has led to overlooking and under-researching existing users' mending practices (Durrani, 2018a-b) and how garment breakdown could inform the fashion design process. Therefore, this paper takes its theoretical inspiration from 'broken-world thinking' with a repair-centred sensibility as its point of departure. Here we take malfunction, as opposed to innovation or design, as the starting point of change and garment design (Jackson, 2014). In order to do so, we go back to the designers' drawing boards and begin by asking the following question:

What happens when fashion designers take breakdown as their point of creative departure?

Through this paper we then explore the opportunities to introduce and weave a repair ethos into every stage of the garment design process. In this way, we highlight the inseparability of repair from design and the importance that basic design decisions can have for facilitating cultures of mending. We also identify the challenges and opportunities that such an approach entail. This paper presents findings from three student workshops in three design universities in different geographical locations. By exploring the preliminary results of this work we open up a discussion on re-evaluating present-day fashion design approaches by initiating a move towards a design sensibility for repair which is fundamental to the process of fashion design, particularly in the context of sustainability. However, before providing details of the research methods and findings, the following section presents an overview of the theoretical framework within which the present work is grounded.

Broken-World Thinking

The present commercial logic behind fashion design is based on linear models, whereby savings in production costs are often met with extremely fast material throughput to the system (Niinimäki, 2018). The businesses or companies for which designers work set guidelines for garment design that follow a fast production business logic (Dieffenbacher, 2013, p. 209). Therefore, any creative approaches to fashion design become limited or constrained by current production-oriented and profit-driven economic thinking (Rissanen 2017, p.542). Fashion designers in the fashion system thus end up creating collections that are based on rapidly changing trends rather than users' real needs, and certainly not on an environmental perspective (Niinimäki, 2011). This business logic is built on fast designing, fast manufacturing and maximising sales, resulting in short use time of garments, low quality and easy disposal. Mass-manufactured garments are not generally designed for long-term use nor are they conducive to mending (Niinimäki, 2011). Moreover, designers' hands are often tied by limited room to propose alternative ways of designing garments (Ruppert-Stroescu, 2018; Niinimäki, 2011; Rissanen, 2017).

However, despite such systemic challenges, if change is to be effectively addressed, alternatives need to be explored. It is for this purpose that in addressing product longevity, this paper takes garment breakdown as its point of departure. In other words, if garments continue to be designed in ways that do not leave much margin for being repaired, is it fair to fix our attention primarily on changing user practices? Although users do play a significant role in extending the use of their garments, they are not the only ones upon which the onus of longevity rests. In addition, repair itself is not usually considered in the design process (Graham and Thrift, 2007), even though the way in which a garment or product is designed can play a role in determining its eventual repair (Terzioğlu, 2017). Though the design of a garment might not entirely guarantee its repair, it can certainly ease the process of mending once the clothing is in use.

To enable this, Jackson (2014) proposes that designers take breakages or malfunction as the point of their creative departure. He states that by applying a broken-world thinking approach to the processes of design, creativity becomes situated within engagements with repair, which can inform the ultimate design of a given product or service. By focusing on repair, a designer's gaze can shift from being production oriented to sustainability oriented, resulting in the shaping and creating of an ethic of care in the creation of products that can be extended to its' use and up-keep (Jackson, 2014). This can further result in designers bringing value to mundane, invisible practices that carry rich histories and ways of doing, and often require high levels of dexterity on the part of the practitioner, yet remain under-stated and under-researched sites (Jackson, 2014; Durrani 2018 a). In moving beyond Western productivists' imaginations and learning from and through breakages and decay, Jackson (2014) claims that unsustainable economic and political systems can be challenged and addressed effectively. Moreover, dichotomies among 'designers', 'users', 'producers' and 'consumers' can be overcome through the creation of products or services that account for and enable acts of mending (Durrani, 2018a). In theoretically drawing inspiration from broken-world thinking, this paper sets out to test whether repair is in fact the prerogative of currently enrolled fashion design students. The following section reveals how this was undertaken.

Method

For the purpose of this research, the experimental design research method (Malpass, 2017) by means of generative analysis (Sanders & Stappers, 2008; Flick, 2014), was used. Workshops were arranged for masters' students of the fashion and textile programme at three universities; the Edinburgh College of Art (United Kingdom, September 2018), Aalto University (Finland, April 2018) and Otago University (New Zealand, October 2017). A one-day workshop was conducted as part of the 'Sustainable Fashion and Textile Design' course at Aalto University that the first author was co-teaching. The other two workshops in the UK and New Zealand took place during the first authors' time there as a visiting researcher.

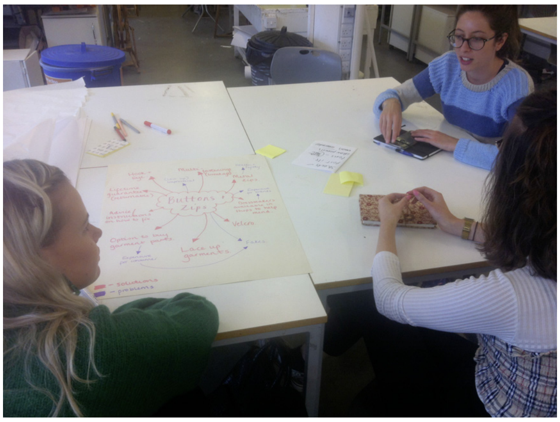

Figure 1. Students ideating during the workshop at ECA (Edinburgh College of Art, University of Edinburgh, United Kingdom), 26/09/2018. Source: Author.

Data collection and analysis

Each workshop began by the first author giving a 30-minute lecture on the problems within the fashion industry. After this, the students participating in the session were divided into groups of four and assigned one task per group (see Figure 1 and 2). These tasks were based on scenarios derived from the first author's three years of ethnographic work on users' garment repair practices (see Durrani, 2018 a-b). The data from the first author's ethnographic research – 67 user interviews coupled with participant observation in a total of 18 communal mending events – helped generate four common sites of garment breakdown. As identified by the users, four areas were listed where break-downs during the use phase of their garments would frequently occur. These were: broken buttons, holes and frays, ripped pockets and worn-out jeans.

Each of these issues was used as a task for students to address conceptually. The students were given 40 minutes and were equipped with sticky labels markers, and flip chart pages, to brainstorm ideas and visualise their solutions two-dimensionally. Each group presented their solutions, which subsequently led to discussions with the class as a whole (see Figure 3). Pictures were used to document the brainstorming sessions and the produced outcomes. The data were analysed using thematic analysis by all authors, both individually and collectively, to provide rigor and validity (Flick, 2014).

Figure 2. Students critically analysing garment breakdowns, Aalto University, Finland, 19/04/2017. Source: Author.

Initially, we clustered the suggestions on the basis of their similarities and differences, to find patterns of possible solutions. Then, we categorised these patterns to find overarching themes that could assist in answering the research question (Ryan & Bernard, 2003; Flick, 2014). The three themes generated are further discussed in the next section.

Discussion on Findings

After the data were analysed, the following themes arose from the findings of the workshop activities:

Materials matter: Re-thinking design decisions

The experience of participating in the workshops led the fashion students to question the entire design process of garment-making. They reflected upon the impact of basic design decisions, from material selection to providing extra fabric for garment seams, on the repair of garments. For example, when evaluating the problem of garment rips and tears, using better quality fabrics and cutting patterns in ways that account for flexibility and replacements was suggested. The use of sturdier materials and better-quality threads was proposed, especially in places such as pockets, elbows and knees, where rips frequently occur. The material dependency of garment mending was raised and the importance of choosing materials that boast durability became visible. The suggested solutions revealed rethinking future practices by learning from material qualities and the ways in which textiles are woven, and basing design technicalities and future decisions upon this.

Beyond productivist ideologies

As the students engaged in discussion, it became clear to them that a designer's responsibility is not limited to designing a consumable product; longevity should also be a significant concern in the fashion design process. The students became mindful of the importance of applying repair-centred design practices to existing post-consumer textile waste as a means of effectively addressing product longevity and bringing existing garments back into use. Thus, collaboration between local recycling centres, crafters, designers and fashion students in hosting regular public events for mending, re-making and up-cycling activities was suggested as a way of creating opportunities to boost and extend the life of clothing.
Such open-events could also offer increased community engagement (Durrani, 2018 b) and support sustainable practices in an enjoyable way. Creating future designed garments that use post-consumer textile waste as material sources to make clothing in ways that situate repair at its core were also suggested for addressing textile waste.

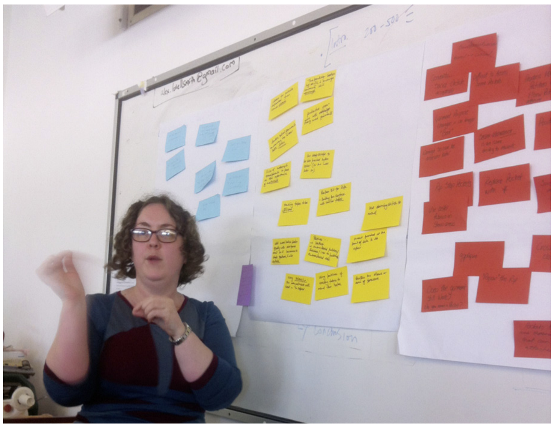

Figure 3. Student presenting proposed solutions to assigned group task at Otago University, New Zealand,10/10/2017. Source: Author.

Altering education systems

During the workshop ideation sessions, the students also identified certain limitations to their knowledge and a lack of experience when dealing with the four garment breakages. They revealed not having studied real-life garment problems such as holes in pockets or worn-out jeans as part of their education. Limitations to exploring breakdowns in garments further created a barrier when trying to ideate ways of solving the given tasks. For this reason, many suggested a more exploratory approach to their current education. Voicing the need to embrace repair and garment breakages in the education system further highlighted a gap in the present system to which fashion designers are exposed, and led to identifying opportunities for furthering research in new and alternative arenas. By branching out in these directions, new opportunities could be created in current garment-making practices. An example that the students also quoted frequently was exploring the natural environment and how it repairs itself as potential inspiration and a starting point of reference.

Conclusions

Although garment mending might not currently be an obvious prerogative of fashion students, the existing education system has hardly made strides in directions supportive of this either. However, what became evident through the workshop sessions was not only an interest on the part of students in exploring alternative ways of designing garments, but also the dire need to rethink the fashion design process, especially in terms of sustainability. Students became aware of the importance of basic design decisions for the maintenance and care of garments. In making breakdown and mending the point of their creative departure they were also able to identify with garments not merely as outcomes of a production line process, but also as materials that have lives and are lived in. The preliminary findings of this study thus highlight the need to explore mundane garment maintenance practices, such as mending, as sources of inspiration, through which to inform and refine future garment design practices that challenge mainstream productivist practices, and to create pathways for closing the loop on material waste.

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PLATE
Product Lifetimes And The Environment

Everything that Went Wrong: Challenges and Opportunities in Designing and Prototyping Long-life Garments in a Circular Economy

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Keywords: Design-led Design Research; Production Models; Collaboration; Communication.

Abstract: This paper considers the case of the Service Shirt, a proof of concept prototype made as part of a design researchers in residence programme at a fashion brand, within a scientific research consortium. During the development of the concept to prototype stage, many problems arose. In this paper the two authors - co-creators of the prototype - explore the challenges encountered when confronting the theoretical framework of new circular economy business models with the material reality of design collaboration and prototyping. The authors argue for the potential of design-led investigation to expand the lifecycle of garments and offer new insights to understand the challenges of developing circular prototypes within a linear fashion production model. By analysing the different stages of the design and prototyping phase through a combination of adapted annotated portfolio and after-action review methods, four main elements of the project were identified as potential focal points: collaboration, the design challenge, manufacturing, and materials. Throughout these categories, it was found that communication and effective transfer of knowledge were keys to success. For each of these aspects, the authors suggest how the design process may be improved in future iterations.

Introduction

In the light of current environmental issues, it is widely acknowledged that new practices and business models for the production and consumption of goods must be put forward. The circular economy provides a model for the perpetual reuse of resources in industrial and biological cycles (Webster, 2017:19), and new technology developments enable recovery and recycling of an increasingly wider range of materials are making this increasingly/ attainable (Östlund *et al.,* 2015:15). Moreover, new business models are emerging to challenge linear and wasteful practices (Ellen MacArthur Foundation, 2015:4). In the case of fashion in particular, whole systems need to be redesigned to provide alternatives to the current fast fashion paradigm (Fletcher, 2008).

Yet for these circular models to be applicable to products and materials, they must be designed with their end-of-life in mind from the outset (RSA and Innovate UK, 2016:3). Indeed, design is considered accountable for a large proportion of the environmental impact of goods, pointing at opportunities to implement meaningful change, not only extending lifecycles, but also making sure that end-of-life can be the starting point for new products (Bakker *et al*., 2014). Thus, textile designers are in a valuable position to tackle issues at the very beginning of the design process (Earley and Politowicz, 2013). Yet there is a distinct lack of research from this perspective; this work aims to explore the gap.

Context

In terms of a collaboration with industry, the Service Shirt takes a far-forward, or deliberate extreme perspective on long-life garments, pushing the concept as far as possible to explore the most ambitious components of new fashion systems. The Service Shirt suggests a model in which a polyester shirt goes through a 50-year lifecycle, first being overprinted several times, then combined to an outer layer to become a jacket, and then cut into strips and upcycled into high-end jewellery before being fed into a chemical recycling process at the end of this extended lifecycle. The use and business model surrounding this garment encourages sharing between users and brand responsibility over the resources.

Methods

This research puts creative textile design practice and reflection at the centre of this exploration into new fashion models. The discipline of textile design is characterised by the importance of hands-on making (Igoe, 2013:59; Marr and Hoyes, 2016:3), and this has been used as a tool towards a better understanding of the potential for long life garments in a circular economy and has led to a first-hand experience of the challenges this incurs.

Three designers were involved in the different stages of the garment's transformation, a print designer and lead researcher (author1), a design for disassembly textile designer and PhD researcher (author2), and an artisan jewellery maker. In designing for end-of-life, each had to consider the next stage of the product from the outset of their own design process, and reversely, consider the state the garment would be in when reaching them and inform the designer of the previous stage of their requirements for their 'raw materials'. This meant that the design concepts for each stage of the shirt's lifecycle evolved concurrently, feeding into each other in terms of technical parameters but also of aesthetic inspiration. This sequential and iterative process can be compared to traditional prototyping (Brown and Katz, 2009:94) but the authors reflect through this paper on the ways in which the questions, conversations and decisions differ when making a circular prototype.

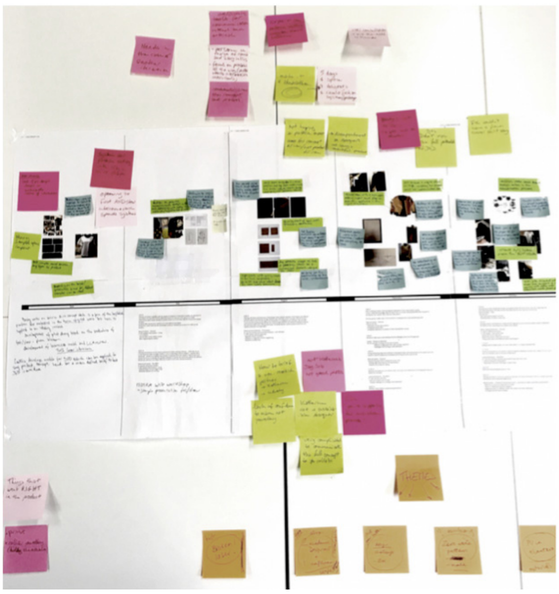

Figure 1. The adapted annotated portfolio process. © Author2.

To aid the reflection process, the prototyping stages were mapped out as a chronological sequence using an adapted annotated portfolio method (Sauerwein *et al.,* 2018:1157) (Figure 1). The insights from this process were then drawn and made into a table in an adaptation of an "After Action Review" (Morrison and Meliza, 1999) or de-briefing phase. Key moments for decision-making and where problems were experienced were identified, leading to a better understanding of the challenges and how they can be overcome and seen as design opportunities (Petroski, 2006:49).

Analysing Shortcomings

The prototype was successful in demonstrating the potential for long-life garments in a circular economy and this collaborative experimental work resulted in a series of aesthetically pleasing and conceptually strong garments. This paper focuses on the elements of the prototypes, either in the process or the result, which the authors consider as having potential for improvement.

Confronting the concepts of a circular economy for textile products to the reality of prototyping and production has led to a number of insights regarding the challenges that this may entail. Indeed, textile designers are versed in "the application of big ideas onto small rectangular pieces of cloth" (Igoe, 2013:19), and the application of these textiles to a garment often comes as an add-on. Here the function and use patterns involved in the garment were included in the design from the first stages, drawing the textile designers out of their comfort zone (Lawson and Dorst, 2009:170), but in the process, leading to ambitious concepts for the systems this garment represents. Thus, bringing together zero waste fashion concepts (Rissanen and McQuillan, 2018) with the use of recycled materials, design for disassembly strategies (Forst, 2018) and upcycling methods (Brown, 2013), and coordinating them as one product, led to a series of obstacles.

These weak spots revealed in the prototyping process born most often from miscommunication, assumptions, inflexibility and technical limitations led the authors to question how the concept would transfer to industry and start proposing how these could be amended in future iterations.

Upon analysis of the process and results of the prototyping, the researchers classified the different “things that went wrong” into four themes relating to elements of the prototyping: collaboration, the design challenge, manufacturing, and materials. Each of these themes led the authors to reflect on how future iterations may be improved.

Collaboration

The circular garment prototyping brought together three designers with different approaches to - and understandings of - products and systems. While this allowed for a rich diversity of perspectives on the work and helped in driving concepts forward through ongoing dialogue, the communication difficulties between the different members of the team led to some challenges which resulted in shortcomings in the final prototypes.

The main barrier was to circulate knowledge across the team. Indeed, while the two researchers had an extensive understanding of circular design parameters, these had to be communicated to the artisan jewellery maker. This led to an understanding that some of the aspects that were essential to the circular garment concept were not an inherent part of this practice and required additional inputs. This for instance, led to the use of superglue in the production of the jewellery which was part of the initial practice but was ill-fitted to a circular garment concept.

Different tools were used by each designer, ranging from hand-sketches and experimental modelling to the use of software programs (Figures 2 and 3). This added difficulty in harmonising the different prototypes into a standardised garment system. Coordinating these different approaches proved challenging and created some extra work and compromises.

To overcome the difficulty in communicating and aligning the expectations for the prototype, closer collaboration between the members of the team could have been beneficial. Indeed, in this project, the collaborative work had to be balanced with other commitments, which made it difficult for all three designers to meet simultaneously and work for any extended period of time. Den Otter (2007) also suggests that in collaborative projects, the means for communication should be agreed on at the start, enabling more effective progress thereafter. In an improved iteration, it could be imagined that the project could be carried out in a “hackathon” format. This would allow to bring the skills of the designers together and limit the need for cross-communication.

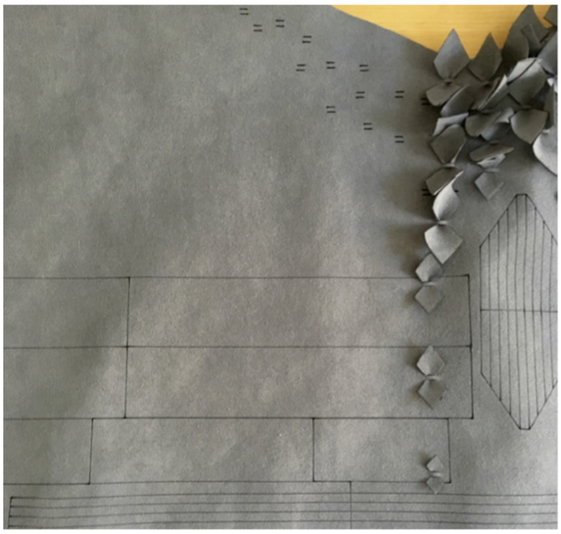

Figure 2. The laser cut garment designed for disassembly based on an Adobe Illustrator file made by Author 2. © Author2.

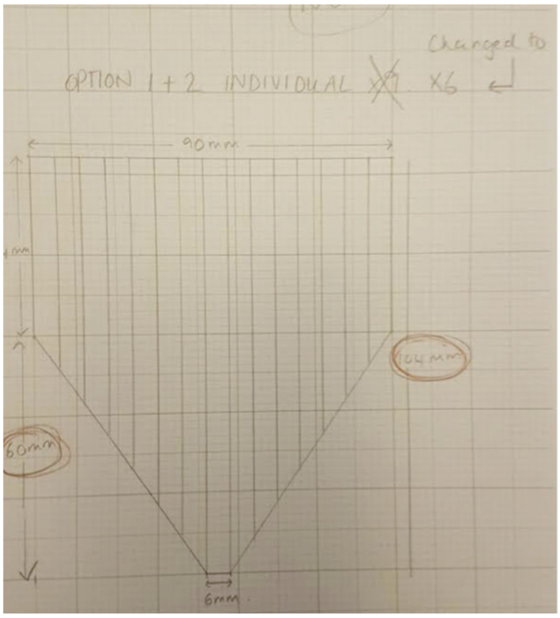

Figure 3. The hand-drawn template for the creation of jewellery which was then adapted into a computer file. © Author2.

The Design Challenge

In order to reduce the environmental impact of the garment, a zero-waste pattern cutting approach was taken. None of the designers involved in the project had expertise in this area and it was felt that bringing in an extra team member would add too much complexity as much time an effort was already invested in the collaboration between the three designers. It was therefore decided to develop a simple zero-waste shape that was within the limits of the skills of the existing team (Figure 4). It was not anticipated how much the simplified shape would influence and limit the aesthetics of the finished garments.

The main aim of the prototype was to demonstrate the potential for a circular garment lasting 50 years in use through a series of remanufacturing stages. Adding a zero-waste component to the brief complicates the message and dilutes the findings. A more selective approach to the design challenge should be taken, picking the right 'battles' depending on the skills available in the team.

In the case where a zero-waste pattern concept should be maintained, then an expert in this field should be brought in. Circular design strategies very often work in clusters (Earley and Politowicz, 2013) and zero-waste would reduce the environmental impact of a long-life circular garment (Peters *et al.*, 2018:22). In order to reduce the need to compromise on the aesthetic aspects of the garment, then a pattern cutting expert should provide key insights at the beginning of the process so that all the parameters of the zero-waste circular garment can be progressed simultaneously.

Figure 4. Making a zero-waste garment prototype. © Author1.

Manufacturing

Given the limited skills of the design team concerning garment construction, help from the fashion brand's mechanist was sought. The fabric was sent to Sweden to be cut and assembled following instructions (Figure 5), however, the zero-waste concept failed to be appropriately communicated and the garments were made following traditional approaches. Furthermore, the finishing of the collar was inappropriate for an exhibition piece in which the inside of the neck would be left visible when presented on a hanger or on a flat table top. These prototypes therefore had to be amended by a seamstress when returned to London.

This failure to communicate circular fashion concepts to the production level is characteristic of the challenges encountered within brands to transfer sustainability targets to the shop floor (Vuletich, 2015:96).

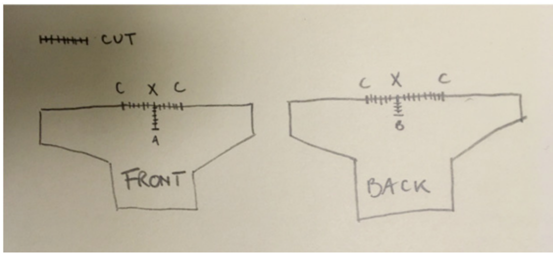

Figure 5. The sketches used to communicate to the mechanist how to cut the garment following zero-waste principles. © Author2.

Within the context of this project, this challenge coincides with the absence of a garment construction expert on the team and with the communication issues due to distance. To facilitate this phase of the prototyping it would be useful to collaborate more closely with an in-house mechanist with whom an ongoing dialogue regarding the expectations for the prototype could be developed.

Figure 6. The cut and sewn shirt. © Author2.

Materials
The materials chosen for the prototype were a recycled polyester for the shirt and lining, and a polyester felt for the outer layer of the jacket. The polyester shirt had beautiful drape and shine qualities, however the felt proved to be too stiff for the pattern of the jacket and gave the garment a boxy look. While this can be a stylistic decision, it felt unplanned to the authors and would benefit from being an aspect of the garment which is more controlled. In addition to this inappropriate quality for the garment type, the felt was difficult to use in the jewellery making techniques, which were subsequently simplified and adapted, to the detriment of the luxurious effect aimed for with these products (Figure 7). Moreover, it was found in later stages of the project that the felt in fact contained a polyurethane binder which causes barriers to the recyclability of the garment, therefore undermining the circularity of the concept.

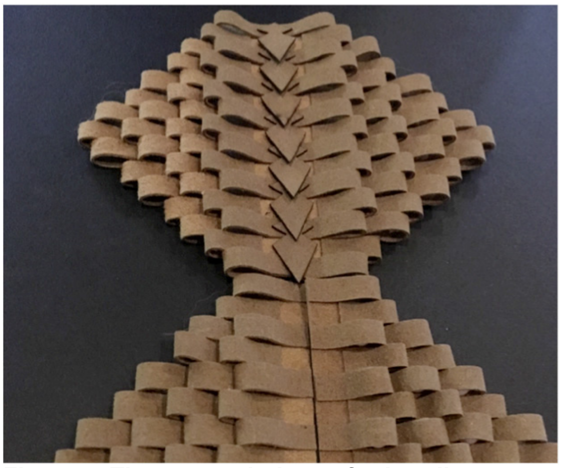

Figure 7. The new techniques for jewellery making based on the polyester felt material. © Source.

These issues highlight the complexities of material sourcing which many designers encounter when attempting to transition to more sustainable practices. Indeed, access to comprehensive information is often restricted. The difficulty in finding appropriate sources often leads to a design process in which the first phases of prototyping are carried out with placeholder materials. While this is common practice in product and interior design (Brown and Katz, 2009:90), when considering garment design, the drape and feel of the material is a major component of the product. It would therefore be useful to start the testing and intermediate prototypes phases with the correct materials and work in closer collaboration with the suppliers so as to better access key information.

Everything that Went Right
It is important to highlight some of the things that went right with the collaborative prototyping process too. Whilst all new collaborations have drawbacks – this one had clear benefits. The finished prototypes were shown in exhibitions in London and Stockholm in 2018 and 2019 (Figure 8), along with innovative work that explored ‘ultra-fast’ circular fashion. Showing and discussing the work in public has stimulated debate with both industry and academic audiences.

Figure 8. The final shirts, jacket and jewellery. © Jelly Luise for Centre for Circular Design, UAL.

Figure 9. The overprinted shirt patterns. © Author1.

The collaboration between the project designers has enriched the respective practices – with the researchers understanding more about craft and industry practices, and the craftsperson understanding more about how research works. The designers at the fashion brand gained new insights from seeing how clothing can be co-designed with accessory designers. The marketing team at the brand could see more clearly that being part of future circular projects would be beneficial. The over-printing shirt approach (Figure 9) gives clear guidance on how printed textile designers can design backwards from an end-of-life plan, using gradually darker tonal aesthetics. This print concept was directly informed by the work the jewellery-maker did.

Conclusion

Overall this paper suggests that to implement circular economy considerations within the design process, this process itself needs to be redesigned. Indeed, a truly circular fashion system cannot emerge from a linear design process. To achieve better outcomes for sustainable fashion, all the stakeholders must be involved in close collaboration at every stage of the design and things going wrong at least in this transition period must be expected and embraced.

The conclusions drawn from the four angles through which the challenges of designing long-life garments in a circular economy were analysed relate mostly to communication and the transfer of knowledge between the members of the design and production team. It is suggested that this type of prototyping could benefit from being carried out by the team in closer collaboration, sharing a studio and experimenting with materials and garment shapes simultaneously.

In a new iteration of the circular garment concept which was carried out following the analysis of the challenges, the insights from this process were taken on board and elements of the design were amended. In a similar way, it is intended for this analysis to allow for future circular design projects to progress with these challenges and opportunities in mind.

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Green Consumption, Green Divestment? Ethical Consumers in the Light of Divestment Practices

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Keywords: Divestment; Sustainable Consumption; Sustainable Design; Lifespan; Cross-cultural.

Abstract: This paper presents findings of research focused on divestment practices and their implications for product lifespans and the environment. Divestment comprises all the activities that include emotional and physical disposal of material possessions. Using a cross-cultural mixed-methods approach, the study compares purchase and divestment practices across four different consumer profiles. Findings show how behaviour on ethical divestment does not match that on ethical purchasing. It is observed that the divestment practices of the study participants are influenced by factors different from those that are relevant at the acquisition stage. Three main components that shape divestment processes are identified: material and immaterial rewards that can be obtained from divestment activities, contextual factors that outline scenarios for divesting items and individual motivational factors. These findings support the need for considering divestment practices and attitudes when designing a new product, in order to encourage ethical behaviours across the entire product lifespan. By considering these elements, this analysis sets the principles for creating a framework that considers the implications of possessions lifespans and circularity of divested items in the pursuit of more sustainable ways of consumption.

Introduction

The goal of this paper is to present preliminary findings of research focused on divestment practices and their implications for product lifespans and the environment. Divestment can be defined as a "point of intersection for practices, where certain forms of engagement with objects have waned or been interrupted, and others have replaced them" (Glover, 2015, p. 127). Divestment also involves a physical or emotional detachment of owners from possessions, including practices such as binning, donating, selling, storing or giving away (Encino-Muñoz et al., 2019).

Numerous studies have shown how current consumption practices are contributing to environmental degradation and social issues, stressing the need for new proposals for transforming consumption patterns and reducing the amount of waste generation. To this end, several scholars have investigated attitudes and behaviours towards ethical practices of consumption. Ethical consumption can be defined as the consumption that takes into account social (sharing, altruism, localism, fair trade) and environmental (waste and resource-usage reduction oriented practices) aspects when making a purchase (Toti and Moulins, 2016).

Studies in this field have tended to focus on the acquisition phase of products (e.g. Geographic, 2009; Peattie, 2010; Nair, 2015). Some of them have established different types of consumers according to sustainable practices when acquiring products, classifying them based on their ethical purchases. Fewer studies, however, have examined to what extent these ethical acquisition practices shape the lifespan of material possessions once they have been acquired. In other words, less is known about if consumers' ethical practices prevail throughout the product lifespan. This topic has a pivotal role in sustainable consumption for the reason that sustainability relates not only to consumption habits, but also to use, disposal and waste generation activities and their motivations.

Users' activities towards keeping (i.e. maintaining, repairing) or divesting (i.e. binning, selling, donating) a product are fundamental for knowing how to reduce impacts of consumption. Opposite to what has been thought about the lifespan of a product, these practices put in evidence the complexity of longevity and its implications, exemplifying how a product lifespan is more than “a property of objects... [or] a rationally calculated number that is inscribed in a product’s design” (Jaeger-Erben and Proske, 2017). When observed under the lens of divestment, lifespan seems to be more a multi-layered theoretical concept that is intrinsically intertwined with users’ daily life experiences. Hence, understanding human practices towards possessions is of great importance for sustainable consumption.

Additionally, the term *green* has been used as a synonym of ethical and sustainable consumption; however, this simplistic approach to analysing consumer behaviour can hinder efforts towards understanding and minimising consumption impact. This study also aims to make a critical revision on the perception of green and ethical purchases: by following consumers’ practices throughout different stages, it is possible to assess replacement and divestment practices and their implications for products’ lifespan.

Methods

A cross cultural, mixed-methods research was undertaken to explore divestment practices in two countries: Mexico and the United Kingdom. The first stage of the research was an online survey conducted to categorise participants according to their attitudes and behaviours towards ethical purchases. This survey was designed based on previous works (Department for Environment and Affairs, 2008; Geographic, 2009; Johnson, 2011; Bemporad et al., 2012) and it was completed by a total of 293 respondents (162 in the United Kingdom, 131 in Mexico). Data was analysed to classify participants into four different groups. These four profiles range from the most ethical consumption behaviours and attitudes to the most indifferent ones as follows:

- Authentic greeners: With a dominant concern about the human impact on the environment, they tend to reduce consumption and buy ethical products. Sustainability values drive their actions. This group also tends to encourage other people to adopt sustainable practices.
- Moderate greeners: Together with their concern about environmental issues, they place personal comfort as a central value. Instead of being exclusively motivated by ecological or social concerns, they feel motivated by comfort, technological developments or any other personal interests that could bring only incidentally environmental or social benefits. Their knowledge about environmental problems could be vast, but it is not their main consumption driver.
- Pragmatic: Direct and circumstantial inputs mostly drive this group. They base their decisions on previous knowledge, price, quality, proximity and motives that are relevant for them.
- Detached: This group do not exhibit any concern about environmental and social issues; instead, they prioritise individual concerns. Their actions have a higher environmental impact – compared with the other three groups – even though their knowledge about environmental issues can be commensurate with any of the other categories. Their decision of not being engaged with sustainability can have different roots: low perceived impact, disappointment on the system, or lack of knowledge.

The second stage of the research consisted of interviews using the Photo-Elicitation method, to investigate participants’ post-purchase experiences with three categories of products that served as units of analysis: clothing, furniture and mobile phones. A thematic analysis was carried out with the aim of understanding not only the participants’ consistency across the stages of the product lifespan, but also concerning the type of goods. For this phase, 30 participants (15 from each country) across the four different profiles were interviewed.

Findings and discussion

Findings of the study reveal the complexity of consumption, as found by other researchers. More interestingly, the study demonstrates that divestment is just as complex, and that it can be better understood if seen as a multi-layered process shaped by individual, contextual and social factors. Findings also suggest that more sustainable ways of consumption can be achieved if divestment factors are incorporated into the design of products’ lifespans.

One of the most noteworthy outcomes is that consumption profiles do not fully correspond with post-purchase activities. The majority of the participants classified as authentic or moderate greeners do not show a resolute interest in keeping their belongings or searching for a sustainable channel for their divestment. The opposite case is also

observed: some participants with low scores for green purchasing expressed the extra effort they make to repair and keep their possessions or to dispose of something in an environmental or socially responsible way. These findings support the need for considering divestment practices and attitudes when designing a new product, in order to encourage ethical behaviours across the entire product lifespan.
Three case studies from the 30 considered during the research are presented in this paper. Oliver and Leo, both Mexican participants and Helen, a United Kingdom participant, were selected to highlight how individual consumption and divestment profiles do not align and how social and personal factors influence the divestment of products. These cases are summarised below and illustrate (i) participants' selection of divestment channels, (ii) their reasons for divesting possessions, (iii) their tendency to acquire second-hand items, and (iv) actions towards keeping their belongings.

Oliver. The story behind a moderate greener

Oliver is classified as a moderate green consumer who frequently acquires products that are environmental and socially responsible, recycles regularly and expresses moderate interest in sustainable features when acquiring something new. Qualitative data show how, even though he is very aware of environmental issues and declares to be implementing changes to live in a more sustainable way, what prevails in his actions towards keeping and divesting possessions is more a self-oriented approach and a strong sense of green identity, highlighting how his actions reflect his concern about the environment and society. His decisions on keeping or divesting possessions are also frequently a resource for making the differentiation of myself versus others:

"…Compared to other people, I am very bad at shopping… I live permanent in conflict because I do not distinguish when clothes are for going out or just staying at home and do the garden; my main objective is to get the most out of my clothes and then donate them…"

Though he emphasises his willingness to be environmental and socially responsible, his decisions frequently reveal that there is a limited intention of making an extra effort to find better ways of divesting his possessions. For example, he often chooses the most frequent channel in Mexico for divesting clothes, which is to donate to their employees (domestic or working for the family business); this is a channel that involves minimum effort. Even so, it is also observed that he feels socially rewarded by his decision:

"…In the case of our employees, you see them, wearing items that were yours and somehow it makes you feel good because someone else is taking advantage of it…"

For furniture, he also expresses strong intentions of being a responsible consumer, trying to keep replacements at their minimum level, because, as he declares, "having an environmental academic background", he is very aware of overconsumption and waste generation issues. However, when tracing how he divests furniture or mobile phones (and electronics in general), it is found that self-negotiations between convenience, practicality and social recognition are the main drivers:

"…to be honest, I also consider as a first option to give it to my employees. The second option would be to take the item to a green point[1] and then the government would be in charge of managing it, but there are only a few of these points around the city and is not practical at all… people tend not to use this service because there is no time, they are quite far… also selling stuff is again, investing time that at this moment I am not able to waste…"

Oliver considers himself as able to buy items from second-hand shops, but not everywhere. There is a contextual component that allowed him to adopt this practice when he was outside the country:

"…when I was living in Canada, or when visiting the United States, I have always made purchases in second-hand shops… now in my context, I don't buy, I am the one who provides the things because sometimes you take so

[1] Waste management establishments run by the government in Mexico where recyclable materials are collected.

much care of your stuff that people would be getting something good…"

By analysing this experience, it can be concluded that these practices are also a matter of receiving social and moral rewards, added to the fact that in Mexico the second-hand tradition is less common and is less socially accepted.

Helen. Detached consumer but engaged divestor

Other layers of complexity in divestment can be illustrated through Helen's practices. She is a detached consumer, with limited interest in ethical purchasing. Although she expresses no shame in replacing items (e.g. furniture for her new home or clothes that she used to like), Helen also indicates that practices such as donating to charities, selling or disposing in an environmentally responsible way are part of her regular practices.

Overall, she is concerned about which channels to choose for divesting her possessions. Motivated by nostalgia, she mentions that for her standard practices are storing and keeping cherished possessions, especially with phones and some other electronics:

"…I regret getting rid of my laptop… It was hard because it was like an old friend, it even had a name and I still feel like I betrayed it. I kept it for a long time, but I stopped using it, so I had to take it to an e-waste recycling point…"

Nonetheless, she demonstrates no hesitation to divest something once she has replaced it. In this case, she is driven by two central values: moral and material rewards. An example can be found in the clothing category:

"…If you become a member of the charity organisation, you get an official number… then you get points with your donations… It is like a membership program… with rewards and everything! Now a major motivator for me is that you get 'nectar' points, which is the latest feature in our relationship with the charity organisation…"

It can therefore be inferred that her motivation for divesting through donation is not solely an altruistic act. She finds herself engaged in a new experience that is partly the beginning of a new consumption cycle and partly the excitement of mastering the donation process, providing a different type of reward. In relation to furniture, Helen openly expresses the relevance of the moral reward component when divesting possessions, which was driven by the feeling of helping an institution from which she benefited in the past:

"…All my furniture that is not from a furniture retailer is from this charitable organisation; so, I feel very grateful to them for providing us with furniture at reasonable prices. Recently, I found out that they were not getting furniture donations, and that fact was a real problem for them. When that happened, we went through a lot of the old bits of furniture of the old house we have not got rid of yet and took it to them in the hopes that this would help…"

Overall, Helen perceives the donation system as both convenient and altruistic; she finds it a resource to get some moral and material rewards. It is an experience that is part of her consumption-divestment ritual, from which she tries to get the most benefits as possible.

Leo. A nostalgic pragmatic

Survey results set Leo in the pragmatic consumers' group. Decisions are efficient, and he does not mention a word related to sustainability, environmental or social responsibility as a consumer. However, by analysing his use and divestment practices thoroughly, a strong commitment to repair and reuse items is observed. Leo defines himself as a practical person when it comes to personal style and technological devices:

"…I can't be bothered about choosing clothes; strictly speaking, I would have to say that the one that chooses my clothes is my wife… maybe for my professional background, I am more into music and books because I am a historian… about my phones, I only replace them because I lose them, and those that I bought are very elemental, just for basic functions."

In the clothing and furniture category, he or his wife invest time and money in repairing possessions. In clothing, he declares to have special techniques through which he can give a shirt a *second life*. He feels particularly proud of his furniture; therefore, he is planning to keep it "for as long as he lives". To illustrate his difficulty to recall any piece of furniture that he divested or that he was planning to divest, he shares his experience with furniture:

"…Just to give an idea, my dining table belonged to my grandmother, it should be from around 1920… I have another one that used to belong to my parents, from around 1950… As you can see I have a few antiques and the goal is the conservation… my wife, which is wonderful for these things, made all the repairs."

In pursuing his aim of reducing consumption and divestment of possessions, he talks about his openness towards second-hand items, declaring "in secret" that he gets clothes from members of his family. This practice builds on the topic raised in Oliver case study: the notion of the socially accepted practices in the acquisition of second-hand items. Morality, in the case of Leo, is also expressed under specific labels:

"…it is a sin to get rid of clothes that are still in good conditions… the only reason for getting rid of them is because they don't fit me anymore…"

This is an interesting case of a religious connotation to classify the moral values of divestment. Leo's motivations are not environmental or social, but their outcome is still aligned with sustainable consumption principles.

The cross-cultural component of the study

Through the cross-cultural comparison, it is possible to detect how context plays a central role in these decisions, not only because it shapes values, but because it provides a structure for adopting specific practices. It is observed that there is a tendency to share similarities between countries more than between participants' profiles: in the case of Mexico, for example, the tendency to reject second-hand items or to donate to employees; in the case of the United Kingdom, the popularity of charity shops as a socially accepted and an altruistic practice. However, the influence of individual aspects on divestment is highlighted, as presented in the case studies, by the fact that the same person behaves differently depending on the type of product: participants were constantly negotiating to decide in which categories of products they want to be ethical. Finally, it is shown that these immediate rewards are mediated by the contextual conditions; this applies to both tangible (i.e. monetary rewards) and intangible (i.e. social recognition) ones.

Conclusions. For what type of divestor are lifespans designed?

This study illustrates the complexities in defining consumers' profiles and the need to consider divestment practices, in particular when it comes to determining strategies for encouraging sustainable behaviours. By identifying the main factors that influence divestment outcomes, this research also demonstrates that divestment is as complex to predict as purchase.

The distribution of behaviour for social or ecological divestment does not necessarily match that for sustainable purchasing. Therefore, it can be concluded that the divestment process is influenced by different factors to those at the acquisition stage. The most relevant can be classified in three groups:

- Material, social and moral rewards that can be obtained through the divestment practices.
- Contextual factors in which possible channels for divesting items are provided.
- Individual motivational factors, e.g. taking advantage of knowledge about a specific divestment practice, which could be linked to self-identity and social recognition.

The importance of considering divestment practices in order to achieve more sustainable ways of consumption can be illustrated by cases like Helen's. She demonstrates a clear engagement in ethical divestment, but ironically these divestment practices find similarities with consumption activities, such as selecting and evaluating goods. Bauman referred to the society of consumers as that in which "everyone needs to be, ought to be, must be a consumer-by-vocation" (2007, p. 55). Divestment activities, then, become more than just altruistic acts. The decision of Helen on selecting a specific divestment channel, its implications and the execution of the activity is an example of how present in contemporary societies is the vocation of being a consumer.

From these outcomes, a categorisation of sustainable divestors can be constructed by analysing drivers and motivations when keeping or divesting material possessions. This analysis sets the principles for creating a framework that considers the implications of possessions lifespans and the circularity of divested possessions in the pursuit of more sustainable ways of consumption.

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Smartphone Reparability Scoring: Assessing the Self-Repair Potential of Mobile ICT Devices

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Abstract: This paper presents our perspective on the reparability of screen-based mobile electronic devices, with a first focus on smartphones. Repair is an effective way to increase the lifetime of electronics, saving material resources and contributing to a lower environmental burden. Transparency regarding the reparability of products can drive the market towards more sustainable designs. Based on previous work and new evaluation tests, and together with recent advances in the state-of-the-art literature, we have further refined our method for assessing the repair potential of smartphones for informal repairers with no-to-low experience. The method consists of a heuristic assessment and a disassembly protocol tracking the disassembly process. The method is used to provide a numerical score for eight criteria, selected by their relevance to capture important information for lay people repairing their own device when replacing only a malfunctioning part. The criteria are: (1) Path of entry; (2) Accessibility of critical components; (3) Availability of spare parts; (4) Availability of information; (5) Type of tools needed; (6) Endorsed repair options; (7) Visual cues; and (8) Health and safety risk. To reduce the complexity of the assessment while preserving comparability, we only take the disassembly of those components into account which are critical to functionality and have an increased chance of malfunctioning, the so-called 'critical components'. For smartphones, the critical components are the display assembly and the battery. Rather than performing a full disassembly, in this approach only the disassembly paths down to the critical components are tracked. To calibrate the method, a set of known outlier devices are assessed and placed at each end of the spectrum. Two flagship smartphone devices are evaluated to show the methods' scoring of representative products in the current smartphone market. This paper will discuss the results of the assessment, observe reparability trends in the current smartphone market, and suggest options for further research.

Introduction

Extending the life of products by means of repair and maintenance is one of the most valuable strategies within the Circular Economy as it uses the lowest amount of resources and energy. In order to help citizens in repairing products and provide transparency about the ability of repairing devices they might buy, iFixit publishes repair guides and reparability assessments (iFixit, n.d.), targeting specifically informal repairers with no-to-low experience in maintaining and repairing electronics. iFixit's reparability assessment method was explored and extended in the context of the sustainablySMART project and presented in previous publications (Flipsen, Bakker, & van Bohemen, 2016; Flipsen & Huisken, 2018). The method was further refined based on additional tests and advancements in the general state-of-the-art literature (Bracquené et al., 2018; CEN-CENELEC, 2019; Cordella et al., 2019a; Cordella et al., 2019b; Kroll & Hanft, 1998; Peeters et al., 2018), which resulted in the current smartphone reparability assessment approach presented in this paper. Our objective is to define an assessment method which is comprehensive while using a limited number of criteria, and yields repeatable and consistent results. This paper presents our perspective on the reparability of smartphones. We have produced a set of eight criteria which are individually scored via a questionnaire and/or by a recording of the disassembly process (referred to as 'disassembly protocol'). A final score is calculated by the weighted sum of all of the individually scored criteria and calibrated with a set of known outlier devices at each end of the spectrum. The score was also calculated for two flagship smartphone models. We will conclude this paper with a discussion of the current setup and possible improvements on the scoring method.

Methodology

iFixit focuses on informal or self-repair executed by lay-people replacing only malfunctioning 'critical components' (abbreviated as CC), and don't perform on board-level repairs or the repair of individual parts. In our scenario, the repair is not executed to upgrade a device or reuse parts harvested from products. Diagnostics are not taken into account - we assume that the fault or failure is known by the repairer at the start of the repair activity. We are aware of the importance of diagnostics for a successful repair, but this is not in scope for this project.

Assessing the accessibility of all components in a device is a complex and lengthy operation. The complexity can be reduced by focusing on a set of 'critical components' (or priority parts as they are referred to in the prEN455554 (CEN-CENELEC, 2019; Cordella et al., 2019a), that sufficiently capture the defining characteristics of the device. Critical components are defined as components which have a high chance of failure during use and which are functionally important. The critical components are predefined for every specific product category as described in (Cordella et al., 2019a). For smartphones, (Cordella et al., 2019b) lists the causes of the main failures and repair requests, and considers the screen, the back cover and the battery as physical critical components. In our implementation, we retain the display assembly and the battery as critical components, but do not consider the back cover to be functionally relevant enough to merit selection.

The criteria used in the original iFixit assessment method were expanded based on an ongoing review of the relevant literature and input from iFixit's own experts as well as members of the sustainablySMART project consortium. In order to make sure that no potentially useful criteria were overlooked, especially from the perspective of self-repair, a list of reparability criteria was also crowdsourced during the Massive Online Open Course (MOOC) on Circular Economy during the fall of 2015. This resulted in 1976 discrete entries from around 400 survey participants, which were grouped and ordered according to their prevalence (Flipsen et al., 2016). A shortlist of criteria was compiled and further refined based on the following requirements:

1. Relevance: the criterion should address an essential aspect of the repair and replace process of critical components within the scope as defined above.
2. Repeatability: the criterion should be measurable in a consistent way, with either measurements, calculations or by checking-off open and searchable items.
3. Volatility: the criterion should be stable over time and exclude highly volatile aspects, such as the prices of spare parts that fluctuate strongly over time.
4. Differentiation: the criterion should allow to distinguish existing products from each other.

Eight final reparability criteria were selected by their relevance to capture crucial information within the repair scenario that was considered. An overview of the criteria and the parameters on the basis of which they are assessed can be found in table 1 and discussed underneath:

1. Path of entry: For a person with little or no repair experience, undertaking a smartphone repair can be very daunting. If the product can be opened quickly and without any special tools, allowing the person who is undertaking the repair to see the parts to be exchanged ("the end is in sight"), this will help build confidence in order to go through with the repair. Conversely, if gaining access to the device is too complicated, there is a high risk that the self-repairer will give up on the repair as a whole. Therefore, the ease of gaining access to the product is of paramount importance for a successful repair. The 'Path of entry' criterion is based on the disassembly protocol and reflects the time required for disassembly and the tools needed to gain access. It assesses how readily the product can be disassembled up to the point where the critical components are visible. The time can either be measured directly or compiled based on the steps as logged in the disassembly protocol. The scores discussed in this paper are based on actual time measurements. The score is inversely proportional to the time required, with the worst performing product in the range scoring zero. The tools are classified according to annex A.4.4 of prEN45554 (CEN-CENELEC, 2019), with additional weight attributed to the need of using a heat source, which is a strong deterrent for many self-repairers.

2. Accessibility of critical components: The time required for the repair as a whole reflects the repair operation's complexity. The more complex the repair, the higher the risk that the repairer will make a mistake, damage a component or simply be discouraged during the repair of before even starting it. The time required for accessing the parts most often needing replacement, is therefore a crucial aspect of the product's reparability. The 'Accessibility of critical components' criterion is based on the disassembly protocol. It assesses the time required to access and remove the parts that were identified as critical components (for smartphones this is the display and battery, see the section about critical component selection). Note that the actual repair process would include the reverse operation (reassembly) which is not measured but which in practice, rarely takes longer than disassembly. As with the previous criterion, the score is based on actual time measurements. Both critical components are accessed independently and the values are summed up. Products requiring over 25 minutes for accessing both critical components individually, get a zero score for this criterion. This threshold, which corresponds to the 75th percentile of the tested samples, was chosen to reflect a feasible attention span for a self-repairer and to allow for sufficient differentiation between products.

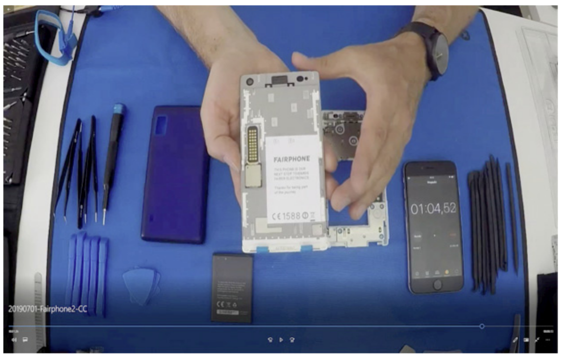

Figure 1. Screenshot from the disassembly video for one of the case study devices investigated.

Both the 'Path of entry' and 'Accessibility of critical components' criteria are measured by recording the time for all activities involved. To measure time and document the disassembly process we have video-taped all disassemblies and clocked every single activity. In figure 1 you can find a screenshot of one of the best-case smartphones disassemblies.

3. Availability of spare parts: In order to repair a product, gaining access to the defective parts - however easily - is obviously useless if a functioning spare part is not available to replace the defective part with. The 'Availability of spare parts' criterion is questionnaire-based. It assesses whether spare parts are made available to the general public. Part availability to professional repairers, whether authorized or not, is not taken into account. The highest weight is attributed to critical components made available by the manufacturer, but the availability of other spare parts is also taken into account, as well as the availability of parts supplied by third parties in case the manufacturer doesn't supply parts to the general public. Any parts for sale that can be found by a Google search for the part number or the model number plus part description, and which are available for delivery in EU countries, are taken into account. While in a sense, the latter tends to reward some manufacturers for an economic reality determined by their market share rather than anything else, it is a very relevant factor in determining the range of self-repair options available, and it does not discriminate against smaller manufacturers as long as they provide spare parts themselves.

4. Availability of information: Self-repairers are heavily dependent on information to successfully complete a repair. The reason for unsuccessful repairs that was most commonly cited by self-repairers in a recent survey of iFixit users was lack of information. Not being able to figure it out and/or not finding a suitable repair guide was mentioned as a cause for one out of three failed repairs (32%) (Duvall et al,, 2016). Therefore, public availability of repair information is considered to be of high importance for assessing a product's ability to be repaired by self-repairers. The 'Availability of information' criterion is questionnaire-based. It assesses whether various types of information such as product and part identification, exploded view and/or parts list, step-by-step guides or instructional videos pertaining to the replacement of each critical component are made available by the manufacturer. Information provided by third parties is not taken into account, unless it is referred to by the manufacturer. Among these parameters, the highest weight is attributed to the availability of step-by-step guides or video guides, respectively. The availability of a parts list or an exploded view in turn takes precedence over other means to identify components such as part numbers printed on components, since these only allow for identification of replacement parts after disassembly.

5. Type of tools needed: The number of tools needed to replace critical components, as well as their precise type and their availability, strongly influence the chance of initializing and successfully finishing the repair. Not having the right tools was cited by 16% of respondents as a reason for unsuccessful repairs (Duvall et al., 2016). The 'Type of tools needed' criterion is based on the disassembly protocol. It assesses how readily the product can be disassembled up to the point where the critical components are removed, based on the tools needed to do so. The tools are classified according to annex A.4.4 of prEN45554 (CEN-CENELEC, 2019), with additional weight attributed to the need to use a heat source, which is a strong deterrent for many self-repairers.

6. Endorsed repair options: Many self-repairers are apprehensive when starting a repair. They can be either reassured or frightened by information provided by the manufacturer about recommended repair options, which may be of decisive influence on their decision to repair a product by themselves, have it repaired, or discard it. The 'Endorsed repair options' criterion is questionnaire-based. It assesses which repair options are endorsed by the manufacturer, based on information provided by the latter regarding recommended options or inversely, options that would void the warranty. In line with the assumed repair scenario, the highest weight is attributed to the endorsement of self-repair. Decreasing weights are attributed to information provided concerning other repair options, the endorsement of independent repairers or the availability of authorized repair services, respectively.

7. Visual cues: Apart from repair guides, information printed on the product itself may help self-repairers to find their way through the repair. Visual mapping and identification of the components (e.g. battery), its fasteners (e.g. screws) and cable connectors (e.g. ZIF) by means of codes, icons or colours can help the repairer to initiate and complete the repair process both with more confidence. It also reduces the chance of overlooking fasteners or connectors and therefore improves the chances of success. The 'Visual cues' criterion is questionnaire-based and assessed during the disassembly process. It assesses whether the type and location of connectors or fasteners is highlighted on the product itself, or inversely whether connectors or fasteners are hidden from view.

8. Health and safety risk: The risk of injury to the repairer influences the repairer's confidence as well as his or her chances of successfully completing the repair. Health and safety risks can therefore pose a major barrier to self-repair operations. The 'Health and safety risk' criterion is based on the disassembly protocol. It assesses the risk of injury to the repairer based on the tools needed to disassemble the product up to the point where the critical components are removed, based on the tools needed to do so. The need for sharp tools, high-temperature tools or chemicals is considered as a health and safety risk.

The overall score of each product is based on the 8 criteria mentioned above. Each criterion is based on several parameters, which are weighted according to their relevance in determining the criterion score. The criteria are in turn weighted according to their importance within the chosen repair scenario (as described in table 1). The three criteria with the highest importance amount to slightly over 60% of the final score. The individual parameter scores are aggregated into a single score though a weighted sum, in line with the approach described in annex A.4.13 of the PrEN45554 (CEN-CENELEC, 2019).

#	Criterion	Parameters	Importance
1	Path of entry	Path of entry time in seconds Number of class D tools required Number of class C tools required Number of class B tools required Requires heat	Very high
2	Accessibility of critical components	Battery disassembly time in seconds Display disassembly time in seconds	Very high
3	Availability of spare parts	Critical components replacement available from manufacturer Other spare parts available from manufacturer Critical components replacement available from independent resellers Other spare parts available from independent resellers The product website displays how long spare parts are available The user manual displays how long spare parts are available Parts are available for 2 or more years after end of production	Very high
4	Availability of information	Unique product identifier present on product Critical component identification present on component Critical component ID leads to replacement component Critical component step-by-step replacement guide available on manufacturer website CC video replacement guide available on manufacturer website Parts list available on manufacturer website Exploded view available on manufacturer website	High
5	Type of tools needed	Number of class D tools required Number of class C tools required Number of class B tools required Requires heat	High
6	Endorsed repair options	Repair does not void warranty Repair voids warranty unless performed by third party repairer Repair voids warranty unless performed by authorized repairer	Moderate
7	Visual cues	Cues facilitate replacement of critical components Connectors and fasteners are highlighted Connectors and fasteners are visible Not all connectors and fasteners are visible	Moderate
8	Health and safety risk	Is the battery hard cased or a pouch cell The battery is not fixed with adhesives The battery is fixed with pull tab adhesives % of battery surface fixed with adhesives Requires gel pad Requires heat gun Requires soldering iron Requires shears Requires wire cutter Requires knife Requires adhesive remover (chemical solvent)	Moderate

Table 1. Overview of the 8 defined criteria and the parameters on the basis of which they are assessed, sorted by importance from very high to moderate.

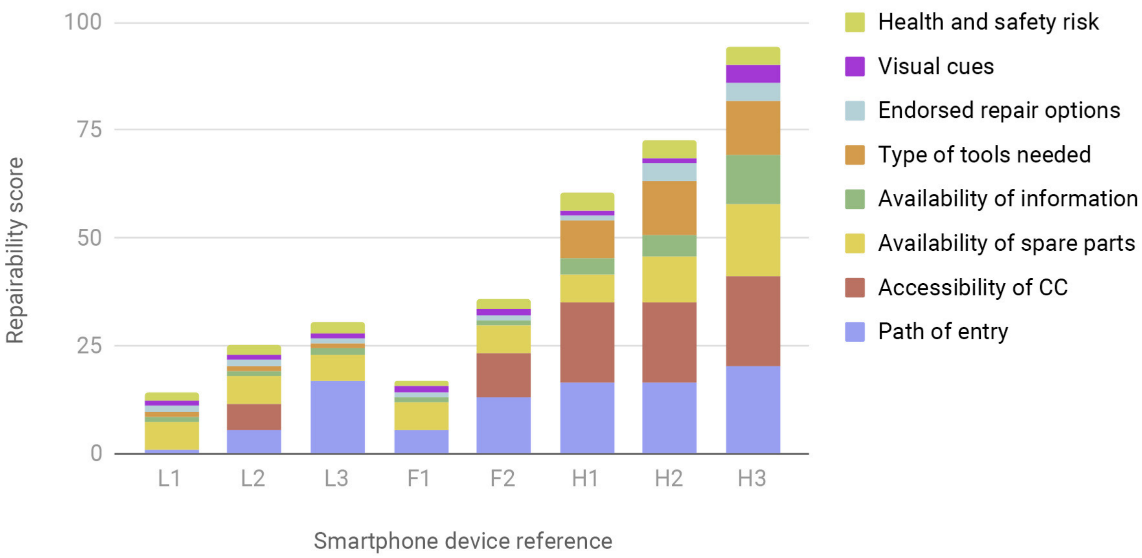

Figure 2. Final score for worst-practice (L), flagship (F) and best-practice (H) devices, subdivided by the eight defined criteria.

Results

Given the repair scenario that underlies our evaluation of products, we have calibrated our method based on a selection of devices that have been on the market long enough for informal repair efforts to be a relevant option at the time of this publication. Therefore, the products chosen are no longer under statutory warranty in the EU or the "burden of proof" for product defects has already shifted to the consumer. Consequentially, we have included only products put on the market until 2018. As a lower limit for product age, we have set the year 2015, the introduction year of the first smartphone design archetype that was established to be easily repaired by its users and marketed as a modular design.

We've chosen midrange to high-end smartphones for our benchmarking efforts. An important reason for this is that neither the few existing, ambitiously modular or reparable designs, nor those with leading-edge ingress protection or durability features (which often make repairs more complicated) are to be found in the lower-end price ranges of the product category. Another reason for focusing on the mid to high range is the ability to cover a significant part of the market by assessing a limited number of products. To attain significant sample sizes faster and reach critical mass, it is promising to focus on brands that cover a large market share with relatively few products. One of the two market-leading smartphone manufacturers, for example, has only introduced 11 new models in the EU between 2015-2018.

We have first selected a number of established outlier devices to map best and worse practices in our assessment system and to calibrate its boundary zones. Three of these devices had formerly been positioned by their manufacturers as highly modular, upgradeable and reparable. These populate the high end of the scale (devices H1, H2 and H3). A corresponding selection of another three products had consistently been confirmed as difficult to disassemble and repair, both in iFixit teardowns and in repair workshops that we have held with students and other laypeople. These populate the low end of the scale (devices L1, L2 and L3). Finally, we added flagship models (devices F1 and F2) from the two market-leading brands which together have consistently held over 50% of EU market share in this device category from 2015-2018 ("Mobile Vendor Market Share Worldwide," 2019).

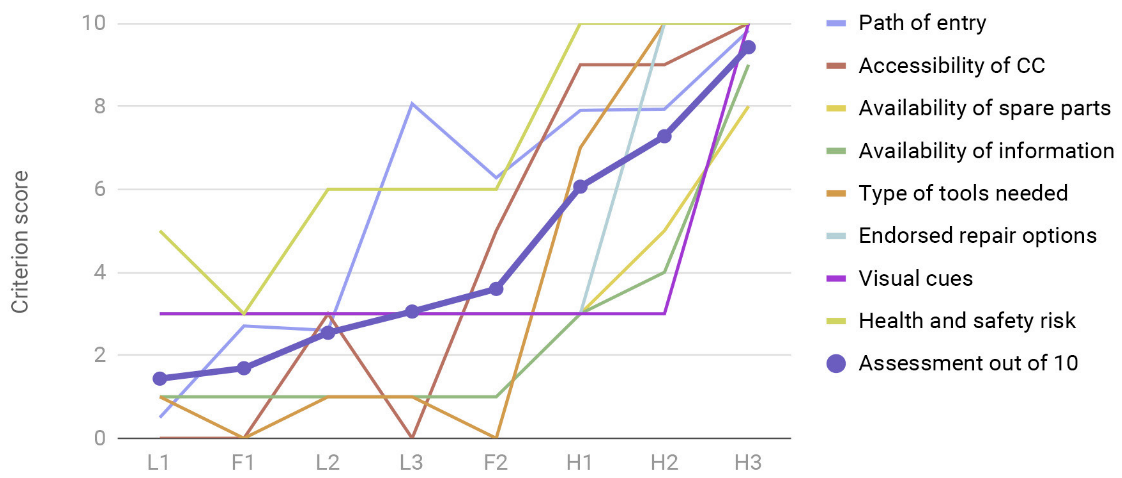

Figure 3. Individual criterion scores for all evaluated devices, ordered by final score.

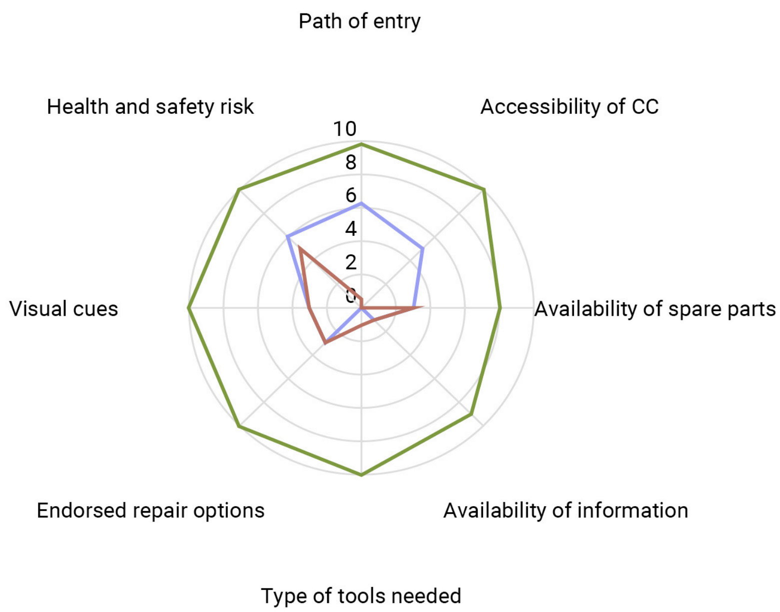

Figure 4. The scores for the separate criteria highlighting the best-practice (H3, green), worst-practice (L1, red) and one of the flagship devices (F2, blue).

The scores for each criterion were calibrated based on disassembly tests of the above-mentioned sample of outlier devices, in order to make sure that the scores would cover the complete spectrum of products on the market and provide sufficient differentiation between products, whilst still keeping some margin at the score extremities for future outliers. Figure 2 shows the weighted individual criteria scores as well as the overall score for the six outlier and two flagship devices evaluated. Figure 3 shows the unweighted score for each of the criteria assessed, for all products ranked according to their final result. It shows the spread of individual criteria scores as well as the correlation between individual criteria scores and final score. Figure 4 maps the unweighted score for each of the criteria assessed in a radar diagram showing the boundaries of individual criteria scores and the performance of the best-performing market-leading device tested (F2).

Discussion

The 'worst-practice' outlier smartphones that we have used to calibrate our scoring system have been assessed at 14 to 31% of possible points, while the 'best-practice' specimen have achieved between 61 to 94% in our current scoring spectrum (figure 2). On the one hand, this leaves some room at both ends of the scale for better or even worse products to be mapped as we grow our product assessment database; on the other hand, it shows that even among the best design archetypes and product support environments we have assessed in this category, achieving two-thirds of the points is already a positive benchmark.

Best-in-class reparability features are far from mainstream in the current smartphone market. The flagship smartphones that we have assessed display many design characteristics of disposable products, and therefore have more in common with the low-scoring outlier devices than with the 'best-practice', highly reparable phones (see also figure 4). Due to aspects like glue use for ingress protection, minimal gap dimensions or proprietary/complex tool requirements, they are relatively hard to open and complex to disassemble; at the same time, they score low in the areas of repair information and spare part availability; their support ecosystems clearly tend to be on the closed-access side of the spectrum. As we add more mainstream products, we expect the median score to be significantly lower than 50%.

When analysing the scores of the 'best-practice' examples in our sample (H1, H2, H3), it is interesting to see that while their different design archetypes are similarly convincing (and high scores have been achieved in various ways), the variation in their scoring has much to do with a broad range of product support strategies: open access implementations, i.e. availability of repair information and spare parts, differ greatly, even in this group of high-performing outlier phones.

One can nevertheless observe a correlation between the various parameters when looking at the data of all smartphones tested (figure 3): products with excellent scores for any given criterion also tend to score fairly well for the other criteria, and vice versa. This suggests that to some extent, all assessed products seem to represent a consistent product development approach, which does or does not aim to ensure the product's reparability across the spectrum of design and support aspects that we assess.

The graphs also provide insight into aspects that are related, but manifest themselves quite independently in some cases: Regarding the product's ease of disassembly, for example, device L3 scores well on the 'Path of entry' criterion, while the score for 'Accessibility of critical components' is very low. What this means in short is that while overcoming the initial obstacle of opening the enclosure is relatively easy in this case, achieving the goal of component replacement remains a difficult task. Inversely, a device can have an outer shell that is quite hard to open (as is the case with device L2), whereas reaching critical components inside is relatively easy once this initial hurdle has been overcome.

Conclusion

Based on expert knowledge and the available literature, eight criteria based on several parameters each were identified to assess the extent to which the two most repair-relevant parts of a smartphone can be replaced by a layperson. The selected criteria consider both the physical product design and the aftersales product support ecosystem, and are evaluated through a questionnaire and logging of the product disassembly. While calculating time for disassembly might offer less variable results, further research is needed in order to obtain representative results for operations specific to this type of repair, such as disconnecting glued parts.

The scores for each parameter and criterion were aggregated into a single score through a weighted sum. The scores were calibrated across a spectrum of known best-in-class and worst-in-class products. While the focus on different reparability aspects varies among manufacturers, a correlation between the performance across various parameters can nevertheless be observed, indicating a fairly consistent strategy on their behalf. It can be observed that mainstream models have more in common with repair-unfriendly devices: best-in-class reparability features are far from mainstream in today's smartphone market.

Outlook

We intend to refine our typology of glued connections in smartphones in order to be able to use proxy time values instead of actual time measurement for capturing the ease of disassembly aspects.

Subsequently, in order to validate the consistency of our method, we will have several operators perform the assessment on multiple samples of the same model of smartphone and investigate the deviation between the scores for the same product.

Lastly, we intend to assess a series of flagship smartphone models amounting to a significant total market share, in order to verify the score calibration across a wide spectrum of models and to assess the prevalence of reparability aspects across the product population.

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A Multi-hierarchical "Design for X" Framework for Accelerating Circular Economy

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Keywords: Design for X; Collaborative Design; Interdisciplinary Approach; Circular Framework; Design Tool.

Abstract: In the past, many frameworks have been conceived in order to support companies and their designers to develop sustainable products. In the circular economy, however, these frameworks no longer appear to be sufficient, due to the difficulty in identifying multiple design strategies for the different product life cycles across time dimensions. By adopting a Design for X (DfX) approach, this paper develops a multi-hierarchical DfX framework that allows designers to incorporate different strategies to better address product life cycles. This framework could facilitate the further development of a more comprehensive and interdisciplinary DfX tool. A key part of the method deployed is an interview guide approach, where five experts from across academia and industry, were interviewed. This qualitative research draws on their diverse expertise and generates an intersectoral link between different fields. Moreover, the DfX tool can be used to highlight relationships between different circular economy strategies, by providing insights into how interdisciplinary design decisions influence each other. Such an approach could allow designers to effectively visualize a bigger picture and positively influence the application and acceleration of the circular economy.

Introduction

Circular product design is a complex and interdisciplinary process. At the early design stages, a variety of designers must make decisions not only about the first lifespan of the product, but also forecasting where, when, for whom and how the product will be reintegrated in the following life cycles, as well as mitigate concomitant objectives in business, engineering, product and service design. Indeed, in contrast to today's linear economy, circular economy (CE) presupposes a constant resourcing cycle aimed at preserving natural assets, maximizing the use of natural capital and decreasing human impacts on nature (McDonough, et al., 2010; Stahel, 2010; Bakker, et al., 2014). This new vision implies a substantial change not only on the product design, but in the entire organizational system of our society. Hence, it is de facto unlikely that an optimal transition will occur if there is an imbalance between disciplines and the system could not be considered as a holistic, complex structure, to be designed and managed (Murray, et al., 2017).

The collaboration between so many fields has always been fundamental to respond to the exponential complexity of systemic thinking for sustainability. Some frameworks, such as Ecodesign Strategy Wheel (Brezet, H., & Van Hemel, C. 1998), Product-system lifecycle (Vezzoli, et al., 2008), Whole System Design (Charnley, 2010) are well known to take in consideration the bigger picture for sustainable and interdisciplinary decision-making. However, these frameworks tend to neglect the different design approaches for the different life cycles of the product, which are essential factors to consider in designing for the CE. For this reason, it is necessary to review these existing frameworks on which the design is often based today and reframe a new and up-to-date framework that also tackles multiple loops.

The first challenge to develop a comprehensive framework among so many variables is to determine a common terminology (Sauvé et al. 2016). Many researchers, published works, conferences and tools make use of the Design for X (DfX) approach to make designers aware about the implications of their design decisions on later life cycle phases of a product. In these

activities, ‘X’ is used as a variable which represents a specific design strategy. Huang (1996), defined DfX as an “imperative practice in product development to achieve simultaneous improvements in products and processes”. Many DfX approaches have also been addressed in the present CE literature (Bakker et al., 2014; Go, et al., 2015; Van Weelden, et al., 2016, De los Rios, et al., 2017 and Moreno, et al., 2017). Therefore, the DfX can arguably be used to map a circular approach, to a sequence of detailed interdisciplinary strategies, acting as a flexible pattern to be applied according to the circular design requirements.
In this paper, through the theoretical application of DfXs, the authors present a framework by which it is possible to hierarchy circular strategies that cover the life cycle of products across temporal dimensions. Furthermore, this paper introduces how the framework could be used for the future development of an interactive and open-sourced design tool.

Methodology

To build robust bases capable of supporting the complexity, information volume, overlapping concepts and the wide scope of design disciplines, a methodology has been structured, in line with Friedman (2003) that comprises of four steps outlined below.
Friedman states that theoretical construction cannot be based on practice. Indeed, it is questionable how critical and systematic thinking can be established based on case studies, that meet specific contextual, productive and temporal requirements. Practice can, however, provide a validation of the questions that were created via theory (Friedman, 2003). Theory can be based on a general structure that can be revised, reformulated and reorganized, according to very precise logic, allowing one to develop a resilient theoretical framework (Webster, et al., 2002).
The research shown in this paper therefore used this theoretical framework consisting of four steps: (1) Discover - an exploratory review of the literature, after which a (2) Define - concept map was defined and developed (3) Develop - three initial hypothesis and finally (4) Validate - the hypothesis was validated through 5 guided interviews (Fig. 1). There are iteration loops from step 4 back to steps 1, 2 and 3. The structure deployed forms part of a larger ongoing PhD research activity and requires further steps in order to develop the final PhD work.

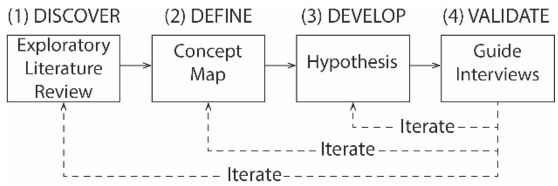

Figure 1. Methodological steps.

Discover - Exploratory Literature Review
To understand and define the main DfX strategies and try to create continuity between them in the various phases of the design process, it was decided to undertake a first research on the most common design practices with respect to the circular economy according to Webster, et al., (2002). The tool used for this research was Google Scholar, the keywords used in multiple combinations were "Design Theory", "Design Disciplines", "Circular Product Design", "Circular Economy", "Design Process", "Systemic Design ","Design for X", and "Design for Collaboration". All the terms were first searched individually and then combined using AND as a conjunction between the different keywords. Along with the material found through the review of the literature, some texts reputed fundamental were added (such as Brezet, et al., 1998, Vezzoli et al., 2008; Stahel, 2010 and Nasr, et al., 2018). All literature generated was considered.

Define - Concept Map

To group and view the findings of the exploratory literature review, the concept map methodology was used. This methodology allows the interdependencies of the different concepts to be connected through logical reasoning (Novak, et al., 2008). Because the goal of the research was to define an interdisciplinary framework, the concept map developed around the word "Design for Collaboration". Subsequently, to give importance to all the design phases, the word “Design for Collaboration” was connected with every single phase of the life cycle of the closed-cycle product readapted based on the frameworks of Brezet, et al. (1997), and Vezzoli, et al. (2008).
This step helped to connect the main influences of different design disciplines with each phase of the product life cycle. For some of the phases of the life process of the product a DfX was assigned in order to establish the possible disciplines which are able to deal with this

design phase. The map presented in Fig. 2 does not intend to be a map that includes all the strategies identified, but only an analysis of key aspects.

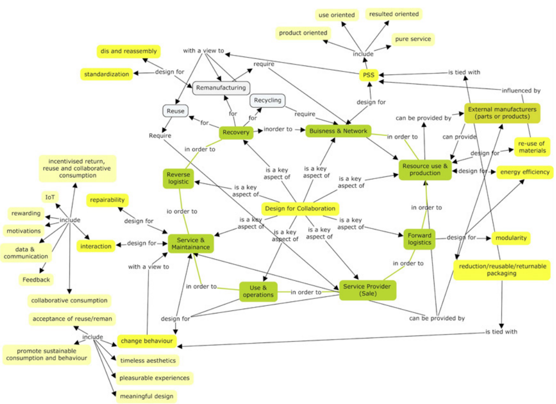

Figure 2. Concept map.

From Fig. 2, a series of observations can be made.

- Some DfXs can be applied by different disciplines / designers simultaneously (Kuo, et al., 2001)
- Some DfXs are applicable exclusively in specific disciplines / designers
- Some DfXs are the consequence of hierarchical decisions (Huang, 1996)
- Some DfXs are mutually non-exclusive
- Some DfXs are mutually exclusive
- Some DfXs are complementar (Van Weelden, et al., 2016; De los Rios, et al., 2017; Moreno, et al., 2017)
- Some DfXs are applicable across time dimensions
- Some DfXs follow different processes in different contexts and times
- Some DfXs are applicable in single and different phases
- Some DfXs can be applied consequently
- Some DfXs can be applied in parallel
- Some DfXs can take effect after the first loop of the product
- Some DfXs may progressively increase or decrease in effectiveness in different loops
- Several DfXs have variable effectiveness on different products

The synthetic DfXs list of observations highlight the complexity of the hierarchization. Consequently, it was hypothesized that a hierarchy of DfXs should follow a multi-hierarchical approach. While a detailed verification of the entire conceptualization presented in Fig. 2 goes beyond the scope of this study, this has been useful to formulate three hypotheses which are the interpretation that resulted from it.

Develop - Hypothesis

Three distinct hierarchies for DfX are conceivable. The first hypothesis relates to the hierarchy of the priority orders of the 'X' strategies. For example, with a view to implement a design strategy for refurbishing (X^1) it is essential, in sequential order, work on design for disassembly (X^2) and then more in detail on design for maintenance (X^3), etc. (Van den Berg, et al., 2015), respectively X^1, X^2, X^3. 'X' may vary in detail in the applied design strategy. The X^1 determines the main circular strategy or in other words Maintenance, Reuse, Redistribute, Refurbish, Remanufacture, and Recycle, whereas X^2, X^3 the possible design strategies to reach X^1. Hence, the first hypothesis is:

H1

To achieve the first degree DfX (X^1) a hyperbolic tree hierarchy diagram, that describes each sub DfX strategy, can be used (Fig. 3).

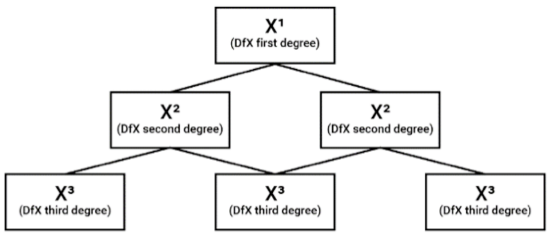

Figure 3. DfX hierarchization based on degrees of priority and design specifications.

Companies organize product development based on the phases of product lifecycle. The choices made during each phase (P) of the process can influence the subsequent phases (Cataldo et al., 2006). In order to achieve X^1, a variety of designers, in different design phases, should coordinate their own DfXs effectively using specific X^2 and X^3. Hence, the second hypothesis is:

H2

Through a circular life cycle phase diagram, it is possible to position any DfX for each phase (Fig. 4).

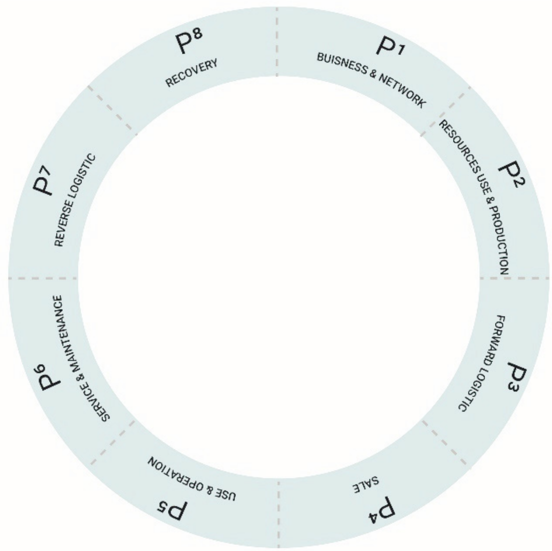

Figure 4. DfX hierarchization based on the phases of the product life cycle.

CE aims at recovering products for many loops by using as less energy and materials as possible for each loop (Bakker et al. 2014). In business terms, the life cycle of the product should last for many loops (L) by using specific combinations of strategies in order to make the business last longer. With that aim, designers should foresee which X^1 should be applied for each product lifetime (L^1, L^2, L^3, etc.) in order to then decide in a hierarchical configuration X^2 and X^3. Hence, the third hypothesis is:

H3

In a spiral loop diagram, DfXs can be applied over multiple product life cycles (Fig. 5).

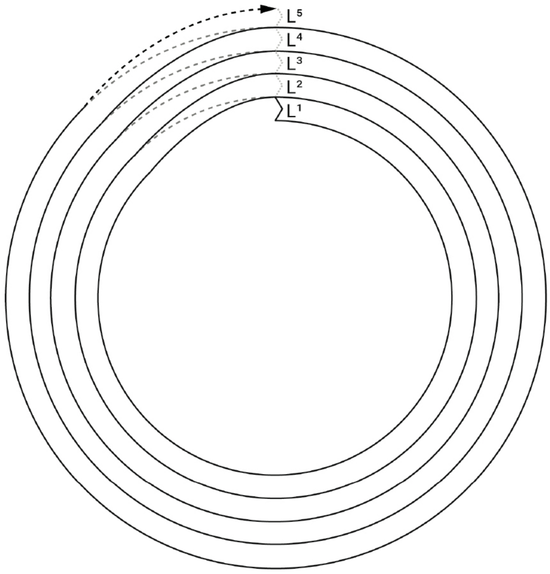

Figure 5. DfX hierarchization based on the different loops / temporal dimensions.

Validate - Interview guide

In the last step of the methodology, an interview with experts from the academic and industrial world through a guided face-to-face interview was undertaken. This methodology consists of asking all the interviewees the same questions, leaving them free to explore specific issues (Patton, 2002) to validate the proposal. A brief description of the profiles and skills of the interviewees has been provided in Tab. 1.

No.	Area of CE expertise	Sector	From
1	User experience and product design	Acade.	USA
2	Transportation and mobility systems	Acade.	USA
3	Consumer electronics, nanomaterials, and lithium-ion batteries	Acade.	USA
4	Policies supporting energy technology, energy systems and information technology	Acade.	USA
5	Product lifecycle design and remanufacturing	Indu.	USA

Table 1. Specification on the competences and origin of the interviewees.

Framework validation

Respondents were informed of the methodological process described above. First, the interviewees were asked whether they found the three hypotheses, Fig. 3, 4, and 5 interdependent and whether a simultaneous use of these hierarchies would have favored an interdisciplinary decision-making on multiple temporal dimension. Subsequently, the specific requirements of the hierarchization of the three dimensions and the potential of a possible tool on the basis of hierarchization were examined. The areas considered in this phase included the requirements related to the application of different strategies in terms of application, relations and management of the different DfXs by different designers. The interviews provided valuable information on the possible hierarchy of DfX, validating all the processes which led to formulate the final framework (Fig. 6). Some key comments can be summarized in two categories, multi-hierarchies and use of the future tool.

Multi-hierarchies' considerations:

- The choices made in L^1, P^1 influence all the remaining choices;
- The design process always begins with L^1, P^1 but may not proceed in sequential order;
- X^1 is the only objective of each phase (P) and each loop (L);
- X^1 varies with the variation of Ls;
- X^1 should be the only target, while X^2 and X^3 may vary in both number and importance depending on the product;
- The common denominator from which to select the DfXs is the cost, to then refine the selection of subsequent strategies;
- X^2 represents the specific strategy for each phase;
- The hierarchy of contents should be standardized to the various disciplines and easily integrated within different companies;
- The choices of the DfXs is influenced also for each loop by external factors such as politics, technology, society, and culture;

Considerations for the future tool for the future tool:

- The tool must be able to simplify the vision but at the same time to maintain a scientific rigor;
- The tool should help to manage the overhead of designing alternatives by defining basic objectives to focus on;
- The tool should help the designer to establish the priorities of the different DfXs in a dynamic and intuitive way;
- To facilitate control by system designers, there must be a mechanism capable of showing quantifiable information flow for prioritizing different DfXs;
- Through case studies, it is possible to facilitate an immediate understanding of the strategy applied in reference;
- The hierarchy is not only direct but also indirect between the different disciplines, so the relationships between different DfXs should be emphasized jointly;
- Different companies could have variable departments and structures and not have complete control of the design process, the tool should be able to be used cross-companies;
- Companies may be able to tailor their approach to different needs;

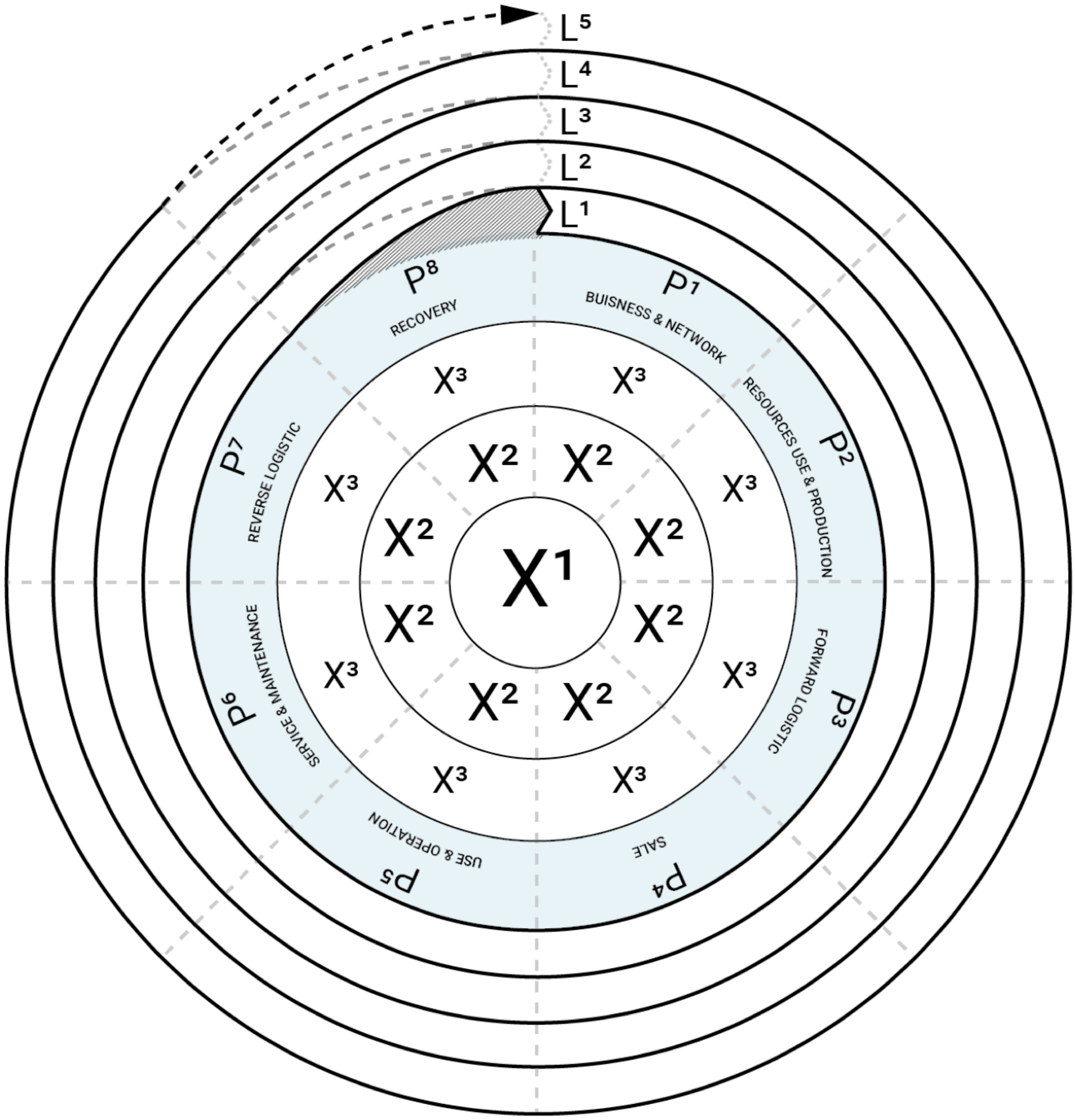

Figure 6. Multi-hierarchical DfX framework.

Circular Design Tool: future development and concluding remarks

In a circular context, the good organization of the different DfX strategies is the key to increase profitability across multiple loops. This paper presents a *Multi-hierarchical DfX Framework* that will shape the basis of an interdisciplinary tool. The tool will help designers to identify for each loop (L) a circular objective, defined here as a X^1 strategy, which might be maintenance, reuse, redistribute, refurbish, remanufacture, or recycle. All appropriate DfX strategies to pursue directly the achievement of the X^1 can be considered X^2 strategies. The same principle applies to the X^3, X^4 and so on. When designing for a new loop, the X^1 strategy may change. If so, X^2 and X^3 strategies may change accordingly. Different designers (e.g. business, engineers, product or service designers) should be able to set an appropriate combination of X^2, X^3 in order to achieve X^1.

Through this tool, designers will be able to dynamically compare and identify DfX strategies from the early stages of the design process. In order to make the management of the complexity easier, the tool can suggest correlated DfXs based on the X^1 identification for each loop (Fig. 7). This could help designers in coordinating relations between design strategies for three reasons; the first reason is to manage the interdependences between different strategies. For example, if the designer decides that X^1 in the L^1 is Design for Refurbishing, in L^2 P^4 a consequential logical X^2 is Design for Change Behavior and X^3 could be Design for Consumer Acceptance of Refurbished Product (Pazhani, et al., 2014; Van Weelden, et al., 2016). The second reason is to exclude the strategies that conflict one another. For example, if the designer decides that X^1 in the L^1 is Design for Recycling, in L^2 P^5 the X^2 cannot be Design for Attachment and Trust. The third and last reason is to help monitoring and forecasting crucial DfX strategies. For example, if the designer decided that from L^1 to L^4, X^1 is Design for Remanufacturing, the designer should define if X^2 in P^8 is Design for Closed Loop Supply Chain Networks, or instead Design for Open Loop Supply Chain Networks (Ene, et al., 2014). These decisions could completely change consequential strategies in the other loops.

This research is a step forward to the mastery of the circular design strategies. More research is needed to collect and map DfXs according to the multi-hierarchical framework presented in this paper. A first prototype of the tool was developed and made available at www.circulardesign.it.

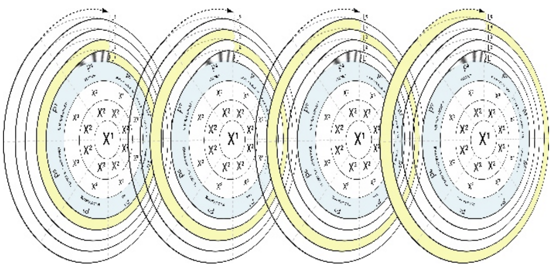

Figure 7. Visualization of the initial decision-making process of X^1 related to each loop.

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Product Lifetimes And The Environment

The "Making" of Product Lifetime: the Role of Consumer Practices and Perceptions for Longevity

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Keywords: Obsolescence; Consumer Practices; Product Longevity; Perception of Use Time.

Abstract: In two studies we explored how electronic devices' use times are influenced or "made" by users and their (d)evaluation and usage practices. Research questions were: What meanings do users attribute to use time? How are these meanings linked to realized, expected and ideal use time? Is use time linked more to attitudes and meanings or to situational factors such as social and material setting? Communicative, symbolic and setting-related predictors of washing machines' and smartphones' use time were tested with multiple regressions. A preliminary online survey (*N*=2.000) explored communicative predictors. It was followed by a face-to-face interview survey (*N*=350) that further included social and material setting. In both studies, the attractiveness of newness was the strongest predictor both for the realized, expected and ideal use time of washing machines and smartphones. Study 2 identified device attachment and the personal norm for longevity as further predictors for longer ideal use times. Results suggest that attractiveness of newness can directly shorten use time, whereas personal norm or responsibility for longevity and the setting may be more distally linked to use time.

Introduction

Our current "metabolism" of electronic devices has detrimental consequences both by severely overstepping planetary boundaries in the case of resource or land use as well as CO_2-emissions, and due to bad working conditions and human rights violations in the process of production and disposal. A longer use phase of devices can reduce resource consumption. The lifetime of products is more than an average number; it is the result of a dynamic process on a at least two dimensions (see also Jaeger-Erben & Proske 2017, Proske & Jaeger-Erben 2019): The *material dimension* where material lifetime is determined by practices of design, creation, appropriation, usage, care, and disposal in systems of consumption and production. The *communicative or symbolic dimension* refers to the production of meaning (Jaeger-Erben & Hipp 2017): What is a product needed for? How is functionality perceived and expected? When is it perceived as antiquated and outmoded? Meanings are a constitutive part of all social practices, they socially justify actions and decisions and embed production and consumption practices in overarching cultural contexts (Schatzki, Knorr-Cetina, & Savigny, 2000; Warde 2005).

This paper focuses on how the realized or actual product use time (*material dimension*) and the expected or ideal use phase (*communicative dimension*) are affected by the user's perception of meaning. It is based on the assumption that users have a relevant influence on product use time by their choice of products, their usage and maintenance practices as well as by their evaluation and devaluation of a product (Hipp 2019, this volume).
Research shows that users often dispose of their electronic devices even if they still work. This can occur due to functional insufficiencies, due to economic or fashion-related reasons such as the attractiveness of new products, but also due to situational factors such as moving houses or changes in the context of use (Cooper, 2004; Granberg, 1997; Jaeger-Erben & Proske, 2017, Hipp 2019). Furthermore, personal norms and values, such as environmental concern, may also encourage or hinder decisions that lead to a longer useful product life (Antonides, 1991).
Yet, to what extent can these factors predict the realized use time of devices? The following paper seeks to answer this question on the basis of two surveys that focus on user experiences as well as behavioural, perceptual and knowledge-related determinants of

longevity. Whereas the first study had an explorative approach, elements of practice theory where applied in the second study.

Theoretical background and Research questions

Our basic conceptual proposition is that the determinants of product lifetimes need to be defined alongside a three-way relationship between design (i.e. designers including production/ producers), consumption (users) and the object. Consumer goods are seen as "becoming" in the course of their biography, a process where they are "neither finished nor inviolable forms at the points of production and acquisition, but […] continually evolving, positioned within and affected by an ongoing flow of […] practice." (Gregson et al. 2007. 250). We refer to the concept of Akrich (1992), who characterizes the "making" of a valuable object as a process of "inscribing" certain qualities, characteristics and functionalities into a product by the designer or producers and the process of "describing" an object by using it. While the inscription is formed by the designer's imaginaries about the user, the description is evolving in "real-time" usages in everyday lives. Like this, some inscribed qualities might not be used or useful, and some descriptive usages might obscure the intentions of the designers. Both, design and consumption are structured by the designer's and user's practical know-how of objects' technical and functional properties, their usage frameworks and contexts. On the side of the user, the everyday life as well as the cultural context are important. What are typical usage practices, what is done for product maintenance? What do consumers expect from their products concerning their use time? Based on different empirical findings as well as conceptual assumptions an exploratory survey (study 1) was developed that covered the communicative, symbolic and material dimension of consumption practices and tried to shed light on the relation between the perceptions of and experiences with use time, attitudes concerning the product responsibility of producers and users and attractiveness of newness.

Both study 1 and 2 focused on smartphones and washing machines as two contrasting products, based on the classification of Cox et al. (2013) who distinguished three classes of products: 'Up-to-date', 'Workhorse'' and 'Investment' products. While the acquisition decisions of 'up-to-date' products such as smartphones tend to be more often driven by appearance and technology changes, 'workhorse' products such as washing machines are prized primarily for their function and their reliability (Cox et al., 2013). Thus, we expected differences in the perceptions, meanings and experiences of users for these two product types.

1st study: Online survey

Method

Sample. The initial sample consisted of 2.000 participants, who were representative for the German population between 14 and 66 years of age.

Design & Procedure. The online survey took place in 2017, with recruitment over a panel institution and coupon reimbursement for participation. Participants were invited via the institution's platform and the sample was curated by screen-out conditions so that representativeness for age, education, income and gender was given.

Measures. The self-reported *realized use time (material practice)* of the previous electronic device was assessed by asking how many months the previous smartphone had been used, and how many years the previous washing machine had been used. The *expected use time (communicative practice)* for washing machines was assessed by inquiring how many years a washing machine should last; for smartphones, by how many months they should last. The *interest in gaining knowledge on prolonging use time* was measured as interest in topics related to user engagement in prolonging use phase with 5 items ranging from 1 = no interest to 3 = big interest, α = .85, e.g. 'how to maintain devices so they have a long lifetime', 'how and where to find repair services', 'how to repair devices myself'. *Attitudinal factors* were assembled in an exploratory fashion, based on previous research. 29 items were assessed by a 4-point Likert scale ranging from 1 = does not apply to 4 = fully applies. *Socio-demographic variables*. Age, education, household income, number of people in the household, gender.

Statistical analysis. Data were analysed using multiple regression in SPSS, with an explorative factor analysis determining attitudinal factors in the model. If necessary, variables were trunked, with outliers (< M + 3.29* SD) recoded to scores the highest value within this range (Tabachnick & Fidell, 2007).

Results

The outcome variables for the washing machine were *M*(*SD*) = 10.13(5.39) years of use phase of the last washing machine (*N*=1519) and participants stated the expectation for use time for a washing machine to be 14.00(7.60) years (*N* = 1757). The last smartphone they had owned had lasted *M*(*SD*) = 24.30(17.14) months (*N*=1472), however, they would prefer *M*(*SD*) = 47.55(27.67) months (*N* = 1813) - four years - as expected use time.

To extract attitudinal factors, the items were analysed in an exploratory factor analysis (Varimax, rotated). Kaiser-Meyer-Olkin (KMO = .91) test verified the sampling adequacy for analysis. Six factors had Eigenvalues over 1, explaining 54% of the variance and were used in further analyses: responsibility for longevity attributed to the producer (10 items, α=.85, e.g. 'Producers of electronic devices should pay more attention to longevity when designing products.') and to the user (6 items, α =.74, e.g. 'consumers should be more careful with their products so they last longer.'), attractiveness of newness (7 items, α=.85, e.g. 'Having new devices is life quality to me.'), satisfaction with the status quo of product longevity in society (2 items; e.g. 'I am satisfied with my rights as a consumer.'), indifference about product longevity (2; e.g. 'I don't have time to maintain devices.') and the purchase criterion of longevity (2; e.g. 'I buy devices that are more expensive but last longer.').

Next, these antecedents, with the interest in prolonging use phase and socio-demographic control variables were entered in multiple regressions for each the realized use phase of the last product and the expected use phase for this product both for washing machine and the smartphone (tab. 2, Appendix 2). In all analyses, assumptions were fulfilled as independent errors (Durbin-Watson) and no multicollinearity (VIF < 10. Tolerance > 0.2, Bowerman & O'connell, 1990).

The realized phase of the last washing machine was negatively predicted by the attractiveness of newness, whereas the other factors were not linked to the use phase. Age positively predicted the use phase, and the number of people in the household negatively predicted the use phase. For the last smartphone, attractiveness of newness also had a negative association, user responsibility had a positive association, men were more likely to have a longer use phase, and the number of people in the household was negatively linked to use phase.

Looking at the expected use phase of both washing machine and smartphone, again the attractiveness of newness was the strongest predictor: The more positive newness was for participants, the lower their expected use phase was. This effect was stronger for smartphones than washing machines. In both cases, responsibility attributed to the user was positively linked to the expected use phase. The interest in prolonging the use phase was only related to the expected use phase for smartphones, but not washing machines. The longevity purchase criterion was only associated with expected use phase of the washing machine. Age was associated with a longer expected use phase of smartphones but not washing machines, and the more people lived in the household, the shorter the expected use phase of the washing machine was.

2nd study: Face-to-face interviews

Next, the explorative results of the first study were put in context with practice theory, shifting the focus towards structural and societal factors (as proposed by Jaeger-Erben & Hipp, 2018). These included competence as well as the material and social setting for longevity and repair. Relevant attitudinal predictors from study 1 were subsumed under the practice theory element 'meaning'. Table 1 gives an overview on the factors considered in the second study, as well as their origin.

Dimensions and variables	**Related research**
Communicative dimension (Meaning)	
Expected or ideal use time	Wieser & Tröger (2015)
Attractiveness of newness	'Up-to-date' mindset, Cox et al (2013)
Responsibility of user/ producers; personal norm	Personal norm, Schwartz (1977); Stern et al (1999)
Purchase criterion longevity	'Investment' mindset, Cox et al (2013)
Indifference, status quo satisfaction	Amotivation, Pelletier et al (1999)
Indifference, status quo satisfaction	Amotivation, Pelletier et al (1999)
Material and behavioural dimension (Setting)	
Realized use phase	Jaeger-Erben & Hipp (2018)

Competence, practical knowledge on repair	Maintenance practice, Graham & Thrift (2007); Gregson, Metcalfe & Crewe (2009); Repair competence, Hielscher & Jaeger-Erben, this volume
Material and social setting	Shove et al (2012); Woodward (2013)

Table 1. Overview of dimensions and variables of the exploratory survey.

Method

Sample. The preliminary sample used for these analyses consisted of *N*=350 participants, who were recruited applying the ADM sampling system. Interviewees were at least 14 years old, with no upper age boundary. This sample was not representative, as data collection is ongoing; the total sample will be *N*=1000.
Study Design and Procedure. Participants were visited at their homes and were questioned in a face-to-face (f2f) interview in 2019.
Measures. The *realized use phase* was assessed as in study 1. The *ideal use phase* was assessed with the question ‘If time and money were no concern, how often would you ideally want to replace the product?’ Answer options were either a time period or ‘I would prefer not to replace the product at all.’. As a dependent variable in analyses, all statements over 6 years and not wanting to replace the product were coded as ‘more than 6 years’. Predictors were all examined by self-report on a 5-point Likert scale, mostly with the option of ‘I don’t know / does not apply to me’. These predictors are described in the appendix 1: attractiveness of newness, device attachment, personal norm for longevity, repair competence, social support, material and infrastructure setting. All constructs were assessed product-based, except the general personal norm for longevity.
Statistical analysis. Analyses were conducted as described in study 1.

Results

The realized use phase of the last washing machine (*N*=226) was *M*(*SD*) = 9.96(6.52) years, the ideal use phase (*N* = 322) was 5 years or less for 19 %, 6-10 years for 20 %, between 10 and 50 years for 4 %, and 55 % of participants stating they did not want to replace their washing machine for a new one at all as long as it still works. For the smartphone, the realized use phase of the last smartphone (*N* = 240) was *M*(*SD*) = 32.23(18.31) months, the ideal use phase (*N* = 329) less than a year for 15 %, 2 years for 30 %, between 3 and 10 years for 15 %, and 40 % of participants do not want to replace their phone.
As seen in fig.1, the personal norm and purchase criteria of longevity on average scored higher than attractiveness of product newness. Device attachment was higher for smartphones than washing machines, whereas participants’ repair competence and material setting for repair was in general low.

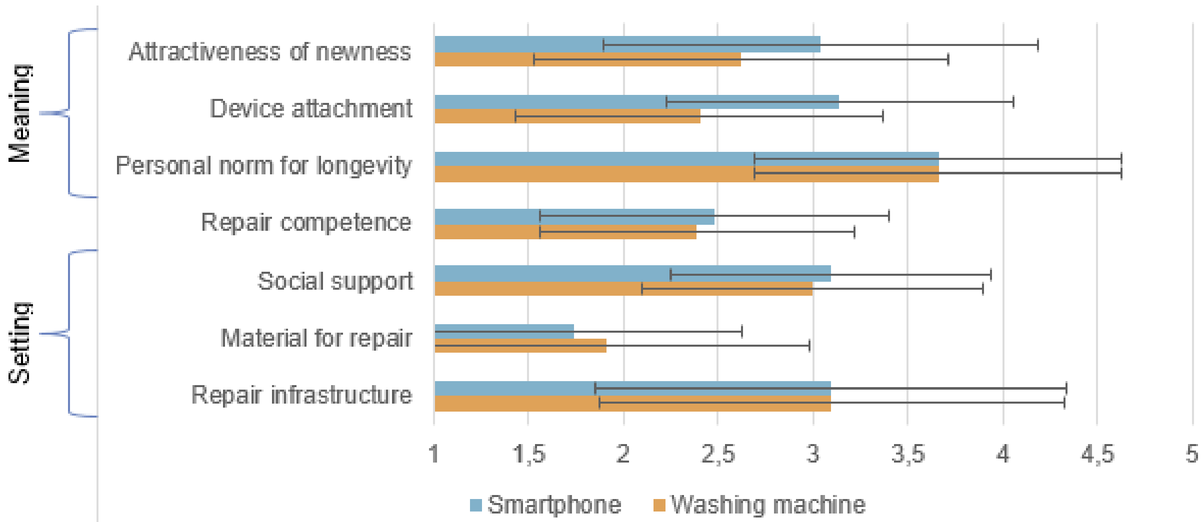

Figure 1. Frequencies of predictors for the two products smartphone and washing machine.
Notes. Interview: N = 334, Range: 1 = low, 5 = high. Error bars = +1/-1 standard deviation.

Assumptions for multiple regression (tab. 3, Appendix 2) were fulfilled (Durbin-Watson, multicollinearity). The realized use phase of washing machines was negatively predicted by the attractiveness of newness (β = -.17) and positively predicted by age (β = .22). For ideal use time, a negative link to attractiveness of newness (β = -.26) and a positive link to the device attachment was found (β = .19). Contrary to expectations, the material for repair negatively predicted the ideal use phase (β = -.18). Regarding smartphones, realized use phase (β = -.19) and ideal use phase (β = -.42), were also negatively associated with the attractiveness of newness. For its ideal use, a positive link to personal norm (β = .23), a positive link to income (β = .18) and a negative link to people in household was found (β = -.17).

Discussion

The use time of the last washing machines was about 10 years in both studies, compared to 12 years in a study by Wieser and Tröger (2015), for the last smartphone use time was lower in study 1 (2 years) than study 2 (2.6 years), compared to 2.7 years found by Wieser and Tröger (2015). The ideal and expected use times were higher than realized use times, showing that users have an interest in increasing product longevity. This also shows in fig.1, where the personal norm for longevity exceeds the attractiveness of newness.

Both the exploratory online survey and the f2f interviews find that overall, the attractiveness of owning new devices is the strongest predictor for both shorter realized and ideal use times of washing machines and smartphones. Further, the use time of smartphones was associated more strongly to the attractiveness of newness, than the washing machine's use time, verifying Cox's categorization into up-to-date and workhorse products (2013).

Additionally, in the online survey the perception of producer responsibility for longevity was linked to the expected use time, yet it had no connection to actual longevity of products. Interestingly, the longevity purchase criterion only correlated with the ideal use time of the last washing machine, but not the last smartphone, and realized use times were not associated at all. In the f2f survey, the personal norm for longevity could only predict the ideal use time of smartphones, whereas device attachment only predicted ideal use time of washing machines. Other factors, especially related to setting, were not linked directly to use times. A possible explanation may be that whereas users' wish to replace a product by a newer one directly shortens use time, the capability to keep a product as long as possible, as most users intended to do, is restrained by situational factors such as product qualities. These setting factors may be more distally linked to use time.

Conclusions

Overall, the attractiveness of owning new devices was the only predictor significant for all use times, realized (material practice) or ideal (communicative dimension). A practical implication to foster device longevity may be to pursue a more positive societal meaning of and attitude towards 'old' products.

Other predictors were more products-specific, such as the attachment to a specific device, personal norm for longevity or felt user responsibility, all of which were only linked to the expected or ideal use time. User intentions to keep their devices as long as possible do not seem to directly translate into longer realized use times, indicating behavioural barriers. To understand these results better, more research is needed.

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Appendix 1: List of items study 2

Attractiveness of newness (Meaning; α_{wash} = .81, α_{phone} = .70)
It is important to me to use a device that is of the newest technology.
To own the newest model is life quality to me.
It feels great to have a brand new device.

Personal norm (Meaning; α = .81)
I feel obliged to use devices for a long time.
No matter what others do, my own values tell me not to throw away devices unnecessarily.
To buy a new device when the old one still works would give me a bad conscience.

Device attachment (Meaning, adapted from Schifferstein & Zwartkruis-Pelgrim (2008)*; α_{wash} = .76, α_{phone} = .77)*
I am attached to the device that I own now.
My current device is very dear to me.
My current device has no special meaning for me (-).
My device is an object of utility that I don't mind replacing (-).

Competence (α_{wash} = .68, α_{phone} = .78)
I know how to care for and maintain my device.
I understand how my device is constituted and how it functions.
I know what to do if my device is not working.
I inform myself about the device in the media, internet or newspapers.

Social setting (α_{wash} = .71, α_{phone} = .69)
I can ask people from my surroundings about tips on how to care and maintain my device, so it will last longer.
I know nobody who I could ask for support if my device does not work (-).
People in my surroundings help me if necessary to repair or let repair the device.
I can ask people in my surroundings if repairing a device is worthwhile.

Material setting for self-repair
I have the necessary tools to be able to repair my device.
I have sufficient access to information with which I can repair my device.

Infrastructure repair service
In my vicinity there are enough providers that can repair my device.

Appendix 2: Full analyses study 1 & 2

Table 2. Study 1: Multiple regression analyses predicting the ideal and realized use phases

	Washing machine										Smartphone									
	Realized use phase					Expected use phase					Realized use phase					Expected use phase				
	B	*SE*	*β*	*t*	*p*	*B*	*SE*	*β*	*t*	*p*	*B*	*SE*	*β*	*t*	*p*	*B*	*SE*	*β*	*t*	*p*
(Constant)	5.07	1.34		3.78	<0.01	9.36	1.53		6.13	<0.01	10.98	4.32		2.54	0.01	5.15	6.47		0.8	0.43
Interest in prolonging use phase	0.30	0.23	0.03	1.31	0.19	0.13	0.27	0.01	0.49	0.62	-0.48	0.77	-0.02	-0.62	0.53	-2.33	1.14	**0.05**	-2.05	0.04
Responsibility attrib. to producer	-0.66	0.34	0.06	-1.97	0.05	-1.5	0.38	**0.11**	-3.92	<0.01	0.44	1.1	-0.01	0.40	0.69	-4.4	1.63	**0.08**	-2.7	0.01
Attractiveness of newness	0.72	0.24	**-0.09**	3.01	<0.01	1.37	0.28	**-0.14**	4.94	<0.01	3.98	0.8	**-0.16**	5.00	<0.01	11.52	1.17	**-0.27**	9.87	<0.01
Responsibility attributed to user	-0.03	0.33	0.00	-0.08	0.93	-0.13	0.38	0.01	-0.33	0.74	-2.78	1.04	**0.09**	-2.66	0.01	1.48	1.58	-0.03	0.94	0.35
Satisfaction with status quo	-0.35	0.21	0.04	-1.67	0.10	0.14	0.24	-0.01	0.57	0.57	-0.32	0.69	0.01	-0.46	0.65	1.20	1.02	-0.03	1.18	0.24
Indifference	0.34	0.21	-0.04	1.63	0.10	0.34	0.24	-0.04	1.44	0.15	0.89	0.68	-0.04	1.31	0.19	0.89	1.01	-0.02	0.87	0.38
Purchase criterion longevity	-0.18	0.20	0.02	-0.89	0.37	0.64	0.23	**0.07**	2.75	0.01	-0.2	0.66	0.01	-0.29	0.77	0.71	0.98	0.02	0.72	0.47
Age	0.08	0.01	**0.23**	8.23	<0.01	0.02	0.01	0.04	1.54	0.12	0.05	0.03	0.05	1.62	0.10	0.13	0.05	**0.07**	2.87	<0.01
Gender	0.09	0.26	0.01	0.36	0.72	-0.14	0.30	-0.01	-0.47	0.64	2.03	0.86	**0.06**	2.36	0.02	2.94	1.26	**0.05**	2.33	0.02
Education level	0.16	0.12	0.03	1.3	0.19	0.16	0.14	0.03	1.11	0.27	0.67	0.37	0.05	1.78	0.07	0.65	0.56	0.03	1.17	0.24
Household income	0.10	0.11	0.03	0.89	0.37	-0.05	0.12	-0.01	-0.40	0.69	0.22	0.34	0.02	0.63	0.53	0.22	0.51	0.01	0.44	0.66
Persons per household	-0.38	0.12	**-0.09**	-3.06	<0.01	-0.52	0.14	**-0.09**	-3.60	<0.01	-0.96	0.39	**-0.07**	-2.50	0.01	-0.57	0.59	-0.02	-0.95	0.34
Note.	*N* = 1519, R^2 = .11					*N* = 1519, *R2* = .08					*N* = 1472, R^2 = .06					*N* = 1472, R^2 = .11				

Table 3. Study 2: Multiple regression analyses predicting the ideal and realized use phases

	Washing machine										Smartphone									
	Realized use phase					Ideal use phase					Realized use phase					Ideal use phase				
	b	*SE*	*β*	*t*	*p*	*b*	*SE*	*β*	*t*	*p*	*b*	*SE*	*β*	*t*	*p*	*b*	*SE*	*β*	*t*	*p*
(Constant)	4.62	4.21		1.10	0.27	9.91	1.94		5.11	<0.01	25.24	11.58		2.18	0.03	0.38	1.23		0.31	0.76
Attractiveness of newness	0.78	0.33	**-0.17**	2.35	0.02	0.73	0.17	**-0.26**	4.24	<0.01	3.04	1.27	**-0.19**	2.40	0.02	0.90	0.13	**-0.42**	6.83	<0.01
Device attachment	-0.51	0.40	0.10	-1.28	0.20	-0.60	0.21	**0.19**	-2.90	<0.01	-2.31	1.36	0.13	-1.70	0.09	0.18	0.14	-0.07	1.25	0.21
Personal norm for longevity	-0.36	0.40	0.07	-0.91	0.36	-0.35	0.19	0.11	-1.78	0.08	-2.43	1.39	0.14	-1.76	0.08	-0.60	0.15	**0.23**	-4.08	<0.01
Competence	-0.54	0.57	0.09	-0.94	0.35	-0.55	0.28	0.15	-1.97	0.05	0.68	1.72	-0.04	0.40	0.69	-0.13	0.18	0.05	-0.73	0.46
Social support	0.04	0.44	-0.01	0.09	0.93	-0.24	0.22	0.07	-1.12	0.26	1.71	1.74	-0.08	0.98	0.33	0.23	0.17	-0.08	1.38	0.17
Material for repair	0.33	0.43	-0.08	0.77	0.44	0.47	0.21	**-0.18**	2.26	0.02	0.08	1.60	0.00	0.05	0.96	0.02	0.18	-0.01	0.11	0.91
Infrastructure repair services	-0.27	0.29	0.07	-0.93	0.35	-0.17	0.15	0.07	-1.15	0.25	0.71	1.07	-0.05	0.67	0.51	0.17	0.11	-0.08	1.54	0.13
Age	0.08	0.03	**0.22**	2.75	0.01	-0.01	0.01	-0.03	-0.49	0.63	0.02	0.09	0.01	0.17	0.87	0.02	0.01	0.09	1.63	0.10
Gender	0.61	0.74	0.06	0.83	0.41	-0.20	0.36	-0.03	-0.55	0.58	-0.57	2.54	-0.02	-0.22	0.82	0.26	0.26	0.05	1.01	0.32
Education level	-0.11	0.38	-0.02	-0.29	0.77	0.21	0.19	0.07	1.13	0.26	-0.34	1.21	-0.02	-0.28	0.78	0.09	0.13	0.04	0.70	0.49
Household income	0.64	0.39	0.15	1.63	0.10	0.36	0.19	0.14	1.90	0.06	2.51	1.23	**0.18**	2.04	0.04	-0.02	0.13	-0.01	-0.15	0.88
People in household	-0.08	0.38	-0.02	-0.20	0.84	-0.26	0.18	-0.11	-1.44	0.15	-2.37	1.15	**-0.17**	-2.07	0.04	-0.09	0.12	-0.04	-0.73	0.46
Notes.	*N* = 206, R^2 = .12					*N* = 284, R^2 = .15					*N* = 214, R^2 = .12					*N* = 284, R^2 = .36				

Positioning Textile Repair: Viewing a Culture of Perfection through Surface Imperfections

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Keywords: Repair; Perfection; Textiles; Imperfection; Culture.

Abstract: The practice of early disposal and trigger-happy purchasing practices are examples of a seemingly illogical response to no longer desired products. Current behaviour toward surface and product imperfections is representative of an endemic issue in the development of negative attitudes and culture towards imperfection, in order to address negative material concerns and habits associated with textile products, the connection between internally projected expectations of perfection need to be considered in conjunction with externally projected ideals. This paper examines the relationship between current adversities to textile imperfections and concepts of human imperfection. It positions the potential role that repair activity can have in addressing the current culture of perfection in textile surfaces.

Adversity to Imperfection

Adversity to surface imperfections in textiles surfaces such as clothing and furniture is representative of current socio-cultural attitudes towards unaesthetic physiological and psychological occurrences associated with ageing, decay and other displays of visual inadequacy (Harper, 2017).

Modern textile surfaces in the form of clothing and furniture are represented as embodiments of newness, which exhibit pristine unblemished aesthetics. Whereas in reality, everyday surfaces that populate domestic environments do not retain or exhibit this untouchable and unchanging perception (Pedgley, Şener, Lilley, & Bridgens, 2018; Lilley & Manley, 2016).

A preoccupation towards an everlasting perfected aestheticism in material surfaces contributes to unhealthy practices in consumption and misjudged treatment of products. Laitala, Boks, & Klepp (2015) attribute 'changes in garments' as being a fundamental cause in the early disposal of clothing and textiles. 27 descriptions of changes in garments are identified by Laitala, Boks, & Klepp, (2015, p.97) that influence early disposal (i.e. before complete obsolescence) these include; Hole or tear, looks very used or worn, stains (not sweat), worn out, colour change or fading, lost elasticity, shape changed (dimensional change) pilling, discolouration, bleeding from other garments, broken seam or sewing failure, shrinkage (dimensional change) (Cooper, 2004).

The textile industry alone contributes to 350,000 tonnes of landfill waste in the UK every year (WRAP, 2019a). This is reflected in the rate of purchasing activity (acceptance and adoption of fast-fashion strategy and habits) low longevity of clothing and the high disposal rate. Length of ownership of clothing and textiles has reduced; WRAP, (2019a) estimates that the average lifespan of clothing is around 2.2 years, whereas the amount of clothing and textiles purchased has increased; On average, 60% more clothes are purchased a year than 15 years ago (Remy, Speelman, & Swartz, 2016; European Parliament, 2019).

Physiological Considerations

The relationship between the early disposal of products that exhibit imperfection in surfaces has parallels to the practice of the rejection of undesirable and harmful traits identified in natural external environment. Norman (2004) suggests that visceral judgements (visual, kinetic and auditory sensations) often form subconsciously and are controlled by inherent biological desires as opposed to rational ones. Increasing dominance and maintaining the existence of genetics is a basic instinct in the animal kingdom. The rejection of undesirable or genetics (and thus species) that display conflicting or inhibiting characteristics is done so through eradication of the threat (Darwin, 1979).

Humans have developed to distinguish between healthy and unhealthy characteristics and have an inherent aversion to those features (tangible and intangible) which have the actual or perceived ability to harm, hinder and challenge; Applying this within the context of surface imperfections in textile, clothing and furniture; a consumer would be more likely to purchase or invest in an object that is 'healthy' as opposed to one which displays 'mutations' or deficiencies (Norman, 2004).

The Influence of the Body

Perceptions of an idealised perfection in product surfaces can be viewed in relation to notions that people have about their physical and psychological state. Concepts of projecting the internal to the external surrounding are often synonymous with design considerations, materials such as textiles fabricate many everyday surfaces, whether this is in the form of clothing or furniture, textiles are interacted with on an everyday basis. The body is the primary influence in interior architecture, and this moves into exterior components; the first layer is the skin, second clothing, third furniture and objects and the fourth colour and surface (Wu, 2017; Weinthal, 2011).

Internal perceptions are projected onto the aesthetic expectations and limitations people place upon their exterior environment. Lajer-Burcharth & Söntgen (2016) share the concept that internal convictions radiate outwards into non-living components and view subjectivity as an inner space, an inner architecture of the self (Paige, 2000).

In clothing and object surfaces, human perception of material change is proposed as the assimilation of physiological, psychological and socio-cultural connotations that become synonymously attached to physically similar characteristics across human and non-human elements (Ben Bridgens, Lilley, Zeilig, & Searing, 2019). *'In refining objects, man creates them in his own image'* (Simmel, Frisby, & Featherstone, 1997, p.38)**.**

Simmel (1997) describes how culture is created through the manipulation of materials into physical objects. Objects can be argued to embody much more than just the physical substances they are created from. *"Just like human beings … material objects also change over time"* (Zijlema et al., 2016).

The creation and attachment of material culture to sentient things can manifest both positive and negative reaction and behaviours (Attfield, 2000). The ability to become emotionally attached to the surface, in particular textiles-based forms, introduce the same challenges and critiques that humans place upon their own body and mind (Wu, 2017).

Physical Expectations

The existence of a culture of perfection is supported by the intolerance to aesthetic imperfection in textile surfaces (disposal due to cosmetic obsolesce) and can be seen in the types of physical expectations individuals and societies place upon themselves and others.

Although cultural perceptions of beauty and ideal physical traits vary, there are commonalities around the world which depict the distaste towards signs of damage and the imperfect. Li, Min, & Belk, (2008, p.444) describe how *'flawless skin like white jade and an absence of freckles and scars'* as the idealised skin across Asian culture like that of Korea. A similar sentiment is mirrored in material surface expectation *'Manufactured products are customarily made with materials having 'perfect' surface qualities, such as uniformity, flatness, glossiness, repetition etc. surfaces are generally devoid of defects'* (Pedgley, 2014, p.1).

Assumptions of ageing and physical surface attributes are linked, wrinkling of skin, balding, greying hair are common associations with negative depictions of ageing (Okoye, 2004). The increase in the use of anti-ageing treatments in order to obtain and maintain an ageless appearance is commented on by Wiseman, (2019) who suggests that having procedures such as Botox has become a social norm *'…a new kind of veneer, a specific bought beauty, itself covetable and ageless.'* Reports that girls as young as 13 are getting Botox, due to desire to liken their looks to perfected celebrities (Adegoke, 2019). It is essential to look beyond the current celebrity culture and to uncover the fundamental reasons why an attraction to erase imperfections exists, Adegoke, (2019) reinstates that *'beauty is a belief system'* and its connotations and implications (particularly in regards to women) have existed long before current celebrity obsession.

Psychological Health

The acceptance of a perfected cultural aesthetic in surfaces such as textiles and the body can be considered from a psychological perspective. Unattainable expectations of appearance can lead to unhealthy perceptions towards physical traits. Body Dysmorphic Disorder Foundation, (2019) and NHS England, (2019) highlight the high rate of body dysmorphia and image anxiety; 1 in 50 people are affected by *'…a disabling preoccupation with a perceived defect or flaw in appearance.'* The value of achieving external perfection is viewable in how young people perceive the significance of appearance. The National Citizen Service (2017, p.20) found that body image and appearance is a critical consideration to young people, 50% of girls have been on a diet by the time they are 17 and 32% of girls say they are obsessed with getting likes on social media with 10% of boys. Overall, when asked how happy young people were with their appearance, 66% of males said they were happy with females at 45%. NHS England, (2019) call for a ban on misleading celebrity-endorsed media campaigns that promote unhealthy behaviours such as the use of diet pills and appetite suppressions.

Material and Human Considerations

A significant influencing factor in premature disposal as oppose to actual product failure, is aversion to imperfections, both Laitala et al., (2015) and Bridgens, Lilley, Smalley, & Balasundaram, (2015) acknowledge that material change contributes to an increase in disposal as this impacts product attachment by lowering perceived value. Acceptance of material change is proposed by Pedgley, Şener, Lilley, & Bridgens, (2018) as being integral to increase product longevity. Increasing tolerance for surface imperfections in the usage stage by increasing knowledge of expected material changes can help overcome unanticipated results as products age (Lilley & Manley, 2016). Extending the product life by nine months can reduce the environmental cost of production by offsetting creation cost with time in use (Remy et al., 2016; European Parliament, 2019).

Finding the best methods to address aversions to imperfections in products requires human and material considerations. Karana, Hekkert, & Kandachar, (2010) attribute the meaning and thus perceived influence of materials as being an interaction of the context in which it is experienced, product aspect (form, function and manufacture), material properties (technical and sensorial) and user influence (gender, age, culture, expertise).

Locating the Potential in Academic Practice and Theory

In academia, there can be argued to be a resurgence of interest in the theoretical and practical benefits of repairing. Repair is becoming recognised as a legitimate counter to unsustainable disposal practices (McLaren, Oxborrow, Cooper, Hill, & Goworek, 2015; Salvia, 2015; Durrani, 2019).

Currently, high standards of repair and mending methods are executed within specialist textiles sectors such as; conservation, preservation, archaeology, manufacturing, specific repair, and mending businesses (Nilsson & Axelsson, 2015; Schulman, Samlal-Soedhoe, & van der Weerd, 2018; Invisible British Mending Service Ltd., 2018). Information that addresses the technical, creative, and practical requirements of how, what and when to repair textile surfaces is not easily accessible for public use. (Gregson, Metcalfe, & Crewe, 2009).

Within academic literature, classification of instances of damage and contamination are not considered in conjunction with material property-specific repair methods. The technical expertise exists across textile-related literature but is not successfully combined in a format which connects damage and contamination with contemporary repair considerations or contemporary communication methods (Schulman et al., 2018).

In conservation and preservation literature, is it clear that aesthetic and material and object-sensitive repair methods are in circulation, but these remain within in niche sectors and are not easily translatable (Nilsson & Axelsson, 2015). Within material culture and anthropology, the intangible information which human-material interaction creates is considered the main focus, where technical processes and practices are documented, these are often illustrated as a narrative and rely on sematic enquiry (Dolan & Holloway, 2016; Andrew, 2008; Reynolds, 1987).

Within educational literature, damage and contamination are not commonly discussed as a stand-alone topic. However, topics such as repair and re-skilling are increasing (Lapolla & Sanders, 2015; Norum, 2013; Elvin Karana, Giaccardi, & Rognoli, 2017).

Within forensic textile identification and damage interpretation, there currently exists vast knowledge on how to technically assess and classify textile damage (Taupin, Adolf, & Robertson, 1999; Schulman et al., 2018). However, everyday wear-and-tear is an area which is under-assessed, according to Williams, (2018, p.7) explains that there is a lack of knowledge on what constitutes normal wear and tear over time in textiles.

Positioning Repair

The activity of repair is increasing in practice in the informal and formal sector, this can be viewed on a global scale by the success of acts and movements such as the Right to Repair, dedicated repair festivals such as Fixfest and through virtual platforms, e.g. iFixit. While the development of informal platforms is a positive indication of increased interest in repair, the standard of repair is varied (iFixit, 2019; WRAP, 2017).

A problem in addressing cultural perceptions of damage and contamination is competence and execution of appropriate maintenance and repair methods. When appropriate material methods are applied, these can enhance the value of objects. However, maintenance and repair that is not material or object relevant leads to the loss of object value, Gregson et al., (2009) describe how *'quick-fix mask'* repair and maintenance often fail and that these object-began failures are socially and objectively problematic.

The accidental sabotage of objects is reflected as sabotage of a consumer's competence. *'Social lives of consumer objects'* as used by Gregson et al., (2009, p.248) can be understood as the social benefit potential and opportunity that an object has to offer to a person's life.

Increasing the technical transparency of damaged and contaminated material (Material DNA) increases the chances of informed repair decisions (Chapman, 2014). Increasing technical comprehension while maintaining awareness of pre-existing human-centred conceptions of perfection is key to addressing the perception and adverse reactions towards damage and contamination in textiles surfaces such as clothing and furniture.

Material, People and Practice

Using a socio-material perspective to examine and challenge the culture of perfection has in the adoption of repair practice is relevant due to the relationship between material, people and practice (Durrani, 2018; Ben Bridgens et al., 2018). When human and material considerations come together a new platform is created, the subjectivity of the human realm merges with the objectivity that non-living forms contain; evocative objects and emotional attachment bring meaning to materials and the products they reside in (Chapman, 2015; Norman, 2004; Karana & Hekkert, 2008; Turkle, 2009). Socio-material practices are used to help overcome dualities between social and technical. The duality that exists between the technical requirements in textile repair, the human conceptions that are attached to materials and the practical skills needed to achieve a repair are examples of the difficulty in the practice of textile repair. Stein, Newell, Wagner, & Galliers, (2014) suggest that in addition to overcoming traditional social and technical dualities, socio-materialism can be used to overcome '*objectivism–subjectivism and cognition-emotion*'. These other dualities are sublayers which sit under the banners of technical and social and are relevant in the discussion of the material and human world. Valuing the physical and emotional relationship textile surfaces have to the human body endorses a material-sensitive and human-sensitive approach to addressing conceptions of imperfection, meeting the demands of objects and their users (Maestri & Wakkary, 2011; Keulemans, 2016).

Conclusion and Future Development

Reducing the need to eliminate and hide signs of everyday wear-and-tear by celebrating the signs of use and the repair opportunities they bring, has the potential to address many of the negative traits associated with current user behaviour, decreasing the normality of early obsolescence in textiles, clothing and furniture (Remy, Speelman, & Swartz, 2016; Daystar, Chapman, Moore, Pires, & Golden, 2019).

Exploring everyday damage and contamination of products is a growing area of interest, within product design and user perception, placing the activity of repair within the boundaries of imperfection has complimentary objectives across the material field (Debra Lilley & Manley, 2016; Pedgley, Şener, Lilley, & Bridgens, 2018). The ongoing role that repair can play in challenging current negative perceptions in imperfection can inform the development of new methods and techniques for repairing textile surfaces. Repairing with the intent of celebrating signs of wear supports informal methods of repair; repair often leaves signs and traces of damage, methods such as darning can rarely eliminate signs of a rip, tear, stain unless executed with expertise (Invisible British Mending Service Ltd., 2018).

Increasing the standard of informal repair practices can be done so by increasing technical knowledge of contamination and damage. How specific damages instances such as a rip, ladder, cut, and stain influence the fibre, structure and surface of a material are dependent on the material property and form.

There is an identifiable gap in the literature that places emphasis on everyday wear-and-tear as a critical entry point for addressing the current culture of perfection though practical repair in textile surfaces. The next stage of the research is the documentation of physical examples of imperfection in textile surfaces and the collection of reactions of owners towards signs of imperfection in personal textile surfaces.

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The Role of Unused Storage Phases (Hibernation) in the Overall Lifetime of a Mobile Phone – an Evaluation of Simulation-based Scenarios Including their Environmental Impacts

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Abstract: Life spans of consumer electronics such as mobile phones are often characterized by comparatively long storage phases after their useful lives, in which they do not provide any further service to their owners. This consumer behavior, which is referred to as hibernation, counteracts measures for increasing the lifetimes and use intensity of consumer electronics, which are integral components of a circular economy concept. Modifications in product design such as design for repair or refurbishment are mainly useful if a cascade use system could be realized in which the devices remain in service as long as possible without being stored in between use phases. This contribution builds upon a simulation model of different service lifetimes and storage phases of consumer electronics at the European level. We use this model to evaluate different scenarios for mobile phones, including smartphones. In the first scenario, an increase in service lifetime leads to decreasing demand for new devices, while in the second scenario, transfer probabilities to storage phases and, hence, hibernation are decreased. By linking the simulated scenarios to the impact factors of existing Life Cycle Assessments (LCAs) for mobile phones, we provide an outlook on the environmental benefits and resource conservation of the respective modifications in the use structure of mobile phones.

Introduction

Measures for increasing a product's service lifetime, e.g. through improvements in product design or the provision of repair services, will only succeed if consumers are willing to participate and change current consumption behavior. Particularly consumer electronics are often only used for comparatively short periods of time before they are replaced by new devices. In many cases, particularly when regarding smaller consumer electronics, products are not further used in a cascade system but are kept in households without providing any additional service. Such unused storage phases counteract efforts for increasing service lifetimes and implementing cascade systems in which a product might have a second and a third service lifetime.

The goal of this contribution is to quantify the effect of modifications in the use structure of a mobile phone (classical cell phone and smartphone) taking into account basic consumer behavior and particularly unused storage faces which we refer to as "hibernation" (Oswald and Reller, 2011). Using a cascade simulation model, we assess different scenario-based case studies. To this end, we particularly focus on consumer decisions and their implications for the use structure. As the model only provides potential reduction quantities of new product purchases, we link the simulation results to LCA studies in the discussion section in order to provide an outlook on the environmental effects of the analyzed scenarios.

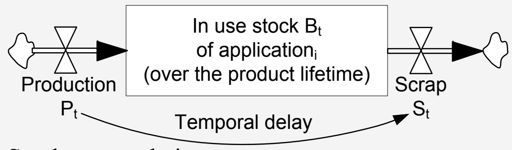
The determination of consumer behavior, their motivations, incentives and obstacles are key aspects of efforts to improving simulation approaches in this context. Therefore, we finally discuss how the simulation tool described here, which is based on a System Dynamics (SD) approach, could be improved by implementing consumer decision-making at the micro level through Agent Based Modelling (ABM). Such improved simulation tools may provide significant additional value for better addressing consumer behavior in the modelling of product life cycles. This is an important aspect for the development of strategies towards increased service lifetimes of electronic devises in particular and consumer goods in general.

Method and Model Structure

For the simulation of different lifetime scenarios, we use a cascade stock and flow model implemented in System Dynamics (SD).

The stock and flow structure within an SD modelling environment enables flexible development of dynamic life cycle simulation models ranging from single stock accumulations over a product's lifetime to detailed aging chains systematically capturing different age cohorts and related exchange flows (cf. e.g. Glöser et al., 2016). The basic concept of stock accumulation over a product's lifetime is shown in a simple illustrative manner in Figure 1. While the valves (flow variables) represent continuous material flows, the boxes (stock variables) accumulate inventories over a certain period of time. The overall system is comparable to a bathtub with in- and outflows. By linking various stocks and flows, detailed life cycle models can be developed.

For the cascade model in this study, which builds upon the work conducted by Thiébaud et al. (2017, 2018) for Switzerland, we distinguish between three different stages in product lifetime and three different storage phases as it is unlikely that mobile phones are used beyond a third lifetime (Thiébaud et al., 2017). After each service lifetime, mobile phones can take three routes: they can directly enter the next service life (e.g. by being sold on to a new user); they can enter hibernation (e.g. by being kept as backup devices); or they can exit the European market by being scrapped or exported to foreign markets. The likelihood of each path is determined by transfer coefficients (see Table 1), which were mainly taken from Thiébaud et al. (2017) and Thiébaud-Müller et al. (2018) and adjusted to the European context with the help of auxiliary data from Chancerel (2010), Huisman et al. (2012), Sander and Schilling (2010) and Sommer et al. (2015).

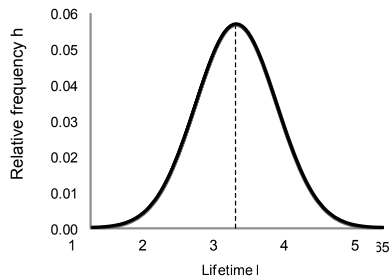


Stock accumulation:

$$B_t = \sum_{t=t_0}^{t} (P_t - S_t) + B_{t_0}$$

Delay with fix average lifetimes:

$S_t = P_{t-l}$ with l as the average lifetime



Delay with lifetime distributions:

$$S_t = \sum_{l=0}^{n} P_{t-l}\ h_l$$ with h as the relative frequency of l

Figure 1. Simulating product life cycles and stock accumulation in use within the System Dynamics (SD) modelling environment (c.f. Glöser et al., 2016; Glöser-Chahoud and Schultmann, 2019).

	Transfer coefficients	Smartphones	Cellphones
1st SL	directly to second use	0,30	0,20
	to first storage	0,50	0,60
	to disposal	0,05	0,10
	to export	0,15	0,10
2nd SL	directly to thrid use	0,30	0,30
	to second storage	0,30	0,30
	to disposal	0,20	0,20
	to export	0,20	0,20
3rd SL	to 3rd storage	0,50	0,50
	to disposal	0,25	0,25
	to export	0,25	0,25
1st ST	to second use	0,50	0,50
	to disposal	0,25	0,25
	to export	0,25	0,25
2nd ST	to third use	0,20	0,40
	to disposal	0,40	0,30
	to export	0,40	0,30
3rd ST	to disposal	0,6	0,5
	to export	0,4	0,50

Table 1. Assumed transfer probabilities between different service lifetimes (SL) and storage times (ST).

In the cascade model used here, each phase of a product's life cycle is portrayed by a separate aging chain. An aging chain consists of a series of stock variables, while each stock represents an age cohort (one for each year of a product's lifetime). After each year, the transfer probability to the following stock (survival rate) or, respectively, the probability for leaving the aging chain (failure rate) is calculated from a probability density function. For the underlying probability distributions, Weibull functions were utilized as this distribution shows the highest flexibility for adjusting the shape to empirical data (see Thiébaud et al., 2017). The three paths mobile phones can take are depicted by the three layers in Figure 2. The top layer portrays the aging chains within the three service lives, while the middle layer portrays the three storage phases, which are analogously modeled. The bottom layer represents the respective sinks in the form of exports or scrapping. The assumed lifetime distributions of the respective devices are summarized in Table 2.

	Parameters Weibull	Smartphones		Cellphones	
			k		k
Service Lifetime	1st service lifetime	3	1,7	2,5	1,7
	2nd service lifetime	2	1,8	2,5	1,7
	3rd service lifetime	1,5	1,9	1,5	1,8
Storage Time	1st storage time	2	1,9	3	1,8
	2nd storage time	2	1,9	2,5	1,8
	3rd storage time	2	1,9	2	1,8

Table 2. Assumed density functions regarding duration of use and storage phases (cf. Glöser-Chahoud et al. 2019). The parameter λ within the Weibull function describes the expected value while k is a shape parameter leading to right skewed distributions with the values chosen here (cf. Figure 2).

While from a modeling point of view, this approach seems reasonable, it has to be kept in mind that the transfer probability in this model structure is a fixed endogenous variable in the form of input data to the model. In reality, this transfer to the next life stage is strongly influenced by individual consumers' decisions and might not only depend on the use phase but also on the age of the respective device and potential further aspects regarding consumers' preferences and resulting behavior. In this context, the structure of the simulation model presented here should be seen as a first attempt to provide a quantitative estimate of product flows in a cascade system that includes hibernation, while further methodological improvements will follow as discussed in the conclusions of this paper.

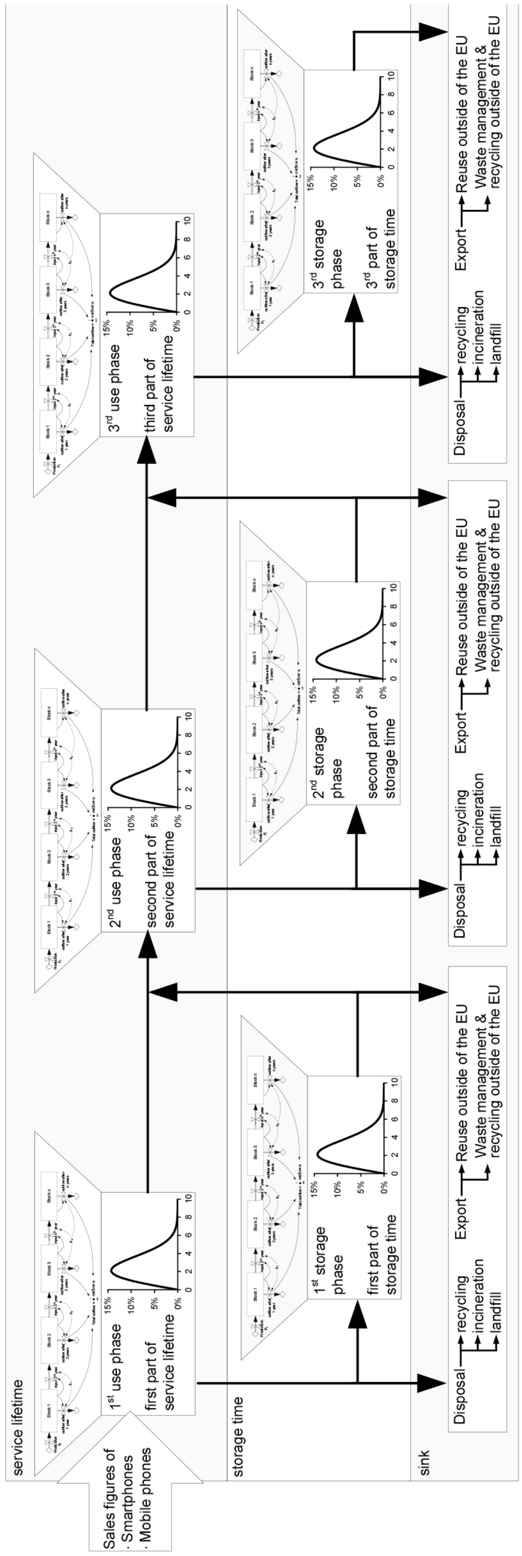


Figure 2. Concept of the cascade use phase model taking into account different stages of service lifetimes and storage (hibernation) of mobile

Beside the transfer probabilities and distributions of the durations of different life stages (summarized in Table 1 and 2), major input data to the model are sales figures of respective electronic devices in Europe. Overall sales figures of portable phones (smartphones and mobile phones combined) were extracted from the STATISTA database (STATISTA, 2018), while their shares were taken from the German Consumer Electronics Market Index (CEMIX, 2000-2016). We distinguish between classical cell phones (for phone calls and messaging) and smartphones with internet connection, touch screens and higher computation capabilities. This distinction seems necessary as historic cell phones were generally less expensive, which increases the probability of ending up in hibernation, while more expensive electronic devices are more likely to form an incentive to resell the used product after replacing it by a new device due to comparatively high residual values. This aspect is indicated by the differing transfer probabilities in Table 1. Figure 3 summarizes the input flows for the past while future development was simply derived from trend extrapolation.

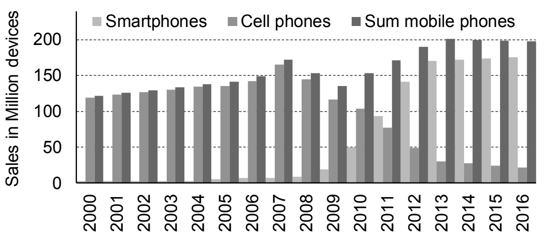


Figure 3. Sales figures of smartphones, cell phones and overall mobile phones in Europe (EU28) based on STATISTA (2018) and CEMIX (2000-2016).

Exemplary Scenarios

As outlined above, two scenarios were modeled with this setup. The basic intention of the two scenarios is to analyze the potential reduction of demand for new devices by modifications in the system structure. With these scenarios, we do not attempt to represent real future development but to provide a basic understanding of the system behavior and of the main drivers to achieve resource conservation.

The first scenario assumes technical improvements, e.g. regarding product design, durability of specific components or software update services reducing technical obsolescence. In this scenario, the underlying transfer probabilities to unused storage faces resulting in hibernation of mobile phones are kept at a constant level compared to the baseline scenario without any modifications. Of course, the individual effect of technical improvements varies and needs case specific evaluation. However, general aspects of such modifications can be captured by the simulation tool presented here. As we do not assume modifications in consumer behavior in this scenario, the increasing product durability is likely to not directly affect the duration of the first service lifetime as the product's functionality in this use phase remains relatively equal compared to the baseline scenario. Only the second and third service lifetimes – as the products are likely to reach technical or functional obsolescence in these phases – are increased by these technical improvements. However, as clearly shown in the simulation results, such technical measures are counteracted by the unused storage phases and the only partly existing cascade use structure in the form of second hand products. The majority of European mobile phones does not even enter the second and third service lifetime but ends up in hibernation and subsequent disposal or export without providing any additional service. Hence, the effectiveness of these technical improvements is expected to be relatively low. This effect is quantified based on the following assumption: From the baseline scenario, the overall stock of mobile phones in service until 2030 is extracted. This is the reference number of mobile devices used in Europe. Figure 4 illustrates relevant results from the baseline scenario.

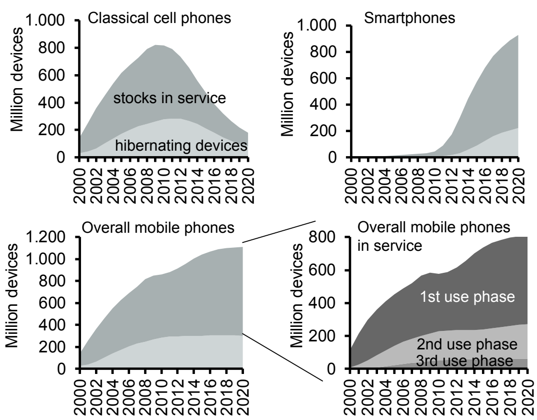


Figure 4. Baseline scenario as a reference case to the following two scenarios. As this scenario is not intended to be forward looking, we only ran the simulation until 2020.

By increasing the second and third service lifetime, the theoretical stock of devices in use would increase. This theoretical increase is balanced by reducing the demand for new devices. Hence, the longer service time leads to a certain reduction of demand and a shift from first to second and third service lifetimes. However, as mentioned before, this effect is moderate as only a mere fraction of overall mobile phones really reaches the second and third service lifetime. In the scenario shown in Figure 5, we assumed an increase of second service lifetime by half a year and an increase of third service lifetime by one year.

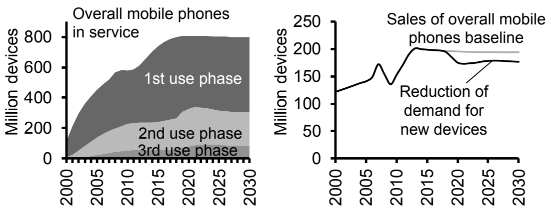


Figure 5. Effect of increasing service lifetime in the second and third use phase.

The second scenario assumes a reduction of hibernation time to 0 by the year 2030, which is achieved by successively reducing the transfer probabilities to hibernation. Such an effect – even though highly theoretical – could e.g. be achieved through product oriented product service systems (PSS) in which the consumer no longer owns the device and simply returns it after the use phase. The potential reduction of demand for new devices in this scenario is shown in Figure 6.

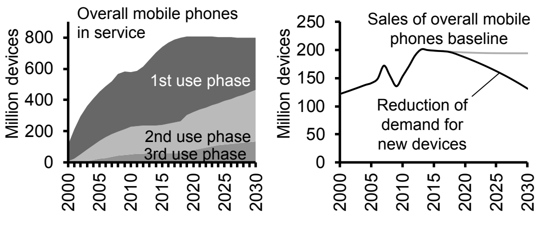


Figure 6. Effect of decreasing transfer probabilities to hibernation.

It is likely that such a theoretical modification in the use structure will be difficult to achieve in practice. Nevertheless, this scenario underlines the counterproductive effect of hibernation of functioning products in the transition towards a more sustainable consumption. This becomes even clearer when combining the results derived in these two scenarios with LCAs of mobile phones and, hence, the environmental impact associated with the production of new devices.

Discussion of results

By increasing the useful lifetime of a product, the need for new devices decreases. Taking the stock level from the baseline scenario as a reference, we analyze to which extent new product flows can be reduced while still reaching the same stock level in service as in the reference case. We thus follow a stock-driven approach such as proposed by Müller (2006). The methodological details of how new product flows are adapted in relation to the desired stock level are described in detail in Pfaff et al. (2018). In order to provide an outlook on the potential environmental impact of the modifications shown in the two scenarios, we additionally utilize LCA data for mobile phones. The body of literature on LCAs of different mobile phones is wide and contains varying results due to different system boundaries, data basis, variations among producers and underlying assumptions. However, some major results can be generally summarized. As shown in Figure 7, mobile phones are among those products which have their main environmental impacts during production and fabrication (particularly for the required material basis and the energy intensive fabrication of these high-tech components).

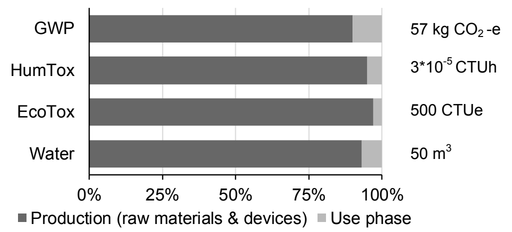


Figure 7. Major environmental impact of a smartphone illustrated in the form of different impact categories from a LCA study (Ercan et al., 2016). Abbreviations: Global Warming Potential (GWP), Comparative Toxic Units (CTU) regarding human toxicity non cancer effects (h) and eco toxicity (e).

Hence, an increase in service lifetimes in order to decrease the need for new devices strongly affects environmental impacts. While the replacement of other consumer products with high emissions during the use phase may be ecologically beneficial, this is not the case for mobile phones. Figure 8 provides the spread and range of CO_2 equivalents (GWP) from a review of existing LCAs for mobile phones (extracted from Suckling and Lee, 2015), which illustrates this point.

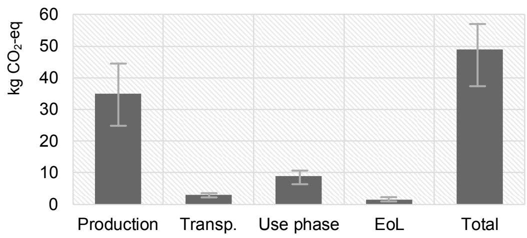


Figure 8. Spread and share of global warming potential (GWP) of different LCAs for smartphones (see Suckling and Lee (2015) for a comprehensive overview of different LCAs of mobile phones).

From an ecological perspective, lifetime extensions appear to be a sound strategy for the product categories considered in this study, as the majority of environmental impacts, including material use, occur during their production and not their use phase (Bakker and Schuit (2017), see also LCA data in Figure 7 and 8). For other product types, this is not the case. For instance, Bakker and Schuit (2017) report in a meta study that lifetime extensions of white goods beyond 10 years do not appear to be environmentally beneficial due to relatively high shares of use phase energy consumption and large efficiency gains between product vintages. Thus, a quicker replacement of less energy efficient white goods may lead to higher energy savings than lifetime extensions. Wieser et al. (2015), however, suppose that this may not be the case for much longer as efficiency gains for some product categories have been slowing down in the recent past.

As illustrated by Box (1983), lifetime extensions can in principle address either the production side (through technical improvements of products) or the consumption side (through behavioral change leading to a longer use of products). However, in practice, a combination of both is necessary to keep products longer in use, since products that would theoretically last longer are not necessarily used for longer periods by consumers. This is because lifetime extensions cannot be considered universally desirable, as different demands towards products may be influenced differently by lifetime extensions (Wieser et al., 2015). For instance, certain products are mainly valued with respect to functional and/or aesthetic characteristics. As functional and/or aesthetic preferences change, old products may not fulfill them anymore. Smartphones, and mobile phones fall into this broad category of products.

In conclusion, an extension of service lifetime of a mobile phone leads to a reduction of demand for new devices. However, as only a comparatively small proportion of devices really reaches the second and third service lifetimes, which we expect to be increased by technical improvements, the overall effects shown in the first scenario are comparatively moderate. Nonetheless, this scenario still includes the problem of unused storage phases, which indirectly leads to resource losses as existing and functioning devices are still hibernating in large numbers.

The second scenario, which simulates a reduction of hibernation times, presupposes the willingness of additional consumers to purchase used products. This implies a shift from the first service stocks towards the second and third service stocks. Even though this is a purely theoretical analysis, it quantifies the potential effect of resource conservation through reduction of unused storage times in the life cycles of electronic equipment.

Both scenarios are not directly comparable because the lifetime extension scenario exemplarily assumes increases in second and third service lifetime, while the hibernation times are successively reduced to 0. However, it can be shown that such a gradual change in consumer behavior can by itself lead to considerable changes in product flows without requiring technological measures. Since the willingness of consumers to forego the storing of products after the use phase is a precondition of any reduction of hibernation times, it is therefore important to understand the causes of product hibernation. Wilson et al. (2017) have identified a number of reasons for product hibernation. Two prominent reasons are data/privacy concerns and emotional attachment. In the former case, consumers are hesitant to directly sell or dispose of products after the use phase because they are unable or unwilling to delete their private data. This appears to be a larger problem if it is impossible for the current owner to access and eventually delete sensitive data but may not be for future (specialist) owners. In the latter case, consumers associate products with personal memories etc. and therefore opt to keep products despite not using them anymore. Consumers have also been found to keep “secondary phones” as backups to their current devices, without actively using them. This behavior partly goes so far that (multiple) predecessors to these secondary phones are kept to the point of “[forgetting] about their existence”, which together with a lack of knowledge about environmental implications and disposal options has been described as “recycling lethargy” (Wilson et al., 2017, p.529).

Depending on the underlying reason for keeping products beyond their service lifetimes, different measures may be necessary to reduce hibernation. Data concerns may be remedied through, e.g., information on “shredder” software that irrevocably deletes data or instructions on the removal of storage units. The desire to keep a spare phone due to emotional attachment in contrast requires other instruments, for example ones that provide economic incentives, such as deposit return schemes. Recycling lethargy may be addressed by information campaigns illustrating the environmental implications of product hibernation and channels through which products can enter secondary markets or the recycling stream. Another possibility are new business models in which the traditional roles of producers and purchasers are dissolved and with that the ownership of and responsibility for products.

Conclusions

The presented cascade stock and flow model can be seen as a first approach to better addressing hibernation and consumers' decisions in the simulation of product life cycles. As indicated with the theoretical scenarios presented above, a reduction of hibernation of functioning electronic devices could reduce the demand for new products. However, this would also require changes in consumer behavior as the shift towards the second and third use phase of mobile phones requires the willingness to purchase or, more generally, to use second hand or refurbished devices. The same is true when regarding the scenario of lifetime extensions. In the current model structure, this particularly affects the second and third service lifetime.

A model is always a simplification of reality and simulation models are generally intended to assess and better understand system behavior under different settings. The model structure presented here allows for the simulation of a cascade use system. However, the durations of different use phases as well as transfer probabilities between different stages in the lifetime of a product are static input data and dynamics derive from modifications of these data. In fact, the duration of a use phase as well as the underlying transfer probabilities are results of individual consumer decisions. The system dynamics approach presented here is not capable of addressing these individual decisions at the micro level. To this end, a hybrid model simulating both the behavior of individual agents and the aging process of products used by these agents would be necessary. Therefore, the combination of a cascade life cycle simulation presented here with an Agent Based Model (ABM) in a hybrid simulation approach would provide a significant methodological improvement for addressing the effect of consumer behavior on the lifetime of a product. This will require further research regarding both implementation approaches and the gathering of the required data.

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Product Lifetimes And The Environment

Reconsidering the Determinants of Longer Relationships with Everyday Products: a Five Point Framework

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Keywords: Product Longevity; Everyday Products; Person-Product Relationships; Materials Experience; Keeping Behaviour.

Abstract: Research into longer relationships with products may currently be biased towards special, cherished or meaningful products. The aim of this research is to contribute to understanding the mechanisms underpinning longer relationships with more everyday products. The study is based on ethnographic research in several phases, including semi-structured interviews with a cohort of 280 participants aged from 9 to 82 years, followed by self-documentation based research with over 80 participants. Nine main determinants in longer everyday product relationships are identified and discussed. These components are regrouped and can be used to generate a tentative five point framework highlighting the multifaceted nature of longer everyday product relationships.

Introduction

With the potential to reduce the throughput of materials and embodied energy (Fisher et al. 2015, Bridgens et al. 2015), product lifetime optimisation and extension have become a large research domain within sustainability. Nevertheless there remains a need to better understand what mechanisms help to prolong product lifetimes in the case of the most common everyday products.

Within the field of research focussing on the behavioural aspects in product longevity, “emotional durability” (Chapman, 2005) is well defined and has generated some valuable frameworks (eg. Haines-Gadd et al., 2017). While highlighting important issues, the emphasis on emotional experiences, also termed rich, rewarding or meaningful (Battarbee & Mattelmaki, 2002) in the literature, may lead to under-representation of other important aspects of person-product relationships. The seminal work by Csikszentmihalyi & Rochberg-Halton (1981) underpinning much subsequent work on product relations focusses specifically on “the meaning of things”. This valuable work also represents another bias; the tendency of product relation research to examine products considered special or cherished by their owners. Information collected on the bond between users and treasured objects may not be transferable to bonds with more ordinary consumer products (Chapman, 2015), whereas in terms of environmental impact the bonds and behaviour with these more ordinary products are arguably the most important to understand. The mass-produced, often anonymous objects of our everyday experience are likely to generate the most ecological pressure (Chapman, 2015).

Everyday person-product relationships

Widening the subject to include everyday person-product relationships potentially means generating different components and more complexity. For this reason it is important to try to create a framework that facilitates an overview of the facets of these relationships while giving a complete picture. While this may be implicit in related research, we specifically target the interaction and experience between person and product over time, which is best expressed as a relationship. It should be noted that the term relationship is used to express a notion of time but is not intended to pre-suppose emotional content.

Some existing research has specifically targeted the person-product relationship in terms of replacement prevention (eg. van Nes & Cramer, 2005, Salvia et al. 2015). Equally there is an important body of research proposing design strategies for longer product lifetimes, for example creating a framework for designing resilient consumer products (Haug, 2016). While the aim of this study is linked to the above research, the focus in this paper is more on understanding "keeping behaviours", looking into the nature of existing longer lasting everyday person-product bonds. Whilst taking into account research on product attachment (eg. Schifferstein & Zwart-Kruis-Pelgrim, 2008), emotional durability and meaningful products, this research also builds on research threads aiming at understanding "why we preserve things" more generally (eg. Odom et al. 2009),

This article is part of a wider research project which also involved an extensive literature review highlighting and comparing existing theoretical frameworks used in the context of person-product relationships (Green, 2019). The study described here is therefore relationship-focussed research in the context of everyday products aiming to create both a wider overview and a clear structure. The findings could inform strategies for specifying and designing products and related services, but are not yet a "tool" as such.

Methods

The ethnographic research which lead to establishing a five point framework to describe longer person-product relationships with everyday objects involved a number of different stages and research tools and took place over a period of six years. The initial research questions were:

- Can we confirm the presence of multiple determinants/components?
- What appear to be the most important determinants in longer everyday product relationships?
- Can we better describe the nature of the principle relationship components?

During the first phase of research, user-product relationship descriptions were collected from a cohort of over 350 people (ages from 9 to 82 years) using semi-structured interviews. These were carried out by design students associated with the research. The interview questions, first tested in a pilot study, focussed on the relationship with one regularly used everyday product that the participant expected to continue to use and own. This phase generated 280 useable interview transcripts which included the nature of the object, the length of time owned, an object description by the participant and reasons why the object continues to be kept and used. Participants were encouraged to re-assess their reasons, and give them a hierarchy of importance. The replies covered over 100 different types of ordinary product. The diversity of products selected by participants seemed to validate the chosen approach which was not to limit the research in advance to one product category or family. Commonly cited products: mugs, notebooks, pocket-knives, jugs/water bottles, head-phones/earphones, pens etc, confirm the everyday nature of the relationships. These products were owned from between a few months to over 40 years. The transcripts were coded using an iterative process to identify and subsequently regroup recurring themes. From this process 9 main relationship facets emerged.

These facets were used as a structure for further phases of research. The aim of the second phase of experiments was to test the validity and relative importance of the facets identified. As the aim of these experiments was to test the context of everyday rather than special or cherished products, in these subsequent experiments multiple product relations were examined. The following experiments used self-documentation protocols (Lee, 2014) rather than interviews. Participants first made a diary of every object touched within their home during one day (see Zucotti, 2015), then returned to this list to describe their relationship with a small number of the products. This second phase involved 2 different cohorts: freshmen design students and adults from 40 to 60 years old. The thematically coded transcripts from this second phase were used to refine and confirm the 9 point structure established, but also to regroup certain points and identify the five main determinants.

Relationship determinants

The nine-point structure generated and confirmed by the first and second phases of research is interesting to compare with relationships described in terms of Product Attachment (eg. Mugge, 2008) and Emotional Durability (eg; Haines-Gadd et al. 2017). In the table below the nine main determinants, and their sub-themes are illustrated in relation to these two frameworks. Table 1 highlights, as could be expected, that the facets of longer ordinary product-person relationships have more in common with the Emotional durability framework than with Product attachment. This comparison also highlights themes missing in the other frameworks, notably related to physical product proximity and the product in it's wider physical context.

At the same time, this table illustrates that themes denoting highly present objects

(Mugge's "living object qualities", or Haines-Gadd's "animacy, anthropomorphism, spirit…"), are missing in our study.

(main) product attachment meanings, Mugge, 2008	facets of Emotional Durability, Haines-Gadd et al, 2017	Determinant groups (Green, 2019)	Sub-themes (Green, 2019)
		CONTEXT/NETWORK	1) place/context, 2) link to other object
		FEELING ON ME	3) pleasure touch, 4) feeling on me, 5) good weight (light), 6) good size, 7) move/manipulate, 8) fit me
	Materiality	**TIME/DURABILITY**	9) material/ageing, 10) resistant quality, 11) reliable, 12) projection of keeping
	Evolve		
	(Integrity)	**TIME**	13) time owned, 14) very old
utility/functional attributes	(Relationships)	**CARE/HABITS/ PROXIMITY**	15) use ritual, 16) care/cleaning
		USE/USEFUL	17) good for/multifunction, 18) easy to use/useful, 19) use my way, 20) nice function, 21) use justification
evoke/give sensorial pleasure	(Imagination)*	**(REMEMBERING) PLEASURE**	22) pleasure moments, 23) pleasure activity, 24) pleasure using, 25) (pleasure) sensation, 26) reassurance
personal history/ memories	Identity	**SELF/MEMORY**	27) history/story, 28) "pure" symbol, 29) self expression, 30) evokes a person, 31) action of other person, 32) gift, 33) social group, 34) event, 35) childhood memory
expressing self identity	Narratives		
representing social links			
style/design/uniqueness		**VISUAL QUALITIES**	36) my image, 37)style/appearance, 38) (good) colour, 39) decoration, *(40) originality)*
living (being) object qualities	Consciousness		
	Conversations		
investment value			41) financial
cultural/religious expression			

Table 1. Determinants compared with those of Attachment and Emotional Durability.

As Table 1 illustrates, from the initial structure in nine points, seven determinant groups were established by combining themes related to time and those related to product use. Of these seven determinants, 5 were confirmed in both the first and second phases of research as the most present, while visual qualities of products and the influence of product context produced more ambiguous results. These five

components are provisionally named: (1) feeling on me, (2) appreciating/noticing time, (3) using/doing, (4) experiencing pleasure and (5) remembering self. The names express the way components are present in the relationship, using a continuous verb form to denote the ongoing nature of the relationships studied.
The five main components largely corroborate and overlap with product relationship determinants present in the literature. At the same time, identifying the points of coherence highlights differences and illustrates that the borders of each component cannot be considered definitive.

Using/doing

The component *using/doing* corresponds to existing determinants in the literature related to utility and functional attributes but does not have many direct equivalents. Regular use of objects is widely seen as a pre-requisite for a prolonged relationship (Mugge, 2008). This component in our research is a reflection of this using/dong being commented on directly and positively. This component can be linked to notions such as engagement (Odom et al. 2009, Verbeek, 2005); defined as the extent to which an object invites and promotes physical engagement during use (Odom et al.) Of the types of lasting relationship described by Odom et al., "augmentation" is also linked to using/doing sub-themes: using in a personal, redefined way, and care rituals. Other themes in the literature such as "flow" (Csikszentmihalyi, 1990) and "transparency" (Rosenberger & Verbeek, 2015) help to clarify that positive relationships with objects may also involve a form of invisibility, which can make identifying this component more difficult.

Feeling on me

The component *feeling on me*, can be compared to evocations of the action of touching and multi-sensoriality in existing research (Schifferstein & Spence, 2008). Product experiences involving multiple sensory modalities are likely to be richer, and touch has been identified as a particularly "sticky" modality both in shorter (Schifferstein & Spence, 2008) and longer term. While there are no direct equivalents in terms of relationship determinants or durability themes, research highlights the probable importance of both vision and touch in product experience, with touch becoming more important over time (Fenko et al. 2008). The nature of this component can be compared to the notion of "intersections" (Odom & Wakkary, 2015); the experiences commented on are small scale and concern close corporal proximity. Odom & Wakkary describe these low-level interactions as ongoing incremental encounters, involving direct manipulation and subtle uses of artefacts that may go unnoticed. This component suggests the importance of corporal proximity and also proprioception in lasting relations. Despite the lack of direct equivalents in research into longer product relations, this component was the most present of the seven initially identified.

Remembering self

The component *remembering self* relates to memories, narratives, social links and self meanings and is well represented in existing research, being particularly relevant to cherished objects with strong emotional attachment. This component remains important in the case of everyday objects studied in this research. It also appears to be the easiest aspect to express, often being among the first reasons given for a lasting relationship. It may be important to keep in mind that this component is undoubtedly linked to the majority of research methods used to explore longer relationships. It also appears to be a reason judged as acceptable or socially correct. There may be a general human tendency to make a form of narrative of our lives, of which everyday objects can be a part. Galen Strawson argues that this narrative way of viewing life is often associated with a well-lived life and true or full personhood (Strawson, 2004) and is probably the dominant view. A weakness of this component is also linked to the fact that self-identity is not necessarily stable over time.

Experiencing pleasure

The component *experiencing pleasure*, matches determinants "enjoyment", "pleasure" and "imagination" present in the majority of relationship frameworks. In the case of our research it is important to clarify this theme in relation to the four others. It can be expected that all components relate to positive feelings. The specificity of this component in our framework is a focus directly on the experience itself rather the related object. Sub-themes such as pleasure moments, play/pleasure activity, assurance/happy mood help to situate this component. Schifferstein & Zwartkruis-Pelgrim suggest that object attachment linked to pleasure is highest in recently acquired objects, which might suggest less perenity for this component. It is also important to keep in mind that pleasure with an object might be linked to the happiness of the experiencing self (the ongoing actual experienced enjoyment) or the satisfaction of the remembering self (retrospective/recalled enjoyment) (Kahneman et al. 2005, 2010). The comments underpinning this component in our research suggest both recent accessible pleasurable product experiences and more global evaluations. This contradicts in part the suggestion of D.Norman that memory is more important than actuality in pleasurable product experience (Norman, 2009).

Appreciating/noticing time

The final component, *appreciating/noticing time*, matches identified existing research themes such as perceived durability (Odom et al. 2009) and ageing gracefully (eg. Chapman, 2005). This component concerns notions of durability, longevity and time expressed as positive attributes as well as time noticed in terms of material changes. It is a component that can be linked to notions of integrity, mindfulness and reflection in existing literature (eg. Haines-Gadd et al. 2017) as it relates to a conscience of time and materiality. The conscience of the object as material that has resisted and has the qualities needed to last is an important part of this component. A longitudinal "cross-sectional" analysis (Karapanos et al. 2010) of replies shows that material awareness linked to time is commented only for objects owned for four years or more. This component is linked to the proposition that making products become 'materially yours' (Karana et al. 2017) can contribute to product relationship longevity. Nevertheless the uneven presence of material related sub- themes in replies suggest that material awareness in everyday product relationships needs to be researched further.

Ambiguous components

Beyond these five main themes, the visual qualities and appearance of objects and the importance of context appear less robust components, pointing to areas for future research. The absence or irregularity of both presence and conscience of materiality is also an important insight. In addition an important emerging transversal theme would seem to be the importance of body actions and movement.

A five point model

The five components described above can be tentatively grouped into a form of map, (Figure 1.) showing possible interactions. The less robust components, requiring future research, are also represented here illustrating their possible links.
The aim of this illustration is also to highlight that certain components are more or less related to the physical presence of the product in the relationship. Moving towards the right are components that can exist without the physical presence of the product. This left-right axis can also express a form of temporality, showing both components linked to global and remembered product appreciation and current, ongoing experiences (see Kahneman et al, 2005, 2010, Schwartz et al, 2004).

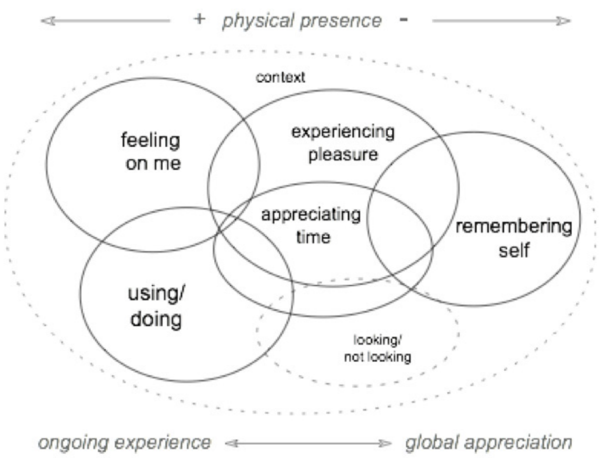

Figure 1. Provisional mapping of main components.

Conclusions, implications

Future research is needed to explore the hierarchy and weighting of these components in relation to different product families, to test these components using more longitudinal protocols and also to test these components as a design tool. Of the five components identified, two are very close to emotional durability and attachment research, but the roles of doing and touching would seem to be equally important to include in future models. The fact that this framework places less emphasis on self-meaning may also make it more relevant for product relationships beyond ownership models. This research seems to confirm the presence of a wider range of facets and thus the need for a framework with wider scope and identifies components that may be missing in cherished object-based studies.

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Objects, Things and Stuff; Exploring the Awareness of Materiality in Longer Everyday Product Relationships

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Keywords: Product Longevity; Person-Product Relationships; Stuff; Sustainable Consumption; Materials Experience.

Abstract: In designing for longer product lifetimes we should consider our relationships not only with "products" but with "things" and "stuff". The role of materiality in longer relationships with everyday artefacts may not have attracted as much attention as other factors, despite environmental relevance. This paper investigates awareness of stuff in the sense of unimportant everyday artefacts and also stuff in the sense of the material make-up of these artefacts. We highlight findings related to material awareness as a component of longer everyday product relationships.

The findings around the role of the materiality in longer product relations reveal an ambiguous picture. Firstly the awareness of the material aspects of the everyday products commented on is very unevenly distributed. Comments related to material qualities of objects as well as the material presence of objects as physical entities are missing from many personal narratives collected. At the same time, an awareness of material, in the sense of the actual physical presence and nature of an object appears important in many of the longer everyday relationships commented. Relations to materiality in the research can thus be grouped into two distinct sections; firstly how materiality is present and appears to positively contribute to longer product relations, and secondly how materiality may go unnoticed in relationships with everyday objects.

Being conscious of stuff as material may not constitute the majority of current behaviour (and may not be easy to encourage) but may be increasingly important in the context of product longevity.

Introduction

Designers tend to describe their activity as creating "products", a designer would rarely refer to creating "things" or "stuff". Nevertheless, most of what designers create enters our lives to become the things and stuff that fill our homes. In order to design for longer product lifetimes it is important to consider our relationships with everyday artefacts which might be better defined as things or stuff.

This paper explores the role of materiality in longer product relationships. We investigate awareness of stuff in the sense of unimportant artefacts in our everyday lives and also stuff in the sense of the actual material make-up of these artefacts. Part of a doctoral research project, this paper highlights findings related to material awareness as a component of longer everyday product relationships.

Objects, products, things or stuff?

Literature around product relations reflects the relative status of the different ways everyday artefacts can be referred to. This choice of words may be worth questioning in the context of designing future material artefacts.

Discussing sustainable object relations, Cupchik (2017) talks of the dynamics that could transform 'a design product into a personally meaningful object'. The word object in the english language is generally reserved for important and singular relations, but also the problems these present (eg. Objects of Desire, (Forty, 1992), Objectified, (Hustwit, 2009). In relation to the sphere of design, perhaps naturally the reference is always to 'products'. In product longevity research for example, strategies propose designing 'resilient products' (Haug, 2016), or for 'product attachment' (Mugge, 2008). This reflects the link of the activity to producing things, reflecting a probable lack of consideration in design practice for the second phase of the life of products: the life after the sale, with the consumer (Findeli, 2010).

The artefacts within our homes are more generally referred to as things, as in the seminal work 'The Meaning of Things' (Csikszentmihalyi, M & Rochberg-Halton, E., 1981). Things are also what might be a problem, Ian Hodder for example examines the 'entanglement of humans and things'. Odom et al. question 'why we preserve some things and discard others' (Odom et al., 2009). In these two cases they are what might ensnare us, and also what could be thrown away, a lesser status than products, with more negative connotations.
After things come stuff. Miller (2010) writes that stuff is 'ubiquitous and problematic…it somehow drains away our humanity' and 'has a remarkable capacity for fading from view'. The fact that stuff is also matter and material, and what things are made of (Markosian, 2015) suggests that design for longer material relations should probably focus on things or stuff rather than products.

Materiality in longer product relationships

As the notion of materials experience is now widely researched it is important to specify what this study is not about. The focus of this research is not about the abstract qualities of materials, (Karana et al., 2010) or material as metaphor (Olsen, 2003). Equally this study is not about comparing one type of material to another within materials experience, nor material choice.
This study concerns materiality in product longevity, and specifically in longer product relationships. This could also be described as awareness of things as material entities and as matter. (Verbeek P-P. & Kockelkoren, P., 1998, Verbeek, P-P., 2005)

Research methods

Exploring relationships with the artefacts around us that 'fade from view' presents difficulties in terms of research protocols. Here experimental approaches linked to the field of design user-research were used. Four separate studies were carried out, two involving cohorts of product design students and two with non-designer adults aged between 40 and 60 years old. Two studies took the form of inventories, in the first case, with 40 design students, as a sketched and annotated list. In the second case the inventory took the form of an interview with participants talking the researcher through key objects in chosen room of their homes. The third study, with a group of 50 design students, was based on in-situ self-documentation (Lee, 2014) in the form of a diary of everything touched in one day, followed by in-depth descriptions of a number of the objects listed. The fourth study with a group of 8 adults aged between 40 and 60 years was in the form of a Design Probe (Lee, 2014, Mattelmaki et al., 2016) and also involved noting everything touched in one day. This protocol was inspired by research by Zucotti (2015) and gives the advantage of recording interactions with objects that might otherwise go unnoticed, giving participants the opportunity to refer to this list to reflect on object relations.
The transcripts from the interviews of the second study as well as participant notes from the other three studies were analysed using an iterative process allowing recurring themes to be clustered. Over 100 different types of object were commented on in the context of longer everyday relationships covering the wide variety of things we interact with in the domestic environment. Clothes and textiles were commented on in a few cases, but were not the main focus of this research.

Material presence

In relation to the research questions around the role of the materiality in longer product relationships the findings reveal an ambiguous picture. The presence and awareness of materials in this study highlight paradoxes inherent in everyday stuff. Everyday things may be those that no longer hold our attention, becoming unnoticed and invisible and potentially neglected (Highmore, 2002). At the same time our everyday experience is constituted of the physical reality of products and their materials (Karana et al., 2017). Karana et al. use the expression 'materials experience' and identify four different experiential levels for this experience: sensorial, interpretive, affective and performative. Our findings in relation to the longer product relationships studied relate mainly to sensorial and performative levels, but also show that this materials experience is sometimes totally absent.
Comments related to material aspects of objects, and in some cases to the material presence of objects as physical entities are missing from some personal narratives. At the same time, an awareness of the material (in the sense of the actual physical presence and nature of an object) emerges as an important part of many longer everyday relationships

commented. Therefore relations to materiality found in the research can be divided into two distinct groups; how materiality is present and appears to positively contribute to longer product relations, and how materiality goes unnoticed in many relationships with everyday objects.

Individual diversity

Our study appears to show that the conscience of material qualities of things is very diverse, even within cohorts that could be considered homogenous (such as product design students). The self-evaluation of fast moving consumer goods in our studies illustrates this diversity. In the student cohort, the number of these products recorded varies between 3 and 34. In the adult probe group (fourth study) between 2 and 22 of these objects were noted down as touched in one day. Whilst these differences might reflect different product behaviour, it may indicate differing object awareness. Equally, in the probe group, the status of these short-lived physical objects in personal comments varies from non-existant to important-to-keep. This heterogeneity appears to be confirmed in related literature.

Lockton & Ranner (2017) highlight the inherent complexity and heterogeneity of behaviour in real peoples' lives. This may be even more the case for the low-level, peripheral everyday interactions, which are likely to be highly personal (Bakker, 2013). The relationships with everyday things can be seen as a form of individual accommodation to the domestic environment, of careful tuning and adjustment which may be far removed from collectively recognised ways of doing things (Thévenot, 2001).

Ambiguous material presence

Our study shows that the ambiguous presence of material entities takes different forms.

Student inventories (1st study) highlighted that participants initially found it very difficult to think of 10 everyday objects that mattered to them, despite the fact that subsequent studies (eg. study 3) indicate that they touch on average between 50 and 100 non-fixed and non-disposable consumer durables per day .(Fixed objects such as large furniture and built-in appliances were excluded from the studies.) The fourth study also highlighted that even when objects were more systematically noted, very few objects were qualified by participants as mattering or for keeping.

A recent study into keeping behaviour (Guillard, 2013) gives insights into why keeping might be seen as a problem. Guillard writes about a form of consumer behaviour named TTG (the 'tendance à tout garder': the tendency to keep everything). Reasons given for keeping things are: anxiety, retentiveness, materialism, nostalgia, guilt, procrastination and altruism. The largely negative connotations of these reasons illustrate why we may not always be comfortable admitting 'keeping' things or stuff.

Another interesting observation from the first study was that despite participants being asked to note down specific possessions, around 30% of the things included were not specific material entities. 20% of the objects could be described as object categories rather than specific objects and a further 10% could be described as 'object groups'. This latter case seems to match the notion of 'stuff' in the sense of (unidentified) material that makes up larger things or fills up various regions of space (see Markosian, 2015). These inventories containing a majority of categories or groups tended to also take the form of illustrations of self identity, suggesting that objects in self-symbolic roles may necessitate less physical presence.

Material entities

The appreciation of the specific material qualities of an object appears to contribute positively to a lasting object relation. This appreciation of material qualities of objects and their specific materials is generated by three main factors, identified as components of longer everyday object relations (Green, 2019). These are 'using/doing', 'feeling on me' and 'appreciating time'. These three components represent three different paths by which people can become aware of the materiality of an object.

The component 'feeling on me' particularly seems to relate to awareness of the physical quality of the object as a whole. Comments collected indicate a particular awareness of the physical object in terms of weight or size judged as appropriate. Equally the material awareness can be in terms of compactness, capacity and volume. In some cases these material comments suggest slight differences with what might be expected. Examples of these cases of low-level incongruity: a purse that is almost too small, or a toiletries bag that seems to grow to accommodate new things stored inside. These experiences could be seen as a subtle, ongoing level of surprise in product experience (see

Ludden et al., 2008, Grimaldi, 2017). These appear to be qualities that are felt, quantified and validated in body actions, for things that are often carried with us, manipulated and checked for weight.

Material qualities

The specific material qualities of objects are related to components 'using/doing' and 'appreciating time'.

Personal ways of using, adapting, or taking care of objects generate knowledge and understanding of their material nature. Physical implication to prolong, repair and modify objects means taking the physical nature of the object into consideration, and increasing related knowledge.

Throwaway objects that have been kept are a good illlustration of the second theme 'appreciating time' in our study. For these generally very banal objects the material qualities need to have been considered and judged, rather than simply taken for granted. The object is judged in terms of it's material potential and durability.

In another form of appreciation of time, Zijlema et al. (2017) propose that the surface marks and traces on an object contribute to a general awareness of the object's past. In our study we could propose an extension to this concept: awareness or sensitivity to the materiality of an object contributes to the longevity of the relationship, and this awareness is in relation to activities with the object, marks and manipulation. The notions of graceful ageing (Chapman, 2005, Haines-Gadd et al. 2017), and embracing imperfection (Karana et al. 2017) suggest that the traces and marks on materials can enrich the relationship with an object. More pragmatically, our research suggests that traces and imperfections help to make the materials and their nature tangible to the owners of the objects.

Relationship longevity component

The notion of products becoming 'materially yours' (Karana et al., 2017) refers to experiences 'with' and 'through' their materiality. The cases we highlight in this research relate mainly to experiences 'with' the materiality of objects: conscience of the physical entity and its' material characteristics. The concept of Emotional Durability (see Haines-Gadd et al., 2017) may not exactly match the everyday relationships in our research, as too much emphasis may be on fewer 'special' products rather than the majority of our everyday stuff. Nevertheless Haines-Gadd et al. (2017) also conclude that strategies for emotional durability should go beyond only psychological extension and should also encourage prolonged physical interaction with products. Our research suggests that attention to, care of and awareness of an objet's specific materiality, even in the case of the most banal everyday objects, contributes to relationship longevity.

Discussion

Making objects more 'materially yours' seems indeed to have potential as a product (relationship) longevity strategy, but the awareness of materiality this entails should not be taken for granted and may not constitute normal behaviour in many cases.

For future research and for future design-for-longevity strategies it may be useful to address the problem of status inherent in product design. Thus future work should probably concentrate on things and stuff, not objects or products

Equally research into this subject raises methodology issues. As Daniel Miller states (Miller, 1998) - "there are many instances where clearly things matter to people even when in speech they deride them as trivial and inconsequential". There may be a form of embarrassment in admitting to everyday material relations and/or an inability to express low-level material experiences.

Future research should also address to what extent cognitive treatment of everyday experience allows for the less economic processes involved in more material awareness.

Conclusion

This research raises questions around awareness of materials and materiality in the context of longer everyday product relationships. Questioning stuff relationships within longer everyday product relations may be useful, particularly in the context of product design for longevity. The findings in this study highlight both the ambiguity and importance of relations to stuff (materials) and stuff (physical entities). More research is needed to confirm whether being aware of what products are made of, paying attention to (materials) stuff, is indeed an important component in prolonging relationships with what surrounds us. Equally, understanding which physical entities are noticed or unnoticed may be important.

Being conscious of stuff as material may not constitute the majority of current behaviour (and may not be easy to encourage) but may be increasingly important in the context of product longevity. There is a need to better understand these relationships to inform design strategy and encourage behaviour change.

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Social Sustainability Approaches in Electronic Textiles Crafts Communities

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Keywords: Social Sustainability; Digital Crafts; Electronic Textiles; Wearables.

Abstract: This paper reports on results from the EU H2020 WEAR project, which between 2017-2019 has facilitated sustainable innovation processes in the field of smart textiles and wearable technology. 46 design-technology interdisciplinary projects and start-ups throughout Europe were selected through two Open Calls, and funded to develop creative solutions for a broad range of sustainability challenges within the relevant industries.

The paper outlines collaboration between two WEAR teams (KOBA, Touch Craft) as makers and facilitators and their audiences through crafts and practical making of electronic textiles artefacts. In particular, it reports how engagement with communities (as customers and/or co-creators) was used to increase social cohesion and well-being as social sustainability potential. Findings highlight the importance of quality of interaction, in particular, ongoing, in-person exchange, either between crafter and customer (KOBA) or facilitator and crafts community groups (Touch Craft). It further emerged that social cohesion could contribute to finding solutions to environmental and economic challenges, through encouraging local production, made-to-order production and local business development.

Introduction

Designers and artists are challenging the processes by which smart textiles and wearable technology are currently designed, manufactured and used. Following two decades of technology-centred research and development, bringing advancements in sensing and data processing capabilities, miniaturisation, efficiency and accuracy, wearables and smart textiles are now entering the market, and a growing concern about environmental and social impacts becomes a focus in public debate. Addressing some of these challenges, the project WEAR (Wearable technologists Engage with Artists for Responsible innovation), funded through the EU H2020 ICT-36-2016 programme, has between 2017 - 2019 facilitated sustainable innovation processes in the field of smart textiles and wearable technology. 46 design-technology interdisciplinary projects and start-ups were supported through a cascaded funding scheme, to develop creative solutions to environmental, social and economical sustainability challenges. Successful applicants were supported over six months with research and development budget, a bespoke mentoring support package and marketing activities.

Alongside the support for individual projects, WEAR developed an enabling framework, by bringing together industrial companies, SMEs, start-ups, actors of electronic textiles and wearable tech communities, designers, makers, local organisations and potential customers - leading to raising awareness and cross-sector open innovation for more sustainable processes in the relevant industries.

While results of the overall project and its outcomes (among them a Sustainability Strategy Toolkit) are addressed elsewhere (Baker et al., 2018; Bryan-Kinns et al., 2018), this paper reflects on socially sustainable practice explored through crafts and critical making, as addressed by two funded projects:

1. KOBA - a tailor shop for electronic textiles and wearable technologies in Berlin / Germany;
2. Touch Craft - a social enterprise for local community engagement and economic development in Penryn, Cornwall / UK.

Background

There is a strong interest and tradition in socially enriching practice through crafts in both academic and making communities related to electronic textiles (e-textiles), bringing together traditions of critical textile crafts (as practised in several impactful design and crafts schools, e.g. Bauhaus or Arts and Crafts movement), with the more recent development of Open Source and Open Hardware advocated in global maker communities.

Different concepts of crafts involving electronic textiles are reported in the open literature. Kettley (2010) describes crafts as a form of critical engagement, enriching crafters (and other beneficiaries) by producing “tangible computational products that seek to be metaphorically meaningful as well as useful”. Others promote crafts cultures and individual practices from specific regions, to provide meaning and new business opportunities for local communities (e.g. Tharakan, 2011). Others again utilise crafts as a means to advance engineering research, and develop innovative prototypes (e.g. Waldhör et al., 2017), while a fourth area of interest focuses on poetic storytelling and making use of crafts to create artistic artefacts (e.g. Sandra de Berducci [1]; Kurbak, 2018). Based on this distinction, we propose to classify the role of crafts in contemporary e-textile practice as follows:

1. *Application-based development for product innovation:* Crafts in this category can be understood as a handmade precursor of an industrially manufactured product. Crafters regularly use ready-made prototyping platforms (e.g. Arduino), however in the view of optimising the later product with regard to specific and robust functionality, energy consumption, washability and comfort.
2. *Crafts as meaningful making:* This category is interested in using crafts as an educational and storytelling method, to engage specific communities and facilitate social enrichment. E-textiles are not produced with commercialisation in mind, but aim to enable inclusiveness and participation in technology development or within specific disengaged or disadvantaged groups or individuals.
3. *Artistic use of e-textiles for performance and conceptual fashion:* This category of makers is mostly concerned with the expression of hypothetical concepts and critical aesthetics.

   Works in this category are less interested in reproducibility, or technical advancement as such, but focus on exploring underlying larger topics such as “sense reframing” (Schwartzman, 2011), body and consciousness, or artificial intelligence.

[1] https://www.sandradeberduccy.com

Social sustainability in e-textile crafts communities

The second and third categories outlined above can be tied to the current discussion on social sustainability in relation to design and craft (e.g. see Mazé, Gregory, & Redström, 2011; McMahon & Bhamra, 2015; Woodcraft, Hackett, & Caistor-Arendar, 2011), which forms an important ingredient in the contextualisation and setting of e-textile craft. Social sustainability is often addressed relating to two different goals[2]:

1. Social cohesion: increasing participation in social activities by individuals; helping to develop a sense of belonging; building links within the broader community; encouraging to contribute towards the community or provide support for others.
2. Quality of Life: increasing mental health outcomes; supporting education, training and skill development; providing access to community amenities and facilities.

To illustrate how these have been addressed by WEAR teams, we introduce two examples of supported projects in the next section.

WEAR Projects

Project 1: KOBA

KOBA defines itself as an “electronic textile tailor shop where anybody can place an order

[2] e.g WACOSS Social Sustainability Assessment Framework http://integral-sustainability.net/wp-content/uploads/sas4-2-hodgson.pdf

for custom-made wearable technology garments and accessories". It was run by artist collective KOBAKANT from January 2018 until February 2019, consisting of media artists and designers Hannah Perner-Wilson and Mika Satomi. The duo is widely known in the e-textile design community for the online knowledge platform "How to get what you want"[3], through which they freely publish materials resources, processes and codes.

Their focus is on textile and electronic Do-It-Yourself (DIY) practice. Commercial product development is not stated as a concern. Instead, they describe the KOBA shop as an artistic and public experiment, and "a story we are telling"[4]. While the audience around their previous work were mostly like-minded makers, designers, crafters and artists, the intention of the shop was to reach out to the general public and allow curious members of the public to discover the possibilities of e-textiles and wearables, and reassess the current production and use patterns of technology.

Original goals of KOBA proposal

KOBAKANT describes their original intention as creating "an electronic textile tailor shop where anybody can place an order for custom-made wearable technology garments and accessories." The proposal addressed social sustainability goals as follows:

- *Accessible/Democratic/Diverse:* Services to the general public, and keeping cost low to invite diverse customers;
- *Maintaining Diversity*: What, how and for who is technology made;
- *Made-to-order* service: May increase personal investment by customers, thereby more meaningful products;
- *Transparency:* Make processes and labour behind production visible;
- *Data/Privacy:* Developing non-exploitative technology solutions;
- *Open Design:* All works published as open-source hardware;
- *Education:* Customers will be instructed to be able to repair, recycle, and reuse parts of their products.

Reflecting on Activities

Upon setting up and opening KOBA after a preparation period of four months, KOBA curated a full programme of activities to run in parallel with the day-to-day business of the shop. These included:

- Commissions
- Shoptalks
- Exhibitions
- Commissioning essays / texts by mentors
- Ongoing critical reviewing of their shop concept

At the end of the six-month WEAR funding period, KOBA had established itself as a critical project and a place for outreach and community engagement. Audiences included the international e-textile community, and new members from adjacent local artists and technological fields. 14 commissions were completed, and several series of public events and exhibitions were curated and frequented by between 10 and 100 visitors per event.

Reflecting on their original intention of inviting the general public to the shop, the team felt KOBA had less of an impact in the neighbourhood than hoped. This was mainly due to the limited time the shop existed. They also noted that people already working in creative or digital industries were "feeling much more comfortable to come in". The high quality of interaction with customers however was pointed out as a positive outcome, rating the possibility of meeting in person highly in terms of importance. A strong common interest either in e-textiles or the shop itself was also identified as a beneficial starting point for customer relations. This quality of interaction extended into the commissions and the produced garments themselves, as they allowed both KOBAKANT and customers to get to know each other, learn and exchange personal stories, and in some cases "to become friends". This also had an impact on the produced garments themselves, which became meaningful to the wearer through sharing of stories with the KOBA team. According to Satomi, the environmental aspects of the work could not be assessed directly due to the lack of clear guidelines. The made-to-order process indicates however that tailored garments with embedded technology may require a slow production comparable to conventional tailored items, resulting in more meaningful products that need fewer replacements, and encourage care and repair.

[3] https://www.kobakant.at/DIY/
[4] https://www.kobakant.at/KOBA/concept-revisited/

Additional events around the commissions further contributed to social cohesion between the various audiences. A final exhibition and event provided the opportunity to showcase KOBA's process and results in multiple formats; from written stories to live-performed ones, the produced garments, verbal presentations, as well as the exhibition of the KOBA shop as such, including work-in-progress prototypes, textile and electronic samples, tools, sketches and models (see Fig. 1 and 2).

Figure 1 and 2. KOBA shop, final exhibition and performances.

Team 2: Touch Craft

Touch Craft defines itself as "a not-for-profit organisation that explores methods of embedding stories into textiles as a way to engage different audiences and contribute towards social cohesion and wellbeing." The project was co-founded by textile and interaction design researcher Lucie Hernandez, and developer Edwin Love. The team uses e-textiles to design innovative soft technology products together with local crafters, and facilitate workshops, encouraging participants to utilise the multi-sensory capabilities of e-textiles (visual, tactile) and electronics (sound, visual, tactile) for storytelling. Their approach is grounded in co-creation and participatory design[5] (Hernandez, 2017).

Original goals of Touch Craft proposal

Touch Crafts' proposal responded to the Social and Workplace Ethics theme set by WEAR as follows:

- *Active involvement of people:* Embedding technology in communities' interests through crafts
- *Advocacy:* Advocate for community requirements and personalise functionality
- *Business models*: Create security and future resilience for the groups activities through reinvestment from profits

They further responded to the 'Environmental Sourcing and Life-cycle theme', providing clear links to the aforementioned social sustainability goals. These included:

- *Circular design*: Community determines best practices for reuse and repair
- *Design for attachment:* Develop a relationship with products, reducing replacement
- *Maintenance training:* Actively involving beneficiaries in repair activities.

Reflecting Activities

Touch Craft initiated two strands of work during the six-month WEAR funding period. One part aimed towards prototyping commercial e-textile interior products. The second was a series of community workshops (see Fig. 3 and 4), which however also explored the concept of market value of "team-initiated" e-textile products. Small batches of the two prototypes *Story Blanket* and *Sensory Cushions (see Fig. 4 and 5)* were fabricated and tested.

The value of community crafting for health and well-being of the participants emerged as the main benefit of the project. Hernandez observed that multi-sensory engagement with the crafted object "enabled people to engage on a deep level" and express and communicate personal stories through materials and local nature-related themes. Hernandez mentions that e-textiles have not yet been around long enough to assess if crafted objects can embody similar meaning to people as traditionally crafted artefacts do, however points out that the process was

[5] see Sanders & Stappers, 2008

similar: using personal storytelling, defining a purpose and the addressee of the object. Participants reflected positively on collaboration, multi-sensory materials and meaning to personal memory. One participant describes their experience on collaboration as, “I was interested in the combination of sound and touch and feel, so the whole kind of concept behind the project”. Another participant reflects, “I love working like this, and especially working with these embroidery silks, it takes me right back, granny showing me how to split the threads.”

Figure 3. and 4. Touch Craft workshop and examples of work from workshop.

Figure 5. Touch Craft product development.

Identifying the communities both as “participants and producers”, Touch Craft sees the benefits on “small-scale processes, slow, local production”, ”nurturing an emphasis on slowness, valuing present time, re-skilling through shared knowledge, learning and co-creation”. They frame this as “durable practices” (see also Chapman, 2009) and observed that “through the act of cooperating and participating directly, people increase in confidence and develop their creativity and imagination.” The aim is to encourage also business activities by producing and selling team-initiated e-textile products. By the end of the WEAR funding period, the prototypes were tested by the participants in their homes.

Discussion

The work undertaken by the teams above highlights that social sustainability aspects of knowledge transparency, open sharing, free education (or at least included in a service) are important to the e-textile communities who originated from a crafts background. Furthermore, these are linked to other sustainability goals through local production, made-to-measure and local business development.

Although KOBA was not intended as a for-profit business, by critically reviewing business practices it may inform how small-scale crafts businesses could use new ways of engaging with local specialist communities to create niche markets for profit. It additionally highlighted how merging different modes of operation could lead to innovative online/offline crafts and technology businesses models.

Touch Craft’s clear goals and reflective rigour have helped in evaluating co-creation values resulting from a participatory design process. They point out the requirement for continuous exchange between communities and facilitators, however are not yet sufficiently progressed in their development to evaluate if sustainable business will be possible. This, however, highlights the shortcomings of funding schemes like WEAR, which only provide limited support for short periods of time. A more sustainable “slow business” approach may be needed, including the access to follow-on funding.

Both teams described how the quality of interaction between themselves and their customers/participants brought a benefit to their projects, which could in retrospect be described as a process of increasing social cohesion in their respective communities. For KOBA this was especially relevant for their commission work, during which the customer and the artists shared the stories related to the commission (why the customer wanted it and what functional and poetic value it would carry), artistic objective (KOBA bespoke technology: what do people want), social sustainability requirements (e.g. open sharing of plans, transparency of making) and technical plans. KOBA challenges current business models prevalent in the electronics industries by allocating significant time and resources for one-off and bespoke commissions, allowing them to build e-textile wearables meaningful to their customers, and publishing detailed information about the process online - all this while operating out a physical, high-street store. The team however repeatedly stated that they had to start with unrealistically low prices to draw in customers, and their "real income" was earned through parallel teaching activities.

The participatory design approach used by Touch Craft allowed them to adjust the goals of their work. Improving quality of life of the workshop participants emerged as a benefit, however the team mentions that the strict timeline of the WEAR funded period was not beneficial for the exploration of slowness as an approach, and further funding will be required.

Reviewing the classification of using crafts in e-textiles, it becomes clear that both teams utilised a combination of these, with an emphasis on *Crafts as meaningful making.* While in the short period of receiving funding through the WEAR scheme it was not possible to explore all aspects of sustainability, benefits emerged from increasing quality of participation, providing education and skill development and transparency of processes and in exchange.

Summary

This paper reported of social sustainability approaches of two teams funded through the WEAR scheme. They addressed social cohesion and quality of life challenges, which are two distinct principles of social sustainability[6].

KOBA utilised a combination of outreach, community engagement and communications to build links between known and new individuals. For KOBA the open sharing of information related to their processes was key, and the WEAR funding was used to test this within an experimental, yet traditional-style tailor shop scenario. By freely publishing all information related to commission, they also contribute to education, training and skill development for individuals who previously have not had participated in e-textile practice. It was however noted that maintaining a for-profit a shop as livelihood would not be possible due to high costs and current low demand.

Touch Craft used an iterative process of engagement with local crafts communities, increasing both social cohesion and quality of life for participants. Continuous exchange over longer periods of time was rated as highly important, allowing the community to build trust and confidence. Touch Craft has taken the first steps towards setting up a social enterprise, using e-textiles and crafts activities to both engage and enrich communities, and (at a later stage) generate income from group-initiated e-textile products.

One way to strengthen crafts-based enterprises, combining co-creation, educational and commission work may be through schemes like WEAR, to support local activities while also facilitating sufficient exchange and outreach through a European-wide network of crafts communities, customers and makers online. However it is clear that support over a longer time would be required to turn socially sustainable and crafts-based enterprises in the area of e-textiles and wearables into self-maintaining businesses. There is a need for more crafts/technology-business development schemes, which allows the crafter to test and implement "slow business" approaches, bringing together traditional crafts development with online and offline outreach and knowledge sharing activities that lead to sustainable community development.

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[6] these principles can be found in various Sustainable Development Goals (e.g. SDG 3, 4, 9)

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The Use of System Dynamics to Verify Long-term Behaviour and Impacts of Circular Business Models: a Sharing Platform in Healthcare

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Keywords: Circular Economy; Business Model Innovation; Experimentation; System Dynamics.

Abstract: Static approaches for business modelling cannot cope with the increased complexity commonly linked to Circular Business Model (CBM) innovation. In this research, we aim to investigate whether System Dynamics (SD) modelling is suitable to verify the long-term behaviour and impacts of CBMs by applying it to a particular case study. The dynamics of a closed sharing platform for healthcare institutions are modelled and simulated. The dynamics of sharing durables and consumables is represented through (1.) a causal explanation of the behaviour, (2.) the structure of stock and flows and (3.) verification through simulation. Results indicate substantial potential impacts for durable products. Products lifecycle time and the number of use cycles determine this behaviour. The use of SD enables experimenting with CBM in this case by connecting the dynamics of sharing to the use of resources and its impacts. Further research should verify the possibilities to design enhanced CBMs from interventions evidenced by modelling.

Introduction

Business model innovation is the bottom-up engine towards a Circular Economy (CE). Circular business models (CBMs) provide the rationale so that companies and individuals can consistently operate and benefit from value retained in products and materials (Bocken et al., 2016; Lüdeke-Freund et al., 2018). Increased complexity is commonly linked to CBM innovation. It arises from the need for collaboration in ever more complex networks of stakeholders (Geissdoerfer et al., 2018), the possibility of rebound effects (Bocken et al., 2016), and from increased risk due to capital tied up in resources and reliance in future people behaviour inherent to solutions of increased lifetimes (Linder and Williander, 2015).

Still, business modelling methods rarely focus on sustainability (Evans et al., 2017) and current research still offers a static view of business model innovation for sustainability (Roome and Louche, 2016). In this work, we aim to investigate whether System Dynamics (SD) modelling is suitable to verify the long-term behaviour and impacts of CBMs by applying it to a case study of a closed sharing platform for healthcare institutions. SD, a modelling paradigm used in environmental sciences (Meadows et al., 1972) and business management (Sterman, 2001), is used to demonstrate the potential impacts of CBMs while decreasing the efforts and risks of experimentation. Through modelling and simulation, the multiple parties involved in business model innovation can further understand the potential impacts and its reasons when aiming for long-term sustainability.

Background

System Dynamics (SD) is a continuous modelling approach capable of representing and simulating specific aspects of systems based on feedback-rich structures and delays among decisions and their effects (Sterman, 2001). Causal Loop Diagrams (CLDs) and Stock and Flow Diagrams (SFDs) are the two major diagramming conventions in SD. CLDs use variables and links to represent the feedback structure of a model (Lane, 2000). SFDs enable simulations of stock accumulations over time, according to structures of inflows and outflows (Lane, 2000).

While the former is effective in communicating and explaining the system's behaviour, the latter enables verification of behaviour through time.

The SD lenses can be used to make sense of the Circular Economy. The CE is a regenerative system where the flow of resources, waste and emissions are minimised through circular initiatives (Geissdoerfer et al., 2017). Stocks can be used to represent the many types of resources in a system. Products, parts, consumables constitute some of the stocks to be maintained in a CE. By contrast, flows depict the transformation processes that affect such stocks: extraction, manufacturing, discarding.

The circular initiatives, in fact, slow or narrow the flow of resources and closing their loops (Bocken et al., 2016; Geissdoerfer et al., 2017). In other words, the CE involves both creating mechanisms to delay flows of resources as to enabling outflows of a given stock to be used as inflow of a less aggregated one. In order to slow the flow of resources, delay systems can be conceptualised to decrease throughput, retaining the value of products. Maintenance services work as delays for functional products to become obsolete, increasing their lifetime as useful stocks. In order to close the loops, outflows of a given resource become inflow of a less aggregated one, retaining value in the parts or materials levels. Recycling makes use of the outflow of obsolete products to be used as inflow of material production.

This resource-oriented perspective, if connected to the dynamics of a given business model, enables the capability of verifying and potentially experimenting with the impacts of CBM implementation through the application of SD.

Research Methodology

A case study of long-term behaviour and impacts of the sharing platform provided by Company A for healthcare institutions was performed. The scope of analysis is the use of a sharing platform in a small-sized hospital with 400 employees.

Medical devices contribute to the high use of resources and waste generation in diverse ways (Moultrie et al., 2015): through recyclable uncontaminated devices ending up treated as hazardous waste, the release of toxic substances from the end-of-life of PVC-based devices, and the Waste Electrical and Electronic Equipment (WEEE) from electromedical equipment. Sharing assets is one of the CE strategies that can be applied to the medical industry towards a more sustainable healthcare system.

A protocol using the SD modelling process proposed by Pruyt (2013) was applied. The following steps were employed: problem identification, model conceptualisation, model formulation and model testing. The sustainable business model canvas presented in Bocken et al. (2015) was applied in order to set the scope of inquiry. Interviews (four) with the platform co-founder, press releases and secondary sources as research papers from the medical and SD knowledge areas were used for model conceptualisation and testing. Stock and Flow Diagrams (SFDs) were developed to simulate model behaviour over time. Causal Loop Diagrams (CLDs) were employed to highlight the structure originating such behaviour. The reasons for the simulated long-term behaviour are discussed. Recommendations for intervention in the real system and initiatives for model enhancement are pointed out. These are derived from the increased understanding enabled by modelling and simulation.

Results

Problem identification: articulating the issue to be addressed

In the platform, different types of resources can be shared: from low-value single-use products to highly complex electromedical devices. Two types of sharing platforms are available: (i.) Closed sharing platforms - where customer companies pay a tailoring fee and annual maintenance fee for a platform to be used by internal teams, and (ii.) Open sharing platforms - where customer companies pay a monthly fee to access products from a network of healthcare institutions. Following five years of market experience, where they mainly acted as evangelists of Circular Economy and Sharing Economy to clarify their business model, Company A is focusing on implementing closed sharing platforms in Hospitals.

Their current challenges towards expansion are:

- Understand the dynamics of sharing in a closed platform;
- Connect the dynamics of sharing to potential environmental impacts of platform use;
- Identify levers so that the potential positive impacts of sharing can be consistently improved.

Model conceptualisation: a theory of behaviour

The model structure about the dynamic aspects of product use dealt by the sharing platform is represented in Figure 1.

advertising occurs mainly exogenously. Word of mouth is a powerful mechanism, which is balanced when the adoption fraction is high – represented by B3. Finally, users may get idle and stop using the platform for some time when

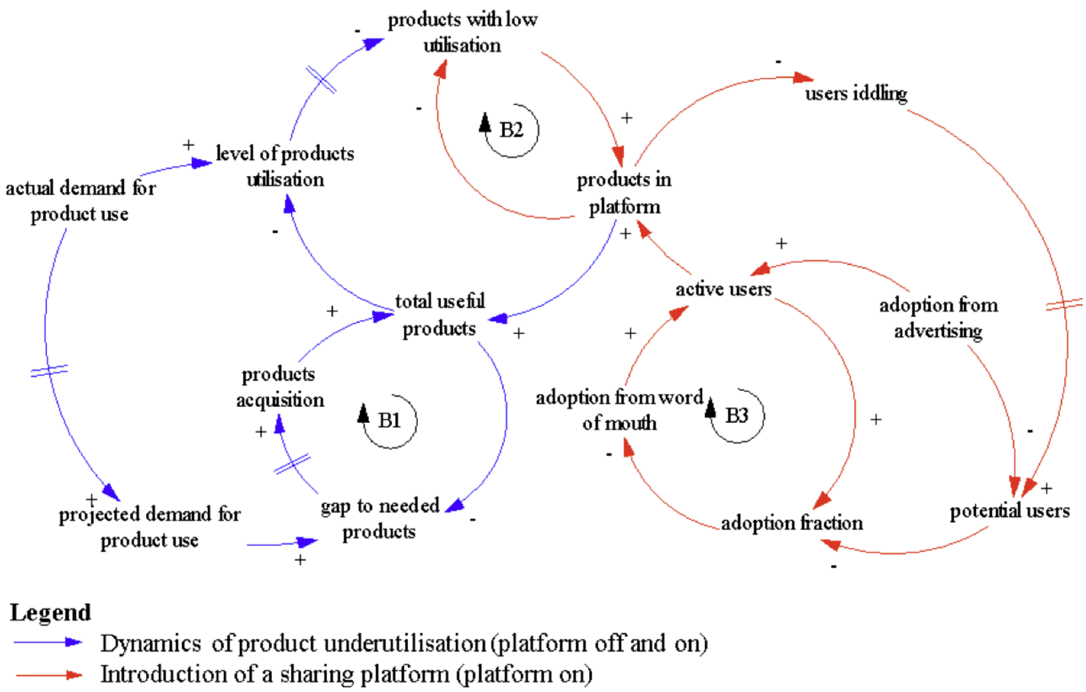

Figure 1. Causal Loop Diagrams (CLD) of sharing platform use.

Low utilisation occurs when the actual demand for product use is lower than the total amount of useful products. Products become underutilised after a while in that condition. It is worth distinguishing durables and consumables. Durables may not be used often – way less than their capacity, and consumables may be kept away from use while approaching the end of their shelf life.

In a hospital which does not use a sharing platform, these underutilised products become obsolete after little use, and the number of total useful products is balanced by acquiring new products to meet projected demand – see B1 in Figure 1.

By contrast, in a hospital with a sharing platform in place, products with low utilisation can be turned into useful products for users that otherwise would not have been able to access them. This mechanism is of limited impact because it is a balancing loop – see B2. Active users in the platform register products and make use of them. The mechanism of internal user acquisition is thus critical. Users adopt the platform through two mechanisms: word of mouth and advertising. Adaption through

they have a negative experience, i.e. when they cannot find products they want in the platform. Some idle users may never try the sharing platform again because of the bad experience.

Model formulation: a simulation model of the theory of behaviour

Towards simulation, the model is organised into four sub-models on the sector diagram represented in Figure 2. Sub-models are parts of the model that could be conceptualized and tested separately, so that modelers could deal with less complexity before assembling the full model. It helps to provide a general description of the Stock and Flow Diagram (SFD) model. Sub-models are: 'use of resources', 'users in platform', 'sharing within a platform' and 'KPI system'. Variables that connect sub-models are made explicit.

The 'use of resources' connects the model to the CE framework by making the stocks the and flows of resources explicit in a healthcare institution. It contains the total stocks of functional, underutilised, and obsolete resources. Acquisition, obsolescence, utilisation and discarding are the main flows.

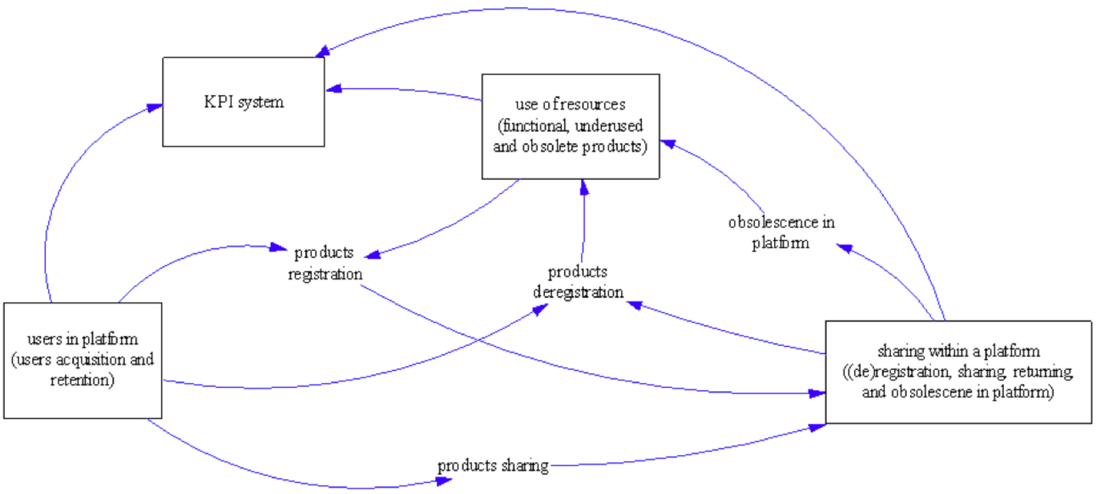

Figure 2. Sector diagram of the four conceptualised sub-models and relationships among them.

The 'users in platform' represent the mechanisms for user acquisition and retention in a closed platform. The Bass diffusion model (Borshchev and Filippov, 2004; Sterman, 2001) is applied to represent the mechanisms of word of mouth and saturation in such a process. Advertisement efforts pushed forward by Company A are used to initiate/reinforce such dynamics.

The 'sharing in platform' represent the flow of underutilised assets being registered in the platform and their consecutive sharing. It connects the two sub-models previously presented. Products registration by users into the platform work as a delay to products acquisition as it rapidly balances the total number of functional products. A balanced ratio of products per users is necessary to enable sharing. When users leave the platform, the products under their responsibility are automatically deregistered and become underused again.

Finally, impacts are represented by the 'KPI system' sub-model, which is fed by all the other sub-models. Total sharing events, total products acquired and discarded, and total unmet demand are some of the KPIs defined to assess resource effectiveness.

Model testing: assessing whether the model is fit for purpose

Table 1 shows the parameters used to model the behaviour of durables and consumables in the 400 employees hospital using a closed sharing platform. Durables account for electromedical machines like MRI, Computed Tomography, X-ray, and Mammography machines. Consumables are single-use devices such as sutures, syringes, and gloves. The variables and parameters used represent the demands and lifetimes of products – durables and consumables.

Durables hold a high lifetime. They get the status of 'underutilised' after 18 months of low utilisation level and the decisions involved in acquisition take longer. Consumables hold shorter lifetimes and a safety stock policy is maintained. Lifetimes of durables are drawn based on the age profiling of imaging equipment in Europe (COCIR, 2016).

Product acquisition is defined by the projected demand for product use. Random time series are used to simulate actual demand for product use. The projected demand is a delayed response to actual demand, considering the time to acquire the product. The actual and projected demands were defined based on a case study for demand forecasting in healthcare (Cote and Tucker, 2001).

For the sharing platform, registration relies on the density of underutilised products per users. Sharing relies on the probability of desired product availability, which depends on the types of products within a category – durables or consumables. Finally, only durables are returned as available products in the platform for further sharing events. Consumables are used only once.

Figure 3 and Figure 4 show the simulation runs for the input parameters for durables and consumables of a small-sized hospital. Two scenarios are presented for each type of product: one representing no sharing platform and another with the sharing platform in place.

Variables	Parameters for Durables	Parameters for Consumables
simulation time (Month)	120	120
hospital employees (People)	400	400
product lifetime (Month)	120	12
time to underuse (Month)	18	6
time to acquire (Month)	3	1
actual demand for product use (Product)	Random time series – mean value of 20, standard deviation of 4	Random time series – mean value of 3000, standard deviation of 600
projected demand for product use (Product)	Information delay of the actual demand for product use considering time to acquire	Information delay of the actual demand for product use considering time to acquire
initial Functional (Product)	19	2800
initial Underutilised (Product)	1	200
Safety stock (Product)	0	300
ratio of returning (Dmnl)	1	0

Table 1. Initial parameters to simulate the behaviour of durables and consumables. Further details on the model choices can be obtained by contacting the corresponding author.

For durables and consumables, the actual and projected demand is the same when the platform is on or off (see Figures 3.a and 4.a). Following Figures 3.b, and 4.b, when the platform is on, users become active, and after a while, an increasing fraction becomes idle. In both cases, when the platform is off, all types of users remain zero. As shown in Figures 3.c and 4.c, total useful products are higher when the platform is on for both cases. Nevertheless, it is more relevant for durables. The total number of acquired products is relevantly lower to durable products when the sharing platform is in place (see Figures 3.d and 4.d).

Furthermore, the sharing platform enables meeting some demand that would otherwise not receive treatment. The total unmet demand decreases when the platform is on. Potential increased capacity is, again, more significant to durable products than to consumables (see Figures 3.e and 4.e).

Based on the experiment, the potential impacts of implementing a sharing platform in the context of one small hospital are substantial. Impacts of sharing durables and consumables in hospitals vary according to factors such as demands for product use, lifecycle time of products and the number of use cycles. The potential is higher for the sharing of durables.

Discussion

The model can represent the long-term behaviour and impacts of sharing durables and consumables in the scope of one small hospital. It can, thus, influence the adoption of the sharing platform by a potential client.

Also, it can assist Company A to communicate or even improve its solution. New mechanisms to improve environmental impacts of this CBM can be enabled by, e.g. expanding platforms for neighbour hospitals or improving the fit to demand by further understanding the reasons for underuse.

Nevertheless, some model limitations must be considered. First, we assume that products become useful as soon as they are added to the platform in the presented model. The actual stock of use cycles of products is not considered. Addressing this could provide a more accurate measure of the level of use for durables. Also, CO_2 consumption during the use phase could be investigated.

Second, item degradation because of underuse or careless sharing was not considered.

Third, the parameters and dynamics of user acquisition need to be further investigated in practice. Nevertheless, the diffusion behaviour works similarly to research pieces used as references, i.e. Borschev and Filippov (2004) and Sterman (2001).

Fourth, the model is still not connected to Company A's operations, costs and revenues. These aspects of the company might influence the overall dynamics of sharing, and these processes should be explicitly considered in the model. This is key to understand the path to enabling the scale-up of Company A's business model. The dynamic business modelling approach presented by Cosenz and Noto (2018) can help in that direction.

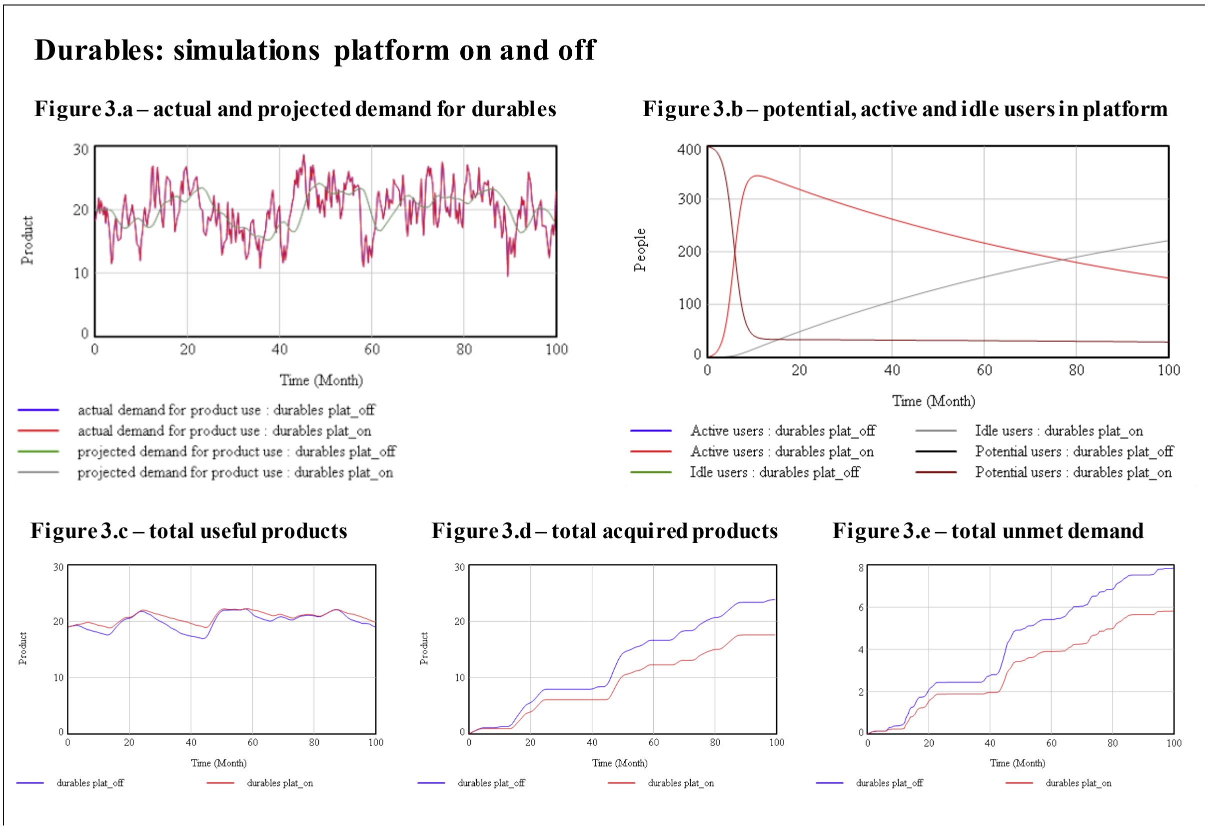

Figure 3. Simulation of durable products in a small hospital with and without sharing platform.

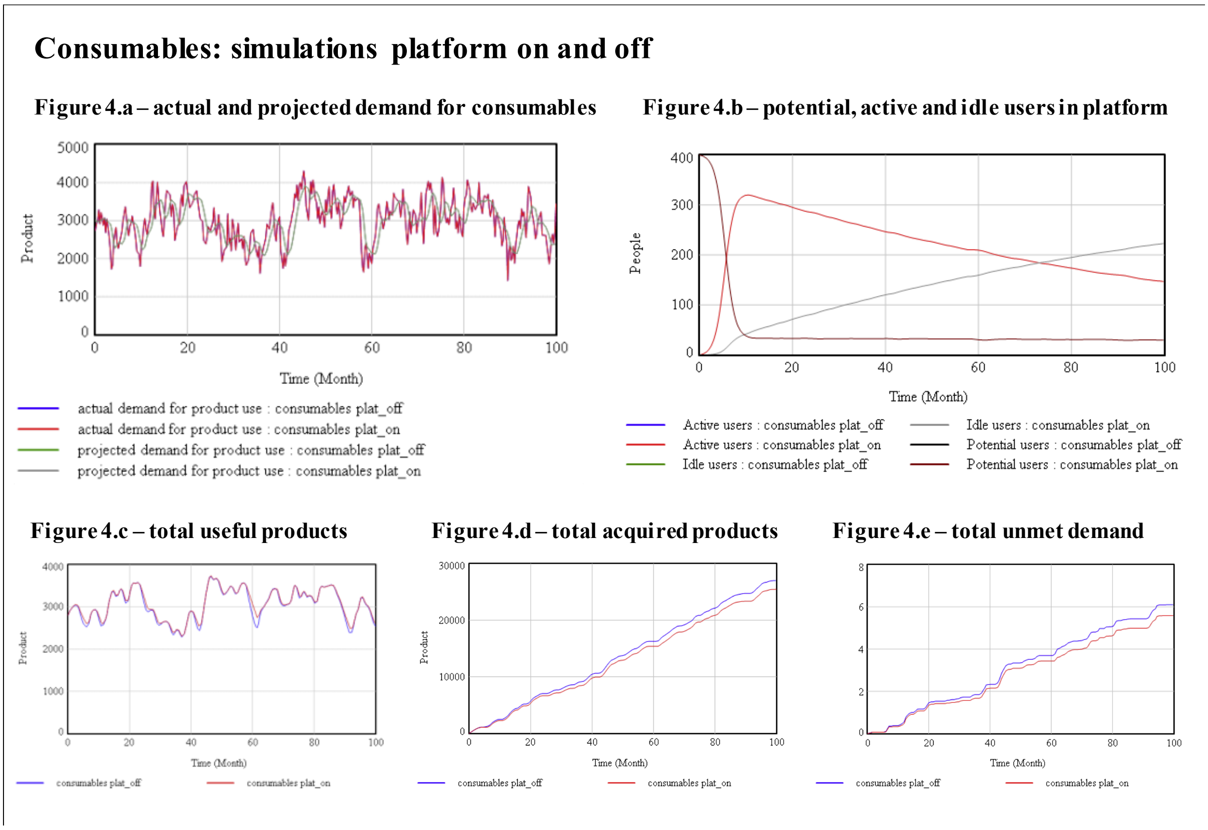

Figure 4. Simulation of consumable products in a small hospital with and without sharing platform.

Finally, while better impacts can be expected when two or more hospitals are connected by a single platform, a limitation of scope is that only the dynamics of sharing within one hospital was modelled and analysed.

Conclusion

In this work, we have experimented with a CBM in healthcare to verify its long-term impacts. Through the case study of a sharing platform, the dynamics of sharing durables and consumables is represented through (1.) the causal theory of sharing, (2.) a stock and flow model and (3.) verification through simulation. Scenarios based on a plausible set of variables lead to increased understanding of the CBM under research. A contribution of this research is thus to provide evidence that SD modelling and simulation can inform decisions i the adoption of business models aiming for long-term sustainability. The method presented in this research is useful to conceptualise a Circular Economy connected to the dynamics of business models. It can be used to verify the impacts of potentially circular business models in further applications. Directions to expand the model purpose are provided. It holds the potential to inform the design of CMBs by evidencing interventions for more positive impacts.

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Self-Healing Materials in a Circular Economy

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Keywords: Self-Healing Materials; Product Longevity; Circular Economy; Repair; Product Design.

Abstract: There are materials currently being developed that have the ability to self-healing or self-repair. While from a materials innovation perspective this technology delivers new and interesting functionalities, for product lifetime extension research, this provides an exciting opportunity to explore how this might facilitate product longevity. Utilising a literature review, this paper investigates what are the key benefits that self-healing material might offer product lifetime extension. Considering two main perspectives of product longevity, i.e. technical and service lifetime, five key benefits were identified. It is proposed that self-healing systems can help to: *Enhance Physical Durability, Maintain Efficiency, Increase Reliability, Enhance Aesthetic Resilience* and *Reduce Cost and Risk of Future Repair*. Lastly, to fully validate these factors future research and field testing of these technologies would need to be conducted to fully realise their product longevity potential.

Introduction

Inspired by biological systems, there is a new category of smart materials that have an intrinsic ability to restore functionality after being damaged (Diesendruck et al., 2015; Bekas et al., 2016). Referred to as self-healing or self-repairing, these materials can recover and repair themselves in response to aesthetic or structural damage, either autonomously utilising inherent functional capabilities or through external triggers (Ghosh, 2009; Aissa, et al., 2012).
Consisting of two main categories, self-healing materials are either extrinsic or intrinsic. Extrinsic self-healing uses microcapsules or vascular networks embedded into the bulk of the material, which facilitate the introduction of either, a healing fluid, or a bacteria able to produce a like for like material at the damaged site (Hager, 2010; De Muynck, 2008). Whereas, Intrinsic self-healing materials have an innate self-repairing capability which occurs at a molecular level, and is activated by an external stimuli, such as heat, electrical or mechanical force (Hager, 2010; Blaiszik et al., 2010).

Showing these in more detail, Figure 1. illustrates how each of these mechanisms operate: Micro capsules (a), vascular networks (b) and intrinsic re-bonding of the material's molecular structure (c).

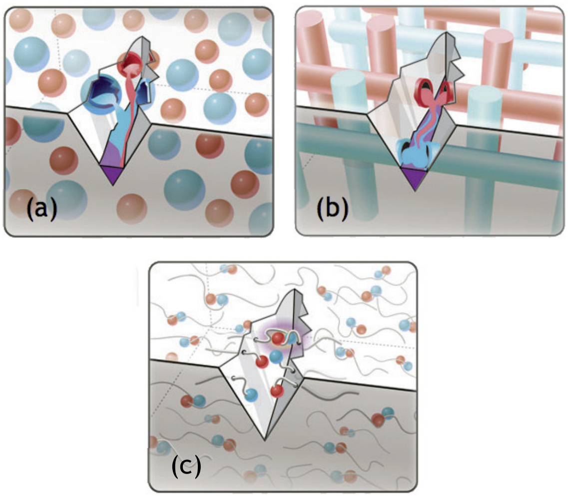

Figure 1. Self-healing mechanisms: Extrinsic - microcapsules (a), vascular networks (b), and Intrinsic – reforming of molecular bonds (c). Extracted from Blaiszik et al., 2010.

This technology has been explored within a range of materials, such as concrete (De Muynck, 2008; Sarkar et al., 2015) polymers (Gordon et al., 2017; Hia, Vahedi & Pasbakhsh, 2016; Mauldin & Kessler, 2010), metals (Ferguson et al., 2014; Ghosh, 2009) and glasses (Singh, 2014) to name a few. However, new material compositions are continually being proposed from within both academia and industry. Moreover, considering the functional benefits they might offer to the energy, construction and automotive sectors, the market for this technology is anticipated to continue to grow (Grand View Research, 2017).

Developed as either self-healing coatings or bulk materials, authors have proposed a number of potential applications that would benefit. These include aerospace (Das, 2016; Gordon et al., 2017), batteries and fuel cells (Wang et al., 2013), medical devices (Wang et al., 2016; Adaptive Surface Technologies, n.d), and consumer electronics (Blaiszik et al., 2012; Wu et al., 2017). Yet, few of these propositions have been tested beyond a laboratory setting, and there are only a handful that are currently commercially available. Of those available on the market, one of the more commonly discussed applications is self-healing paints, especially for the car industry to withstand day to day scratches (AutoScene, 2009; Nissan Motor Corporation, n.d). However, there are others that can be used in deep sea and military spaces as a method for preventing corrosion and increasing the overall integrity of the surface and structure (Automomic materials, n.d).

In regard to self-healing technologies that have been applied at a product level, consumers can now purchase self-healing bikes tires (Slime Products, 2019), car tires (Continental, n.d), self-healing gas tanks (HIT-USA, 2019), and self-healing jackets and bags (Imperial Motion, n.d). While each of these employ different types of self-healing, the variety of products that have utilised this technology indicate the potential market and industry that could exist for this innovation.

Since 'Virtually, all materials are susceptible to natural or artificial degradation and deteriorate with time' (Ghosh, 2009, p1), self-healing technology presents a unique opportunity to explore ideas relating to the lifetime extension of products. As, within a Circular Economy, one of central philosophies is to 'keep products, components and materials at their highest utility and value at all times' (Webster, 2015, p16), materials and products that can maintain their physical integrity for longer could assist in this endeavour.

Developed as part of the EPSRC funded research consortium 'Manufacturing Immortality', this paper examines how self-healing might relate to product lifetime extension, and addresses the question of *What are the benefits that self-healing might offer to product lifetime extension within Circular Economy contexts?*

Methodology

To explore the research question defined above, firstly, a literature review and state of art of self-healing materials and product lifetime extension was conducted to locate and analyse where these two fields of enquiry might converge. Using the search engines Google Scholar and Scopus the following key words were used to define the literature considered 'Self-healing', 'Materials', 'Durability', 'Product Life-time Extension' and 'Circular Economy'. The results of this review process is presented the next section.

Results and Discussion

Product Lifetime extension and self-repairing systems

Product lifetime extension is defined as 'the postponement or reversal of the obsolescence of a product through deliberate intervention' (Bakker & Schuit, 2017, p.12) and it has been proposed as a central strategy for addressing and reducing the environmental burden of products (Allwood et al., 2011; Bakker et al., 2014; Ardent & Mathieux, 2014).

A product's life can be prolonged through a number of different approaches, such as reuse, maintenance, repair, and remanufacturing (Bocken et al., 2016; Nußhol, 2017). However, repair and maintenance has been proposed as a pertinent strategy, as it allows for a greater material efficiency (Stahel, 2013). By following the Inertia Principle, repairing practices replace or treat only the smallest part of the technical system, therefore allowing the highest economic value to be preserved (Stahel, 2010). So, if considering this in relation to self-healing, a technology that has the ability to maintain and self-repair itself in situ, without the need for human intervention or considerable resources, would most likely be considered highly advantageous from this perspective.

A viewpoint that has been initially explored by Akrivos et al., (2019), they proposed that self-healing systems would apply to the inner most loop of the technical cycle facilitating a practice of self-maintenance shown in Figure 2 below.

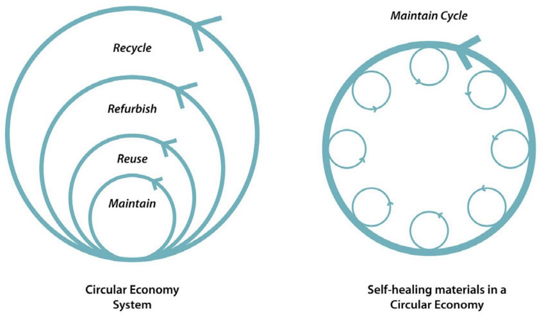

Figure 2. Extract from Akrivos et al., (2019).

Although only a preliminary supposition, it highlights the importance of a products primary lifetime in more detail. This is important as 'central to product life extension is the concept of a product's lifespan' (Bakker et al, 2014), which according to Cooper (2010), should be considered from two perspectives: the products technical life and the products service life.

The technical life of a product is defined as the 'maximum period during which it has the physical capacity to function' and the service life as the 'total period in use from initial acquisition to final disposal as waste' (Cooper, 2010, p9). While these distinctions describe two different viewpoints for how the lifetime of a product can be assessed, when considered in relation to self-healing materials, two opportunity spaces can be identified. Firstly, the structural and functional longevity, whereby the product or a part's mechanical properties are maintained, preserving its technical life. Secondly, the aesthetic functionality whereby the product is kept in service by preventing or repairing issues of wear and tear. These distinctions are explored in more detail below.

Extending the technical lifetime of a product

The primary benefit that self-healing materials provides is the ability to enhance the physical integrity of the material, slowing down the aging of materials or parts (Aissa et al., 2012; Ghosh, 2009; Schlangen & Sangadji, 2013). While overall this would provide an improvement to the lifetime of the product or material, this could be particularly beneficial in scenarios where damage cannot be easily detected. Some materials such as concrete or asphalt can develop micro-cracks over time, which aside from being difficult to diagnose, affect the overall integrity and durability of a material increasing the risk of more catastrophic failure to occur later (Herbert & Li, 2013; Su et al., 2017).

The application of self-healing technology could also help to maintain the efficient operation of energy producing products. For example, wind turbine blades are often subjected to a great deal of external stresses affecting the overall efficiency of the machine (Yang, 2013). So, the integration of self-healing as a method of minimising costs of repair and to ensure an efficient long-lasting product is an area of significant interest (Fifo, Ryan & Basu, 2015).

Lastly, beyond reducing the overall environmental burden a product may have over its lifecycle, there are some situations where the application of self-healing materials also provides an added benefit by reducing the costs and the risks that can be associated with repair (Hager et al., 2012; Aissa et al., 2010). This is particularly important in circumstances in which repair is typically expensive or dangerous, as for example with medical implants or extreme environments. With medical devices such as pacemakers, the replacement or repair of devices can be both costly and at great risk to the human health (Costea et al., 2008). So applying self-healing materials where maintenance is not possible, such as prosthetic limbs and other implants would be highly beneficial (Hai, Vahedi & Pasbakhsh, 2016).

In summary, considering all the examples provided above regarding how self-healing applies to the technical lifetime, three key benefits were identified. These are that Self-Repairing systems provide: *Enhanced Physical Durability, Maintained Efficiency* and an *Increased Reliability* to products.

It is predicted that these factors would contribute to the extension of the technical lifetime of a product. This would benefit not only user by providing a product that is more durable and reliable, but also producers, who can provide longer lasting quality assurance, reducing the cost and risk associated with future repairs or replacement.

Extending the service lifetime of a product

Aside from physical longevity, self-healing could also mitigate issues relating to emotional obsolescence and aesthetics. Wear and tear has been shown to be key determinants for why durable, functioning products are replaced by consumers (Van Nes & Cramer, 2005). While some researchers in the past have approached this issue by considering materials that can age with grace (Chapman, 2015; Bridgens et al., 2015), materials and surfaces that can be designed to withstand scratches and discolouration could also reduce this type of premature replacement. While it has been more commonly proposed for the automotive industry, there could be a significant advantages to applying these to 'shorter' living products, such as mobile phones, tablets and laptop computers. Furthermore, this also assists with the reuse and resale of objects, as it would help products retain their value for longer, and in turn stimulate the second hand market.

Another opportunity for extending the service lifetime is within the cycles of reuse and refurbish. Products such as broadband or TV boxes can operate in up to 5 different households in their lifespan. Throughout these lifetimes these products undergo wear which can result in the external casings needing replacement between each user (Teleplan, 2016). This practice causes both environmental and economical issues for the product refurbisher. Therefore, the application of self-healing coating could alleviate this situation, whereby the material would undergo a process of refurbishment and be returned to a like new condition.

In summary, contemplating the examples presented above one key benefit that self-healing offers was identified, which is that it provides an *Enhanced Aesthetic Resilience* to products. This factor is not only beneficial to users, but also remanufactures, demonstrating the wider value that this technology could provide for sustainability contexts.

In all, while there are some benefits that are more specific to the technical lifetime, and others the service lifetime, there are some that apply to both such as the *reduced cost and risk of future repair*. However, when considered together they represent the overall benefits to product lifetime extension. These have been consolidated into Figure 3, below to demonstrate how they relate to one another and the stakeholders they benefit.

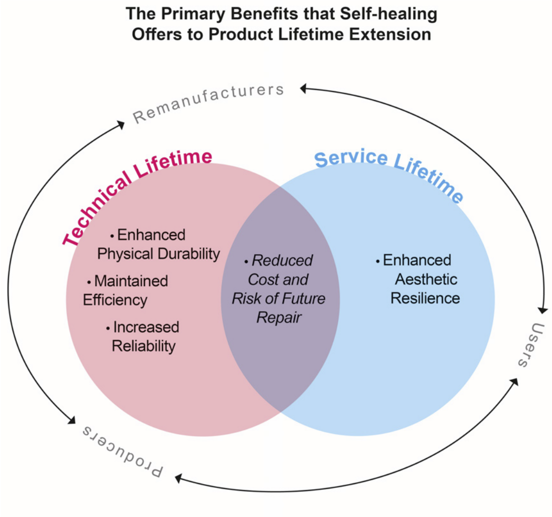

Figure 3. Proposed benefits that self-healing might offer lifetime extension.

Limitations, challenges and future research

One key limitation of this field of research is that very few self-healing materials have been tested beyond the laboratory scale. Self-healing concrete is the first example of a material found in the literature to be tested in the field (Wiktor & Jonkers, 2016; Al-Tabbaa et al., 2019). There are however, several self-healing coatings available on the market, which would have undergone industrial testing and therefore ready for application. Future studies are required to test newly developed materials to advance this field of research and therefore confirm their ability to contribute to product lifetime extension.

Another limitation with self-healing systems is that while it has been demonstrated that healing can be effective on small scale damages, such as scratches and microcracks, self-healing of large scale damage has yet to be fully realised (White et al., 2014). Initial solutions include the introduction shape memory polymers to close larger cracks (Ferguson et al., 2014), and the integration of gel like substances that act as gap-filling scaffolds (White et al., 2014). However it must be understood that there may be some levels of damage that are beyond repair. This then would indicate that there must be careful consideration of the design application spaces for these materials, and a good understanding of the conditions that need to be created for the self-healing to occur.

One of the potential issues with self-healing materials within a Circular Economy context is the notion of persistence. Identified as a factor that must be deliberated when trying to understand the toxicological and eco-toxicological characteristics of how materials flow within the technosphere and biosphere (Braungart, McDonough & Bollinger, 2007), some materials persist within the natural system resulting in negative environmental impacts (Lindahl et al., 2014). So, materials that have the potential to reform bonds or integrate healing fluids in response to mechanical damage may present issues at end of life. Therefore, it is important to investigate, from a whole systems perspective, the potential rebound effects of adopting self-healing materials within industrial product systems.

Conclusions

In conclusion, through literature review of self-healing technologies and product lifetime extension, five key benefits were identified. These relate to both extending the technical and service lifetime of a product. They are: *Enhanced Physical Durability*, *Maintained Efficiency*, *Increased Reliability, Enhanced Aesthetic Resilience and Reduced Cost and Risk of Future Repair.*

Lastly, in order to fully validate these factors identified, future research and field testing of these self-healing materials and coatings would need to be conducted, to uncover whether or not they positively contribute to the overall lifetime of products.

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Turning Utopias into Material: the Case of an Open Space for Experimentation in Helsinki

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Keywords: Materialized Utopia; Experimentation; Lab; Open Space; Humble Design.

Abstract: With an increasing number of open laboratories for cultural and technical experimentation in place, questions arise regarding how and with what effects they come about, what they mean to those who partake and how they organize themselves in order to satisfy those involved. Recognizing the way that these spaces reach of alternative technologies and alternative ways of being we conceptualize them as materialized utopias, which are fragile socio-material arrangements. Rather than articulating grand utopian or ecotopian alternative societies, we look at materialized utopias as the gradual tweaking, probing and fixing of things. We elaborate on this with the study of *"Test Site"* a campus-based open space for experimentation in Helsinki designing with matters such as soap, compost or wood. We show that the thriving of this space is dependent on purposeful misunderstandings. However, its hybrid character being open to different interpretations does not only help to spur momentum but by the same token also leads to tensions internally as well as externally. Materialized utopias are then bound to be compromised, but in the best case scenario, turn unproductive anxieties into productive care taking of the socio-material surroundings. As the site is in the making, materials and events function as checkpoints and create legitimacy.

Introduction

Frying oil turned into nice-smelling soap or urine turned into tomatoes into Bloody – these are some of the things happening at an experimental site next to the Aalto University campus. They underline current tensions between what sustainable forms of life appear to request and what the current technology and political regimes can deliver. Sustainability narratives thrive on the idea of radical disruptures between what is and what should be, informed by utopian thinking including classics such as Callenbach's Ecotopia (1978) and contemporary movements such as transition towns. By speaking of materialized utopias we want to highlight approaches where rather non-futuristic and quite mundane activities of design and production such as creating soap from waste oil and setting up a collective to continuously engage in such practices are meant to fix parts of the present rather than fully abandoning it.

Open spaces, as well as other forms of utopia, raise questions of the relations between individuals and the collective and those of recruitment and organizing. In this paper we ask the following question: What are the barriers for participating in and materializing utopias in the everyday? The paper draws on the ongoing study of a campus-based open space for experimentation in Helsinki since its preparation phase in January 2018. To answer the questions, we make use of interviews with members, participatory observation, field notes and data from the internal communication channels. We argue that sites for such gradually tweaking the present are utopias. However, since they are open in terms of agenda, rules and outcomes, they are hybrids and highly fragile. In order to stabilize, the role of material and designing with it therefore become essential as checkpoints.

Open spaces as materialized utopias

Utopianism offers several propositions and analytical distinctions for the study of open spaces. Firstly, as Karl Mannheim has suggested, utopian forward-looking thinking is what keeps societies alive (Mannheim 2013). Utopian promise stems from the recognition that we do not live in the best of possible world. Hence, deliberate efforts to think beyond what is reasonable, possible and 'real' may be particularly relevant for sustainability and has contributed to ecotopian thinking (Callenbach 1978). With our notion of materializing utopias we want to add to these distinctions a notion of radical modesty and highlight arrangements which are not premised on abandoning the present but rather reworking it. Be it activities of fixing and mending, self-build or permaculture, these are activities combining elements of quite mundane and non-futuristic kind.

Concurrently with such activities of fixing, repair and do-it-yourself, a host of spaces dedicated to technical and cultural experimentation have appeared. Amongst others they have been described as fab labs (Hielscher and Smith 2014), open workshops (Lange 2017) or shared machine shops (Dickel et al. 2014). While some are initiated as part of academic research projects or showcase new means of urban governance, many appear to be self-initiated by small groups of people as reported in the case of open workshops. These initiatives driven by civic collectives exemplify new modalities of innovation, production and needs based consumption (Lange and Bürkner 2018).

There has been a wave of real life experiments, situated in the wild, therefore not aiming at producing general valid knowledge but at exploring specific cases and adopting generic technologies locally (Jalas et al 2017). They exemplify semi-protected spaces, premised upon welcoming failure and irritation as part of learning, and being productive in terms of new ideas, knowledge, artefacts and practices. Hence, Lange and Bürkner (2018) conceptualise such spaces as assemblages, where actors, materials and tools link together in changing constellations. What is interesting in the open labs is open-ended, imaginative, and footloose propositions which are developed in there and how this is qualitatively different and complementary to traditional science organization rather than competing with it.

Openness can be understood as a free access to the means of production as found in the majority of fablabs (Lhoste and Barbier 2018), but also as less hierarchical, egalitarian structure, and trust. Regarding the supposedly flat organisational structure, Lange and Bürkner (2018), in their study on open workshops in Germany, point out that power imbalances are present, and what is more, ironically, readily accepted by the practitioners. To be more specific, the founders or amateur experts within the space can even unintentionally create hierarchies and regulate access (Toombs 2016). At the same time, there are also various practices of mutual material and social support, which are claimed to be signs of emerging post-growth modalities (Lange and Bürkner 2018) and might be conceptualized as repair work on a communal scale (Hector 2018).

We next turn the focus to the organizing principles of the sites and in particularly on what kinds of organizing work is done with the notion of design. Here, the practice of open spaces indicates a more humble design practice of tweaking existing reality, fixing material and building collectives.

Humble design

Utopian thought is part of design theory and practice since its formal origins at the end of 19th century. The rise of modernism by the 1920ies located design as central means to support social change on a grand scale. The supposedly mass-produced products of functionalism were hoped to deliver quality to everybody, while social housing in the form of new building blocks provide the cocoon within designed settlements. In the second half of the 20th century the paternalistic take of modern design was critically reflected upon and became gradually substituted by research into specific, situated user needs (Dorrestijn and Verbeek 2013). For Drukker (writing at the turn of the 20th century) this period (60ies and 70ies) was the final chapter of socially engaged design, replaced by the decorative and ironic elements of postmodernist aesthetics (Drukker 2004). Others have argued, that the critique of rational, unified progress exemplified by postmodernism still puts forward utopian ideals, namely that technologies can after all mediate the multiple ways of people living their life (Dorrestijn and Verbeek 2013).

Across these epochs, design was intricately linked with utopian thought reliant on some form of technical mediation. This mediation took different forms from highly functional to more metaphorical ones. Specifically with respect to the less functionally driven aesthetic of early postmodernist design, we see parallels to contemporary developments of speculative design and design fiction. Here, not solutions but issues are foregrounded and made explicit with the help of designed artifacts (Auger 2013).

Graphical illustrations as well as more immersive three-dimensional settings shall help to point to future(s) often far ahead in time. No matter if they depict the future infrastructure of living and commuting, or provocate in the form of seemingly functional, everyday objects, they make use of an essential component of utopian stories. The new and distant needs to be connected with the old and familiar (forms) (Sargisson 2007). The weaving together of presence and future as well as the level of technological sophistication might however take different routes as shall be explored in the following.

In collective sites for experimentation, new but also old, forgotten practices are explored and made available to others through designing digital but also physical and social infrastructures (Hector 2018). Thus, while they embody hopeful and partly hyped visions of a better future, they appear to be much more pragmatic. What we refer to here, is the use of rather mundane activities, tools and infrastructures in order to materialize parts of utopian futures in the presence. Compared to earlier utopian designs they are not endpoints in the sense of products delivered to users, but ongoing experiments, premised on relative broad accessibility. Most strikingly, when thinking of the ad-hoc and DIY approach, design in this context often starts with what is at hand rather than conceiving something complex no matter what resources it will take (Jencks and Silver 2013). Comparing these characteristics with other forms of design discussed above we suggest to referring to this as humble forms of design

Methods

For this study, the first author has conducted 4 semi-structured interviews with members (three of them involved strongly in three of the 6 projects each and the fourth joining for some of the meetings and workshops) of the initiative lasting between 30 and 60 minutes. The interviews focused on question regarding the forming of the project, the internal and external relations as well as everyday organization. Furthermore, both authors have participated in the monthly meetings of the initiative throughout the year 2018 as well as in three special events, from which they have collected field notes. These events were the planning meeting, the official opening day and the building of the dwelling. Internal communications have been organized through a whatsapp group which was recently substituted by a slack channel. The first author has accessed these digital pools in an ongoing manner for purposes of participating in the initiative as well as this study.

Case Test Site

Figure 1. Photoshop visualization by one of the students.

‘*Test Site’* is an open space located on the campus of Aalto University in an outer city district of Otaniemi in the greater Helsinki region. This outdoor space was set up at the start of 2018 by students who were interested to explore low-tech, frugal innovations for sustainability, and is funded and planned to exist for a minimum of two years. From the beginning the exploration was planned to target both infrastructure such as water, energy and sanitation, food, soil health and food production issues, material circulation, but also exploration on organising events and creating learning opportunities for sustainability. Key to the set up was the will get out of the classroom, out of theory and conceptual thinking.

Despite a low profile start, the *Test Site* initiators have collected support from and created diverse interests among the University campus management, from teachers in the field of sustainability, researchers working on innovations for sustainability and the business development and start-up actors at the campus. As of this moment there are 5 projects on the *Test Site* (Pee-osk, Garden, Solar Disk, Eco Soap Toolbox and Community Shelter) and the frequency of members visits of the site during the summer season was around 1-2 times a week.

Dates	Actions
Fall 2017	A handful of Creative Sustainability (CS) MA students begin to look for support for different project ideas Head of CS MA Programme and Sustainability liaison of the university had discussed sites of display for the work related to sustainability
January 2018	Open call for students to propose activities results in over 30 proposals
April 2018	Physical area designated
May 2018	Official opening of the site with 4 projects
November 2018	Exhibition at university with 6 projects put forward by 18+ regular collaborators, coming mainly from the CS MA programme with background in design, engineering and business.

Table 1. Timeline.

Discussion

We see different interpretation among the actors inside the Test Site. Similar to FabLabs, also the case at hand is neither a living room, workplace, nor scientific laboratory (Kohtala and Bosque 2014) and represents something different to all members. Therefore, the implementation of such spaces in itself appears to require experimentation and trial and error (Hector 2018). When achieved, open-endedness of the agenda and any results of it, might render them interesting to different groups of people and different purposes (Akrich et al 2002). Here, activities and artefacts of open spaces can be brought into networks by purposeful, partial interpretations and even purposeful misunderstandings. Indeed, when looking at the initial "Call for proposals" for the *Test Site*, it clearly attracts more people if you talk about hybrid, experimental spaces where the outcome could be almost anything as long as it fulfils some criteria such as excluding hate speech.

However, the open-endedness also brings problems. This includes overcoming frustration related to obstacles, slow pace of progress and the difficulties living up to the ideals of the open space discourse. Quite clearly, notions and experiences of efficacy seem to require clear leadership and management of the activities. Different than Lange and Bürkner's observation of assemblages, our own empirical analysis hints at more ordered spaced organised around visionary leaders, who introduce and push ideas about projects or events (Lange and Bürkner 2018).

The flipside of open-endedness further appears in the difficult negotiations between different actors both regarding external as well as internal relations. When potential newcomers do not really know what the initiative is about, this highlights one important point about such experimental sites. Often neither the purpose nor the rules are clear – unlike say a football game – they are continuosly in the making. Therefore, the discourse of open-ended, imaginative and latent places needs to find material forms and get articulated in real outcomes as Kohtala (2018) suggests for maker-spaces. Hence, the great joy for example when a pile of compost soil arrives at the *Test Site* as a product of a large scale centralized municipal operation and delivered by a commercial service provider. This pile of soil functions in several ways. Firstly, it allows the students to implement the gardening project and thereby adds to the overall site. Secondly, it underlines that they have reached a certain level of visibility and credibility, if these actors work with them. Much the same can be said about the sustainability event in which the site was displayed as the recent successful impact of the school.

The site responds to the anxiety of the impasse of sustainable consumption and represents utopian thinking in its attempts to imagine, articulate and practice social life. Despite diversity of participants and their understandings of the place, the rhetoric of openness indicates that these spaces facilitate trust, respect and aims of participating individuals. Ideally, some of such spaces may turn unproductive anxiety of individuals to inspired collective action, be it growing food, making soap, building shelter, find support for the initiative or decide about the name and look of the place.

In contrast to bold, spectacular and visionary design, open spaces are compromises themselves. These tamed utopias are not fixed spatial utopias as earthly heavens, even when good for temporary relief. In the *Test Site*, projects like the Peeosk (using human urine to produce food) or the Eco Soap (using waste cooking oil to produce beautiful objects), turn ideas which appear radical to the majority into practice. The projects implicate the body, bend and blend politics and, as we have suggested, come out of the humble design attempts to reconcile human existence with other beings and sustainability. They are, however, also communities of innovation-in-practice, which seek to produce the component parts of sustainable forms of human life for broader use in the society (Smith et al. 2016). By the same token, they are not completely estranged and do not demand by far as much time as e.g. intentional communities require (Sargisson 2007).

To continue this thought and to be very blunt, the cases seem not to be able to deliver their original, radical utopian aspiration and might even be bound to "fail" in this sense. Still, they can continue to exist and deliver something. Acting out your ideals is utopian in the sense of the forward-looking society of Mannheim. Different to the strict, modernist narratives on future, open spaces and particularly the modest, humble design and trial and error in there, can be thought as a new, postmodern modality of engaging with our material surroundings.

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Understanding and Practicing Wood Waste Qualities in Norway – A Case of Adaptation Work in Circular Bioeconomy

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Keywords: Obsolescence; Quality; Service Life; Wood Products; Wood Waste.

Abstract: Understanding the quality of new raw material sources will be of great importance to ensure the development of a circular bioeconomy. Building up quality understanding of wood waste is an important step in this development. In this paper we probe two main questions, one substantial and one theoretical: *What different understandings of wood waste quality exist and what significance do they have for the recycling and re-use of this waste fraction?* And, *what is the evolution of knowledge and sustainable practices of wood waste qualities a case of?* The analysis is based on diverse perspectives and forms of methods and empirical material. Studies of policy documents, regulations, standards, etc. have been reviewed to uncover what kind of measures and concepts that have been important for governing and regulating wood waste handling. Interviews concerning wood and wood waste qualities have been conducted with key informants and people visiting recycling and waste management stations in Oslo and Akershus in Norway. By studying quality conceptions through the social birth, production, life, end-of-life and re-birth of wood products, we analyse socio-cultural conditions for sustainability. Furthermore we show how the evolution of knowledge and sustainable practices of wood waste qualities, in the meeting with standards and regulations, is a case of adaptation work in the evolution of Norwegian bioeconomy.

Introduction

Efforts are being made to develop new and adapt old regulations for waste handling in Norway and in general within the European Union. In the national *Norwegian bioeconomy strategy* (NFD, 2016) and the Norwegian white paper *Waste as resource* (KLD, 2017) the importance of understanding qualities of new resources, and its central role in the development of a sustainable bioeconomy, is emphasized. EU's future regulatory framework will have a major impact on the Nordic countries, which have large areas of forest and a long tradition of using wood material in buildings and other constructions. Re-use and re-cycling of wood before energy recovery is linked to the cascade principle in the bioeconomy and the idea of keeping carbon as long as possible in the cycle. In such an overall context, quality understanding of the forest resources, wood materials and wood waste will be of great importance. Understanding the quality of new raw material sources will also be important to ensure the development of a circular bioeconomy. Building up quality understanding of wood waste is a necessary step in this development. Before re-use measures are initiated, one should therefore study opportunities and limitations that lie in such cooperation locally and in the individual region where efforts and measures are planned.

Against this backdrop, several important general questions need to be answered: How is ‘quality’ understood in the bioeconomy? Which actors' understanding of quality should be considered? What are the implications when something that has previously been understood as waste becomes upgraded as a new resource? These and other questions make it obvious that the shift to a circular bioeconomy also represents a shift in understanding the quality of products and materials. The focus of this paper probes the adaptations to such a shift in quality understandings and practices in the bioeconomy, and especially related to the understanding of quality of wood waste.

By studying quality conceptions through the social birth, production, life, end-of-life and re-birth of wood products, we analyse socio-cultural conditions for sustainability. Furthermore, we show how the evolution of knowledge and sustainable practices (Shove and Spurling, 2013) of wood waste qualities, in the meeting with standards/ regulations/guidelines, is a case of adaptation work in the evolution of a bioeconomy in Norway.

Context and research questions

According to the European Waste Framework Directive (Directive 2008/98/EC), waste is defined as all objects and materials that the owner regards as discarded or is required to discard. In Norway, 792.000 tons of wood waste were produced in 2016, and wood waste is thus the 4th largest waste fraction (in weight) (SSB 2017). The wood waste originates from four different sources; households, construction and demolishing (C&D), service industry and manufacturing industry (SSB 2017). Together, households and C&D account for 72% of the total quantity. In Norway, wood waste is mainly sorted into two fractions; mixed wood and impregnated wood. Further fractionation is common in countries outside Norway where wood waste is used in, among other things, production of wood-based boards/panels. Various sorting strategies and fraction groups have been prepared in the EU (European Industrial Emissions Directive, 2014). In addition, several European countries (British Standard, 2012; Bundesministeriums der Justiz und für Verbraucherschutz, 2003; Alakangas et al, 2015) and producers of wood-based boards (Egger, 2016) have made their own sorting rules with grading for wood waste that distinguishes different qualities. In our review of the Norwegian context we did not find similar quality systems for sorting and grading wood waste for reuse or for other uses than wood-based boards/panels. Within the field of wood technology, there are several well-established methods and strategies for defining quality and properties of wood materials in general. Several of the methods and tests are standardized and approved via e.g. International Organization for Standardization, European Committee for Standardization and Japanese Agricultural Standard. It is relevant to review these methods to adapt relevant and effective systems to define the quality of wood waste for further reuse in the Norwegian context.

Waste is a phenomenon that has been given little attention in culture and social sciences (for an example, see Thompson, 1979). Studies of obsolescence (Slade, 2009), product life and waste are established research topics, but quality understanding of wood waste and its importance for recycling and material recycling has been given little attention. The results from this project will contribute to fill this gap.

The aim of our analysis is to analyse various actors understanding of wood waste quality in a recycling and re-use perspective, and to unpack adaptive practises (Hegnes, 2013) that are necessary for a sustainable turn in Norwegian wood waste management. As mentioned, there is considerable knowledge about regulation and standardized qualities (de jure), but less about how these qualities are perceived and practiced (de facto). Our approach is thus to probe the relation between *de jure* and *de facto* qualities by employing and combining perspectives from both natural and social science.

Our overall research question is: What different understandings of wood waste quality exist and what significance do they have for the recycling and re-use of this material fraction? Our sub questions are:

1. How are wood waste qualities defined in standards and regulations?
2. How are wood waste qualities understood in the public?
3. How are qualities of wood waste understood by those who dispose, receive and re-use?
4. What is the relationship between the different understandings of wood waste?

To study the Norwegian context, we focus especially on the cases of Akershus and Oslo, as mentioned. In Norway, about 90% of wood waste is recycled as energy. In 2016 wood waste accounted for 50,538 tons in Akershus and Oslo County. For impregnated wood waste, there are no exact figures in Statistics Norway's waste statistics for Oslo and Akershus, as this fraction is included in statistics for hazardous waste. However, Follo Ren IKS' own figures show that they received 7852 tons of wood and 1276 tons of impregnated wood in 2016, which gives a ratio of about 6:1. If surrounding waste companies have similar conditions, one can expect that the region will receive about 8500 tons of impregnated wood a year. In construction projects over 400 square metres there are requirements for waste plan and recycling. Smaller projects are not covered by such a scheme. There is therefore less control over this waste which is often delivered to municipal recycling stations or private operators. As mentioned, approx. 90% of the wood waste is used for combustion. This practice is conventional even though a part of this fraction is still usable and can be utilized for other purposes in line with the cascade principle.

Method, data and analytical approach

The analysis is based on diverse forms of methods and empirical material. Studies of policy documents, laws, standards, etc. have been reviewed to uncover what kind of measures and concepts have been important for regulating wood waste. Interviews have been conducted with key informants and people visiting recycling and waste management stations in Oslo and Akershus, Norway.

Our analytical approach is not dedicated to any specific methodological or theoretical tools but takes inspiration from a set of relevant perspectives from natural and social science to describe and understand the adaptation work of wood products and waste. The general aim of our analysis is to explore why people dispose wooden products and to develop and nuance the theoretical tools to understand the motives for obsolescence and disposal practices, in meeting with regulations and other ways of controlling the wood waste. In other words; we will map different aspects in the dynamics of de jure and de facto quality conceptions.

The many faces of quality in wood product life - Preliminary analysis

De jure – standards and regulations

From a natural science perspective, the product's or component's *service life* is in question – more than obsolescence. A product's or component's service life is the period of use in service. In ISO 15686-1, a standard that regulate service life planning for building and constructions, service life is defined as 'the period of time after installation during which a building or its parts meets the performance requirements'. The use of wood in buildings and constructions in Norway have long traditions, and great effort has been put into methods, materials and solutions to enhance service life of wood in these applications. Putting effort into extending the service life of a component in its primary application is an important principal within the bioeconomy. When a wooden component in a building fails in its function, - technically, economically or aesthetically – the service life of the component has ended. At end of life, the component will be discarded and be regarded as waste. As an example, the service life of a wooden cladding board in an outdoor façade has normally ended when an area of decay is identified within the board. The acceptance of how large the size of the decayed area can be before replacement can vary between individuals and this will have an impact of the total service life of the board. Failure analysis of non-loadbearing wood and wood-based products is described in various guidance documents fitted for the application in question (SINTEF Byggforsk 2015, SINTEF Byggforsk 2017, Lukowsky 2015).

Another set of standards, regulations and guidance papers become operative when the wooden component shifts its 'status' to wood waste. Depending on what the wood waste will be recycled into, various quality aspects and demands will apply. Wood waste can be re-cycled using several strategies: reused in its original form, direct recycle (new timber products such as particleboards, finger jointing and lamination, MDF, wood plastic composites) and indirect recycle (non-timber products such as animal bedding, landscape mulch, surface products, composting, cement boards) before energy recovery. Wood is used in conjunction with other materials like paints, varnishes, various additives, metal fixings, laminates, foils and so on. Recovered wood is therefore very heterogeneous and so its suitability for a particular end-use must be verified before further processing.

Mainly three standards are used for sorting wood waste into quality classes in Europe; the German Altholzverordnung (Altholzverordnung 2002), the EPF standard (European Panel Federation 2002) and British standard on Specification for the Requirements and Test Methods for Processing Waste Wood (British Standard Institution 2012). The principles with these standards are that there is one quality class for untreated/unpainted solid wood waste, and 3-5 classes with various requirements regarding the content of glue, paint, additives, other materials and amount of toxic elements such as heavy metals, halogens and compounds.

The conception of service life within a natural science paradigm may be contrasted and compared to a social science perspective on obsolescence and the socio-cultural understandings of wood and wood waste.

De facto – socio-cultural understandings

Sociologists have been analysing different aspects of obsolescence. Baudrillard addressed the relative rhythm of obsolescence related to norms and social class structure (1981:36). Bauman discussed the socio-material nexus between identity and products (1996:23). Merton payed attention to the intended and unintended psychological consequences of the enforced obsolescence of skills when labour-saving technology replace durable products with products with planned and immediate obsolescence (1968: 564). These perspectives are mostly critical, with an underlying assumption that both production and consumption of products may be related to alienation through the understanding of obsolescence.

As mentioned above, service life is obviously determined by the natural science understanding of quality, if the wood decay or other deterioration processes takes place. On the other hand, the experienced cultural quality and obsolescence is equally important.

According to our material from the interviews there is a range of different understandings and ways of perception and practicing wood waste and wood waste qualities. There are differences between regulators, genders, generations and people with different socio-cultural background. Some of the material that is disposed is thought to be as good as new, but according to regulations it cannot be re-used. Some of the material that is disposed is even considered to hold better quality than the material accessible in stores. Some argue that it is difficult and expensive to get the desired quality, and that the poor quality gives shorter life time for products. Carpenters report that they dispose new wood material because it is more expensive to store it than to buy new.

De jure-de facto nexus

De jure and de facto understandings of wood waste quality may be divided on an analytical level. However, these analytical categories constitute a mutual nexus. To be aware of this quality nexus is important in circular economy and may also be transferable to other kinds of qualities. It's important because our de jure and de facto understanding of qualities impact on how we practice management and handling of wood waste.

Concluding discussion

The concept and many faces of wood waste quality are important in the context of obsolescence. On the one hand obsolescence is determined by the natural science understanding of quality and service life, if the wood rotten or other deteriorating processes takes place. On the other hand, the experienced quality of the consumer is equally important. In the new circular economy the boundaries between producer, distributor and consumer gets blurred. Opposed to the traditional modern consumer, which produced non-usable waste, the consumer in the circular bioeconomy is also a producer of raw material for a new and continuous production loop. It can thus be useful to understand this in line with the concept of the *prosumer.*

Our preliminary conclusion is that the relationship between de jure and de facto understanding and practice of quality is of importance in bioeconomy. The evolution of wood waste qualities in Norway can be understood as a chain of adaptations and adaptive practices necessary to unite the dynamic ordering of modern international regulations with the national and cultural status of wood products and waste. Whether the regulations are too strict or too loose, it will have an impact on the degree of utilization of wood waste. This means that the de jure and de facto understandings and practices need to be adapted and harmonized to meet the goal of increased degree of reuse.

In more general terms, our analysis of how wood waste qualities in Norway is understood and practiced, can be said to represent a case of adaptation work in circular bioeconomy. Sustainable utilization of wood waste is dependent on adaptation of de jura and de facto understanding and practice. Identifying mechanisms for obsolescence and quality is a first step in identifying *sustainable adaptation practices.* More research is needed to understand the adaptation work between de jura de facto.

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Apparel as a Resource – Results of a Literature Review and Laboratory Textile Tests of Garments Subjected to the Laundry

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Keywords: Apparel; Laundry Care Process; Textile Tests; Ageing of Garments.

Abstract: The objective of the study was to obtain an overview of existing literature on the ageing of apparel on the one hand and to carry out its own series of tests on the other. Almost 30 relevant scientific studies were evaluated. All the authors approached their studies differently and were able to gain many insights into the effects of the laundry care process, but no study explicitly deals with household circumstances. Therefore, the present study highlights this part. Two trousers are washed in the gentle washing program and dried in the air. Evaluations of the laundry load were conducted prior to washing, as well as after various wash and dry cycles. The test methods air permeability, colour range, dimensional stability (thickness and measurements of the trousers), subjective hand-feel and total mass were used. The main differences between the trousers in the tests are the substrates and the textile manufacturing methods. This is reflected in the results of the test methods. Trousers with a higher cotton content are more susceptible to the washing process parameters, i.e. the time, temperature, mechanics and chemistry. Overall, the study documents a status quo on the behavior of an average garment in the care phase of 20 washing cycles.

Introduction

Apparel is an everyday product. Users are used to wash their clothes after wearing them to prepare them for the next use phase. The aim is to achieve the longest possible lifetime and maintain the resource ‘apparel’.
The so-called use phase can be divided into the wearing phase and the care phase. In this paper the authors mainly deal with the care phase, especially with the laundry care process. Manufacturers of home appliances are developing new washing machines and washing programs with the IEC 60456 cotton base load, which consists of towels, pillowcases and sheets. The specifications of the three textiles are as follows: The substrate for all is 100% cotton, pillowcases and sheets are a plain weave linen and the towel is a huckaback weave. All textiles are white and some are sewn. However, these specifications do not correspond to what can be found in an average wardrobe. Consumers use a wider range of garments. These have many different fibres, such as, for example, man-made fibres or wool, knitted fabrics, nonwoven and other woven fabrics. In addition, joining technologies vary more and more: Besides sewing there is also welding and bonding. Moreover, all imaginable colour shades are possible, apart from white. All specifications show that the complexity is much higher than the cotton base load indicates. Therefore, the present study tries to reduce the complexity and to illustrate the ageing of clothing through the laundry care process by means of a typical example from real clothing. The study is designed to illustrate the ageing process of a typical product. The result is a status quo on the ageing of a garment based on its textile properties.

Methodology

In order to achieve the study’s objective, a literature review was carried out, followed by a test series.

Literature review

The literature research serves to evaluate different scientific perspectives on the ageing of apparel. The authors searched for international scientific publications in German or English language. With regard to relevance, there was one restriction: Only publications published after the market launch of automatic washing machines in Germany were searched for or used, using the following search terms: use phase of textiles, ageing of textiles, (domestic/industrial) laundry, textile parameters and textile physical tests. If a scientific publication was found, the corresponding reference lists were checked for additional references that were not found in the search. The studies found were listed, content criteria recorded and similarities and differences between studies analysed. The evaluation criteria were: investigated cause, test material (substrate and textile manufacturing method), test unit and drying process.

Laboratory tests

The tests were carried out on real apparel from April to July 2019. Apparel is made from textiles, so the properties of the textiles are directly reflected in the apparel. Seams and accessories on apparel, such as buttons and zippers, further influence the properties. Two different trousers were tested. Figure 1 shows the technical drawing of both trousers. The first pair of trousers was a pair of jeans made of 98% cotton and 2% elastane. The blue jeans are weaved as S-twill and are available in different sizes. In the test series the jeans were named JEA_44 to JEA_63.

The second pair of trousers was a cargo pant made of 65% polyester and 35% cotton. The cargo pants were also blue and its fabric was a S-twill weave. In the test series, the cargo trousers were named with JEA_149 to JEA_169. They are all available in the same size.

Figure 1. Technical drawing of cargo trousers (left) and jeans (right), front view. © HTW Berlin.

The test series were carried out with a washing machine from Siemens (WM14Y540). It is a frontloading washing machine with a maximum load of 8 kg. As washing program, the authors chose the standard gentle program as it is the second most popular washing program in german households (Ellmer, 2016) and should be washed with a half loaded washing machine. The washing temperature is defined as 40°C because these garments are most often washed at 40°C (Ellmer, 2016). The standard setting of the maximum rotation speed (1200rpm) on Siemens washing machines is not changed. Four jeans and four Cargo trousers are randomly selected for washing. The base powder of the reference detergent A*, following the IEC 60456:2017 methodology was used as washing detergent. The authors did not use the other two components because of the colour of the trousers. The dosage was carried out as specified in the above standard. The trousers in the test series were new and not worn at the beginning and were not soiled during the washing cycles. Therefore, artificial soil had to be added to the laundry. This was implemented by SBL 2004 Ballast soil on cotton. Four items per wash cycle were added. The test series included 20 washing cycles. After each washing cycle the laundry was air dried.

The test methods used to examine textiles are basically destructive and non-destructive tests (Reumann, 2000). This publication deals only with non-destructive test methods.

The following non-destructive test methods were carried out prior to the test series (W00) and after one (W01), three (W03), five (W05), ten (W10) and twenty (W20) washing cycles:

- air permeability (EN ISO 9237),
- colour range (DIN EN 105-A02, using a 9-step grey scale),
- dimensional stability (thickness DIN EN ISO 5084 and measurements of the trousers),
- subjective hand-feel (hard/stiff versus soft/flexible and rough versus smooth) and
- total mass.

The test methods air permeability, thickness and colour were always performed at the same test sites. A total of four measuring sections were defined for the measurements of the trousers. These included the two length measurements inside leg seam and side seam, as well as the two width measurements waist width and hem width. Due to the limitation of the length of the paper, the method of subjective hand-feel cannot be explained in more detail.

Due to the different sizes of the jeans, a pair of trousers (JEA_52) in the laundry was not taken into account in the results for total mass and measurements.
It was planned to do all test methods in standard atmosphere (20°C ± 2°C and 65% ± 4% relative humidity) but the air conditioning system at HTW Berlin failed and it was not possible to wait with the start of the test series.

Results and Discussion

Literature review

The results of the literature research are about 30 studies published between 1963 and 2018. Each author or team of authors uses a different methodology due to the many different objectives. Similar to the complexity of clothing, the objects of investigation and parameters of the studies are also complex. The publication shows this with three examples:
First, there are many different causes of aging of textiles that have been investigated. They varied between domestic and industrial washing process, washing temperature, detergent, drying method and wearing phase. Secondly, both natural and man-made fibres and various fabric constructions were investigated. Thirdly, the washing machines with which the textiles were washed varied between a front loader, agitator and laboratory washing machines. This parameter depends strongly on the origin of the respective study and of course the study's objective.
The majority of studies consider the laundry care process. Four of them partially highlight the wearing phase (Chippindale, 1963; Morris & Prato, 1977; Palme, Idström, Nordstierna & Brelid, 2014; Viertel, 1968). Some authors show that the influence of the washing process on ageing depends on the following factors (Agarwal, 2011; Kotb, 2012; Pusic, Soljacic, & Dekanic, 2014; Quaynor, Takahashi, & Nakajima, 2000):

- substrate,
- yarn manufacturing method,
- textile manufacturing method,
- workmanship and
- washing conditions.

The washing conditions refer to the parameters of the Sinner Circle (mechanical action, temperature, chemical action and time) according to Sinner (1960). Looking at the complete laundry care process, the drying process in the tumble dryer is the most damaging process step (Anand et al., 2002; Morris & Prato, 1977). Line drying has no effects. Spin leads to the next larger effects, followed by rinsing and washing (Anand et al., 2002). Compared to the Agitator, a front loader is more gentle on textiles (Easter, Cinnamon, & Baker, 2013). Textiles undergo the greatest change in the first five to ten washing cycles (Cheriaa, Marzoug, & Sakli, 2016; Midha, Suresh Kumar, & Nivas Kumar, 2017). In general, the density of stitches, the pilling, rising height (velocity of soaking water), thickness, mass per unit area and drapability properties increase with washing (Agarwal, 2011; Cheriaa et al., 2016; Kotb, 2012; Midha et al., 2017; Nyoni & Brook, 2018; Orzada, Moore, Collier, & Yan Chen, 2008; Pusic et al., 2014).
Another result of the literature review is that the studies do not help to select appropriate test methods for the investigation of the ageing of apparel. Reasons for this might be the the complexity of the apparel and the diversity of approaches.

Laboratory tests

After the first washing cycles, a fibrous film has deposited on the trousers, probably from the SBL 2004. This change in the surface of the trousers has an influence on all test methods and must be taken into account in the results.
Regarding the standard atmosphere, the temperature in the test laboratory only after the first wash was not within the tolerance (W01: 22.4°C). The relative humidity varied: Only the tests after the 20th wash took place under standardised conditions. After all other washing cycles, up to 34% too little relative humidity prevailed in the test laboratory.
The test results of the jeans show how trousers change over a number of wash cycles. Figure 2 shows that the total mass of the jeans increases. There are many reasons for this: Cotton reacts strongly to humidity. The test climate condition was normal, such that more water was stored in moist fibres and therefore the total mass increased. Additional reasons could be the fibrous film, the accumulation of detergent residues, lime or soil. The air permeability decreases after the first washing cycle and then remains relatively constant. The change is probably caused by the removal of finishes applied during production so that the material can shrink during the first wash cycle. The thickness varies between 1.02 and 1.07mm until the 10^{th} wash cycle, before falling to 0.93mm after the 20^{th} wash. This result speaks against the increase of the fibrous film on the surface. Probably the trousers are

mechanically stressed in a way that material is removed. As far as the dimension is concerned, the length dimensions (between -4.5 and -5.1 %) of jeans change more strongly than the width dimensions (between 0 and -2.3 %). Both measurements become smaller, the jeans shrink. This is due to the partial balancing of the tensions in the textile that have arisen during processing. The textile surface strives for a stable final state (Latzke & Hesse, 1974; Gries, Veit, & Wulfhorst, 2015). On average, the jeans colour has deteriorated from an initial score of 5 to 3. The subjective hand-feel of the jeans becomes softer and more flexible with the first three washes, but by the 20th washing the jeans becomes rougher and stiffer again.

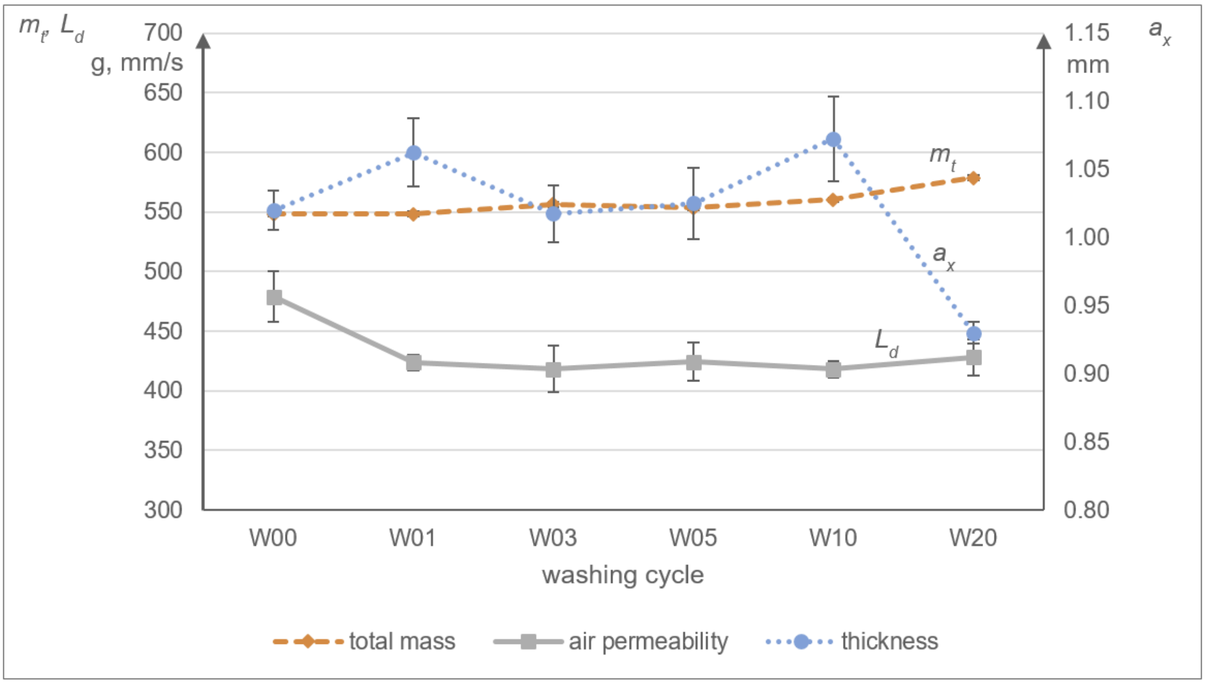

Figure 2. Results jeans: total mass (m_t), air permeability (L_d) and thickness (a_x).

Figure 3 shows the results of the cargo trousers. The total mass remains almost constant over 20 washing cycles. The air permeability increases after the first washing cycle and decreases after that. Between the 10th and 20th washing cycle the value rises again slightly. The thickness increases up to the 5th washing cycle and then decreases again. The cargo pants were probably finished. These finishes wash out with the first 5 wash cycles and give fibres the opportunity to swell. The textile gets thicker. The colour of the cargo trousers has hardly changed from the initial mark 5 to a 4.5. The dimensions of the cargo trousers vary between -2 and -3.6 percent, with no difference between length and width. As with jeans, the reason for the shrinkage lies in the relaxation of the textile.

The surface of the cargo trousers is smoother and more flexible than that of the jeans. Therefore, the fibre film is probably not as pronounced as with the jeans. The subjective hand-feel of the cargo trousers becomes slightly more flexible over the washing cycles, but also rougher.

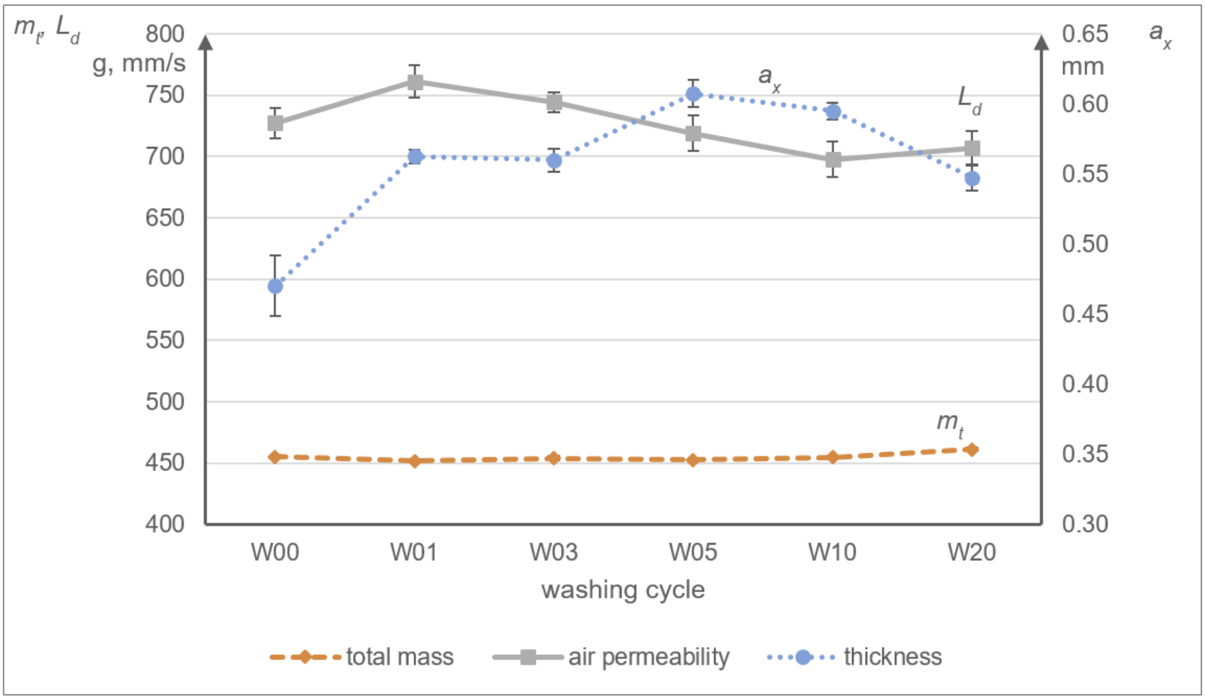

Figure 3. Results cargo trousers: total mass (m_t), air permeability (L_d) and thickness (a_x).

When comparing the two trousers, it is noticeable that the trousers with the high cotton content (jeans) change significantly more than the cargo trousers. This applies in particular to the properties of total mass, colour and dimensions. The shrinkage of textiles depends on the substrate used and the parameters used in textile manufacturing method (Latzke & Hesse, 1974). The threads woven for the cargo trousers are thinner than the threads used in the jeans. That's why cargo trousers have closer and more crossings between warp and weft threads. The threads can therefore not easily change their dimensions because they are tightly bound. Consequently, the jeans shrink more than the cargo trousers. The total mass in the test series is related to the climatic conditions in the test laboratory. For both trousers, the total mass increases after the 20th washing cycle, where for once, the measured values of the humidity are in the standardised range. Due to the substrates, the total mass of jeans increases more than the mass of cargo trousers. The jeans have a much higher cotton content and cotton reacts stronger to moisture than polyester (Bobeth, 1993).

Under the stereomicroscope (Zeiss Stemi 2000-C) at 20x magnification, the change of the textile surface becomes particularly clear. Figure 4 shows the new jeans before washing; figure 5 shows the jeans after 20 washing cycles. The surface of the new jeans looks smooth; the fibres are neatly arranged. The hairiness is low.

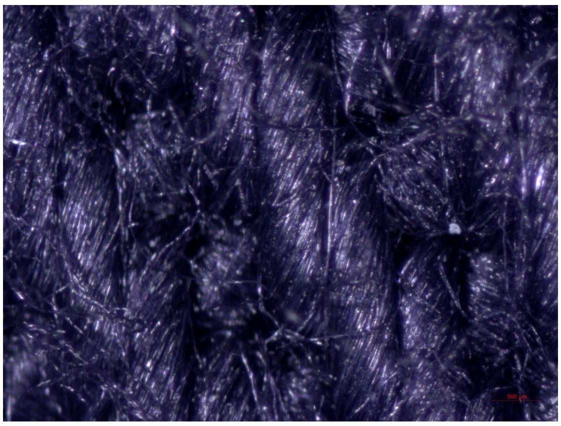

Figure 4. JEA_62 before washing. © HTW Berlin.

After the 20 washing cycles, some fibres have dissolved and are already forming so-called flames. Flames are elongated structures of fibres and are the precursor of pilling.

On the figures, the brightness of the colour and thus the colour change of the jeans is visible. The assumption suggests itself that the cotton thread in the jeans is only dyed on the surface and thus the colour can easier be removed from the mechanical action in the laundry, than with the cargo trousers. The polyester in the cargo trousers can be spun-dyed.

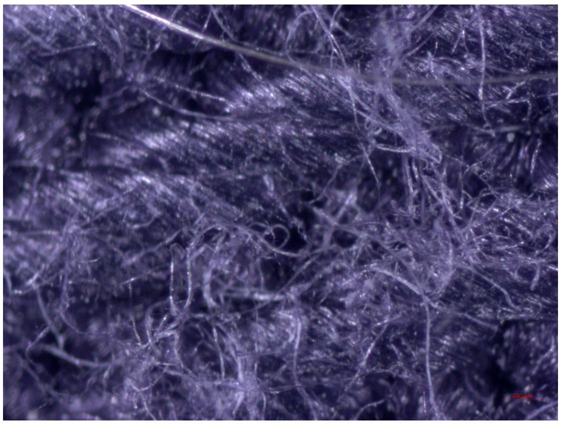

Figure 5. JEA_50 after 20 washing cycles. © HTW Berlin.

Conclusions

The studies evaluated studies illustrate the complexity of textiles and apparel. However, the various research approaches make comparability difficult. The authors of this study have obtained an overview of the research in order to incorporate findings into their own test series. This test series was set up in order to subject real-life apparel to a realistic care phase and to examine it in the process. The tests have shown that both trousers change as a result of washing. The effects of the changes are different and are based on the properties of the textiles. A reliable climate condition is important for future studies and the artificial soil must be reconsidered. The soil ballast could be replaced or washed in an extra laundry bag to minimize fibre loss. The changes in the properties, such as the strong bleeding of the jeans colour, are noticeable after only 20 washes which underlines the need to look at the ageing of apparel more closely. In addition, the demand for sustainable and durable clothing increases. If apparel is regarded as a resource, the entire life cycle, including production and disposal, must be considered. The use phase is just one specific part of that holistic process.

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Resisting Obsolescence? The Role of a 'Culture of Repair' for Product Longevity

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Keywords: Repair; Do-It-Yourself; Consumer Practices; Longevity Enhancing Practices.

Abstract: Repairing and caring for consumer goods can significantly prolong the useful life of products. So far, there is a lack of research that investigates the take up and appropriation of repair practices and their integration into people's everyday life. The paper draws on social practice theories to investigate everyday repair, examining the material, spatial, and temporal dimensions of repair. Empirical data derived from a citizen science project reveals the procedural and dynamic character of repair practices as processes that unfold in space and time.

Introduction

In recent years, repairing and making initiatives have experienced a significant upswing in many industrialized countries (Anderson 2012, Kohtala 2015). A growing number of people fix and make their own products through small-scale, decentralised workshops (Hielscher and Smith 2014). Within these initiatives, repairing and making is perceived as an emancipatory act where people claim the right, for example, to repair things, since – as the Repair Manifesto teaches us – 'if you can't fix it, you don't own it'. Initiatives enable repair of goods in local production and consumption systems; whilst culturally, practicing repair is argued to cultivate post-consumerist values through stronger associations with the objects created and repaired (Ratto and Boler 2014, Rosner 2013).

Currently, the main focus of existing research is on repair and maker initiatives as spaces of collaborative repair and making. There is little research that looks at repair work conducted in people's homes, examining how practices of repair are appropriated and integrated into people's everyday life outside the collaborative workshops. Moreover, there is also a lack of empirical evidence that our relations to 'things' change through self-repair and do-it-yourself (DIY) activities so that the useful life of products is prolonged.

Against this background the paper presents a new methodological approach to social practices of repair and making to answer two research questions: 1. How are social practices of repair performed in daily life? & 2. How do they change human-object relationships? In the following, we present some conceptual ideas and empirical findings from a citizen science project where these questions have been our main starting point to investigate repair practices.

Conceptual framing

We draw on social practice theories to examine our research questions. It draws attention to the interactions between people and their objects in existing daily routines, especially focusing on the performance of practices. These performances are influenced by people's bodies, their minds, the knowledge and competence they possess, the discourses they draw on and the emotions they feel – elements that are all interconnected (as concluded by Reckwitz 2002). In addition, they hold the practice together through shared competences, conventions and material resources as these elements exist over time (Shove and Pantzar 2007). Following Shove et al (2007), objects and individuals are not explored in isolation away from everyday life but are considered as related. Objects create networks that help to reproduce processes and practicalities of use, as they 'are not just semiotically communicative' (2007:13) in the accomplishment of practices.

Practice theories regard subject-object (people and products) relations as significant as

subject-subject relations. Warde (2005) and Reckwitz (2002) have suggested that objects have importance in that they make certain practices possible, echoing the work on the relationship between objects and people conducted by writers in science and technology studies (e.g. Latour 1992).
'Social change is a change of complexes of social practices, it presupposes not only a transformation of cultural codes and the bodies/ minds of human subjects, but also a transformation of artefacts (a relationship which deserves closer study)' (Reckwitz 2002: 213).
Objects are not only regarded as symbols but are used in motion as part of everyday practices. Bodily and mental activities can potentially be influenced through 'limitations' and 'allowances' of the materiality of objects. We used this approach to study practices of repair in three regards:

- The appropriation and integration of practices of repair into everyday life.
- The materiality, material arrangements and human-object relations that characterise everyday repair.
- The socio-spatial and socio-materiel dimensions of everyday life important for practices like repair.

Research methodology

To explore our research questions a mixed-method approach based on citizen science research was conducted in the frame of a publicly funded research project 'Repara/kul/tur".

Citizen science & Repara/kul/tur project

Current social science methods like interviews and questionnaires are of limited use to study everyday repair activities. This is why this study made use of citizen science research. Citizen science is the practice of public participation and collaboration in science research. Frequently, citizen science approaches have been grounded in collective data collection activities rather than co-designing project aims, methods and analysis. Our aim in the Repara/kul/tur project was to further develop methods for data collection and analysis, collaboratively with the repair and making community that aid the process of making visible daily life experiences and knowledge related to repair and making (for more information about the project see https://reparakultur.org/).

An open call for participating in the research was distributed through several mailing lists of repair and making networks. Additionally, project partners from the repair and making movement, spoke to organisers, visitors and members of several repair and making initiatives to gather possible participants. In total, thirty-two citizen scientists took part in the research at four Repair Cafés and Makerspaces across Germany between March 2018 and December 2019. The sample was diverse in age, socio-economic background, roles taken in the initiatives (incl. frequency and amount of visits), and repair and making skills. The citizen science research was grounded in 1) mixed-method approach that made use of cultural probes (method derived from design research), 2) two participatory research workshops in four repair and making locations, and 3) sixteen follow-up in-depth interviews within citizen scientists.

Cultural probes

Cultural probes are packages of open-ended, creative activities that participants in the research (and in our study citizen scientists) engage with on their own terms and in their own time, including creative tasks (such as maps to complete or cards to fill in, as well as cameras, photo albums and postcards) (Gaver et al. 2004) (see Figure 1). These designed probe tasks reflect an articulation of the researcher's thoughts that are then send to the participants. The participants have to interpret these forms of expression in their own time at home and by undertaking the tasks they express theirs. These interpretations and reflections are finally revealed in the returned probe packs often challenging the researcher's own perceptions. To emphasise this challenge, Joensson et al. (2004:24) have drawn attention to the ''friction' included in the probes that potentially can encourage participants and researchers to view environments, situations and objects in a new light 'with new glasses'.'

Figure 1. Picture of cultural probes.

Cultural probes have opened up new ways of thinking about design-led research methods that can work alongside, or contest, more reductive science based approaches to research. Sociologists have adapted and reinterpreted cultural probes for a variety of settings and research projects to understand something of people's lives, values and aspirations (Joensson 2004).

In our research, we created probe packs with 16 tasks that were sent to the citizen scientists. The packs have included a mixture of informational and 'inspirational (i.e. fragmented clues) data gathering activities. Our aim was to appropriate the method for citizen science research to encourage the citizen scientists to engage in and record self-observations and reflections about their repair and making practices.

For instance, informational data was gathered through citizen scientists keeping a repair diary, whereas inspirational data was collected through citizen scientists a) writing an obituary for one of their objects and b) representing the social structure of a Repair Café as bike parts (e.g. who takes the role of the handlebar?). Our cultural probes comprised of activities such as taking photos, drawing pictures and maps, or inventing and telling stories. The citizen scientists had three months to engage with the tasks (see Figure 2) before coming together for the participatory research workshop.

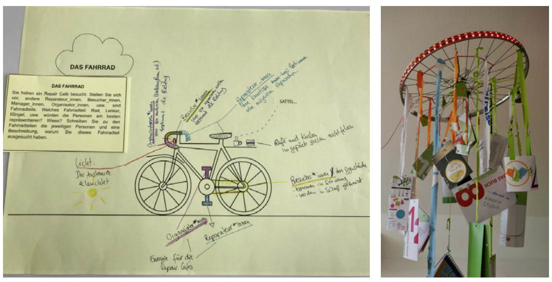

Figure 2. Data gathered by citizen scientists.

Workshops and interviews

Two participatory research workshops were conducted in four locations (in total eight workshops) (see Figure 3). The first workshop was conducted prior to sending out the probes. The aim was to co-develop the probes in the pack with the citizen scientists. The second workshop took part after the data gathering phase i.e. citizen scientists engaging with probes at home. During the second workshop, the data collected by the citizens was collectively analysed as part of 'thematic analysis' groups based on individual probe comparisons. At the end of the workshop, each group shared their findings.

Figure 3. Participatory reserach workshops with citizen scientists.

Furthermore, in-depth face-to-face-interviews were conducted with sixteen citizen scientists, who wanted to continue with the analysis. The interviews allowed researchers and citizen scientist to delve more deeply into people's own probe pack and deepen the citizen's individual 'repair biography'.

Empirical findings

Dimensions and phases of doing repair in everyday life

This section makes use of repair stories derived from the probe analysis with the citizen scientists to delineate the dimensions and phases of doing repair in everyday life and discuss changes to human object relationships (see Table 1). The repair process can be divided into diagnosing (i.e. establishing that an object is in need of repair and identifying the 'fault'), fixing (i.e. making time to look at the 'fault' and repair the object), and integrating (i.e. integrating objects back into daily routines).

Our analysis has drawn attention to several dimensions of doing repair in everyday life that are implicated in the performance of repair: (a) condition of object in need of repair, (b) socio-material arrangement for repair at home, (c) repair skills and experiences that exist in households, (d) object in need of repair and its role as part of performing everyday life, (e) socio-temporality of practices associated with object in need of repair, and (f) socio-spatial arrangement of object in everyday life (see Table 1 for an overview and examples).

Diagnosing (pre-diagnosing)

Repair activities often start way before people make their way to a toolbox. There are several daily activities in which we order (e.g. clothing in cupboard), clean (e.g. surfaces on coffee machine), and use (e.g. cycle to work) objects. They provide moments in which we 'pre-diagnose' the conditions and functions of an object. The hole in the jeans has become too big to wear it, the broken handle of the frying pan makes cooking with it difficult, or the tap in the garden has started to leak. These are only a few descriptions from the fieldwork but they start to illustrate the *temporal and spatial dimensions* of repair. Some of our objects get 'pre-diagnosed' more regularly then others. For instance, jeans get worn, washed, hung up, and order back into the cupboard. They are rotated through our homes and are regularly inspected. Other objects, such as, garden taps that have a more 'seasonal' use get diagnosed far less often. Some of these 'seasonal' objects are so well stored away (such as tents) that we hardly ever come to 'pre-diagnose' them and can even forget that we own them.

Moreover, what becomes apparent is that phases of pre-diagnosing, diagnosing and fixing are somehow fluid and have diverse *temporal patterns*. Jeans can be worn until holes becomes too big and taps can leak worse and worse until we get bothered enough to do something about it. Scanner/printers are just used for scanning if they no longer allow us to print something. People try to find ways to lengthen the time between diagnosing and fixing.

Our citizen scientists found that people have innovative ways to lengthen this time. Objects do not only break and then no longer can be used. There are *different types of object* in our homes that have varied ways to lengthening the diagnosing time: assemblages of similar things (e.g. CDs, t-shirts, cables) where a broken item can be easily replaced. Memory objects (e.g. Julie's desk) where 'faults' such as scratches and breakages are accepted because they become part of the memory.

Moreover, looking at the *socio-spatial arrangements of objects in daily life*, it became apparent that objects in need of repair do not only derive from people's homes. In particular, some of the 'serious' amateur repairers regularly pre-diagnose objects left on the street and auctioned on the internet. One example is Mike (all names anonymized), who regularly auctions objects in need of repair for a small price in order to fix them. He now has collections of computer parts and power tools that have been waiting to be repaired. Similar, Adrian has recently found a broken ladder on the street. He fell in love with it; it looked somehow 'Italian' for him.

Dimensions of doing repair in everyday life	
Condition of object in need of repair	*Can no longer be used *Some functions still work *Can be used in different ways
Socio-material arrangements for repair at home	*A few basic tools in kitchen cupboard *A toolbox with basic tools and a bit more *Several toolboxes and specialised tools *Dedicated repair space (e.g. garage) with specialised tools storage and tools & collection of spare parts *Dedicated repair space that is highly ordered
Repair skills, experiences and competences in household	*Strong socialisation through role figure from early age *Interest in opening object up from early age *Formal training and job experience *Multiple training experiences *Long lived hobby, self-learning, and tinkering *Middle and low socialisation through family members
Object in need of repair as part of performing everyday life	*Invisible workhorses *Visible workhorses *Daily tools *Home making objects *Collections *Memory objects *Assemblages & containers *Overflow objects *Morally worn out objects
Socio-temporality of practices associated with object in need of repair	Regular or non-regular use; e.g. *Seasonal practices with seasonal objects (like ice-cream-maker) *Special occasion practices (like fondue set) *Regularly performed practices
Socio-spatial arrangement of object in everyday life	*Hidden spaces e.g. garages, cellars, second ceiling, spaces at the back of the cupboard, top draws and cupboards *Waiting spaces e.g. cupboard, baskets *Rotation spaces e.g. laundry basket, dishwasher *Routine spaces: kitchen cupboards, shoe rack *Display spaces: mantelpiece *Spaces outside the home

Table 1. Dimensions relevant for doing repair in everyday life (the Table represents the repair trajectories that emerged in our fieldwork (other ones might also exist).

Diagnosing

Once pre-diagnosing has occurred, diagnosing the object in need of repair can begin. Sometimes diagnosing is pretty straightforward, the 'fault' makes itself visible. For instance, the handle from the frying pan comes off, the steps on the ladder are partly broken, or plant pot has shattered into pieces. Other times, diagnosing can take time and even starts to overlap with fixing. For example, the hobs on the electric oven can no longer be turned on. Mike had to slowly and carefully open up the oven in his cohousing project, keeping track of how the different parts fit together and in which order. Some citizen scientists make pictures of each diagnosing/ fixing step to make sure they can put the object back together after fixing it. Additionally, Mike had to make sense of the electric circuit: how are the different parts connected and how does the electricity flow through the object. Different tools that can measure the electric current helped him along the way. In the end, he had to draw a detailed electric circuit to explain to himself where the 'fault' might be uncovered.

Mike's example also makes visible the *socio-material arrangements for repair in people's homes* and their *repair skills and experiences.* These differed greatly between the citizen scientists. Repairers, like Mike, have dedicated, specialized tools to conduct the diagnosis (e.g. electronic measuring instruments). Such specialized tools are sometimes even needed to open up objects such as 'pentalobe' designed screws used in smart phones that can only be unscrewed with particular screwdrivers. Space also seems relevant to be able to take objects apart so that the 'fault' can be detected and the parts can be left sometimes for days. A small number of citizen scientists had dedicated repair spaces where they had all of their tools, lighting, etc. A handful of these repairers had developed dedicated storage spaces for their tools, spare parts, and other useful materials. More common was that the citizen scientists had one tool box at home and often used the kitchen table to conduct necessary repairs.

For some of the citizen scientists, examining and diagnosing objects started from an early age. 'You are so destructive. You always destroy things that I have bought', this is what Oscar's mother used to regularly say to him when he was curious about how the radio looked like from the inside. The neighbor, who was a keen tinkerer, recognized Oscar's interest and allowed him to observe and encouraged his own experimentations. Over time, repair, making and tinkering has become a way of life for Oscar. He sometimes gets paid for it and other time he does not. Quite a few of the other 'serious' amateur repairers went through some formal training, for instance, studying engineering, where they learnt different processes to diagnose objects' 'faults'. Thus, early engagements with parents, siblings, friends and neighbors or formal and informal educational settings socialized an interest in repair or a certain fearlessness to start repairing i.e. open broken objects. This makes it easier to proceed from diagnosing to fixing.

Fixing

Collaboratively analyzing the probes during the participatory research workshops, it quickly became apparent that fixing objects sometimes (and regularly) becomes an integral part of our daily live. We regularly conduct 'routine' fixes (such as sewing ripped trousers, gluing the soles of a shoe, and repairing a bike puncture). Glue and tape is used quite frequently. Although people fix objects, they do not necessarily consider these as repairs.

Other 'routine' fixes can consist of exchanging parts that are broken or missing, for instance, replacing a broken washer from the water sprinkler or exchanging a broken light bulb. These fixes depend on people getting or having the necessary spare part. They can take days because people might need to buy the part but often require little time, effort and knowledge. 'Serious' amateur repairers have a slight advantage. They often have collections of spare parts at home and do not have the additional trip to the shop before fixing the object. Moreover, they usually know what type of part (e.g. screw) needs to be the replacement/ bought.

The object's role in the performance of daily practices regularly plays a key role. As seen above, people often try to lengthen the time between diagnosing and fixing. Quick, 'half' fixes often are an option, for instance, using safety pins for holes in clothes. It seems that we live with quite a few 'half fixes' and 'half working objects' around us to sustain the performance of daily practices e.g. wearing clothes. Until the point is reached or there is a bit of spare time to fix the object or even have it fixed.

'Serious' fixes often take longer and can even become long term projects e.g. the diagnosis might take a long time, specialized tools can be needed to diagnose the broken item, spare parts need to be bought. Sometimes, citizen scientists have had to consult the internet or professional sales or repair people along the fixing process. For example, Julie took her broken tablet back to the shop and asked whether she could get a replacement charger for it. The salesperson told her that they no longer sell them and that she would need to get a new tablet. Julie did not want to give up, went home and consulted the internet. Within an internet forum, she could read that there still is a charger, which works for her type of tablet. She ordered it and the charger arrived in a few days. Testing the charger, Julie realized that it was not only the charger that was no longer working but also the battery was damaged. The battery could no longer be fully recharged. This time, Julie went straight to the internet and found a video where someone described how to replace the battery of her tablet. After watching the video, Julie felt that she wanted to give it a go. She ordered a battery. Once it arrived, Julie prepared her kitchen table, got out her mobile phone to be able to take a photo of each step. Julie fixed the tablet.

The tablet is a good companion for Julie in her daily life. She likes to quickly look things up on the internet. Further, she is able to take it with her during her travels, booking her accommodation whilst travelling from one place to the next. The tablet seems to be a 'workhorse' (see Cox et al. 2013 work) for her i.e. in regular use and always on standby. These objects when broken create a vacuum that soon needs to be filled to be able to perform 'normal' daily live. Additionally, Julie had the self-trust, knowledge of repair procedures and willingness to ask for advice, consulting different sources to successfully fix her tablet (see dimension *repair skills*).

Integrating (or not)

After the fixing phase, objects can potentially be integrated into the daily performances of practices (such as a fixed bike puncture allows the person to cycle to work again). It becomes again an integral part to these performances and keeping practices alive. Such integrations are not necessarily a given. Quite often in Repair Cafés, people have their objects fixed and rather than taking them back home, offer them for free to the organizers. 'I have already bought a replacement'. Here, the need of the object to perform daily routines might be key (*socio-temporal arrangement* of everyday life). Rather than having the hoover fixed, people sometimes buy new ones to continue their weekly hovering routines. Buying a new object shortens the diagnosing to fixing period (because the need to fix the item is no longer needed).

As seen above, some objects in need of repair are newcomers to someone's home (see Adrian's ladder). Once the object is fixed, new practices need to be developed so that the object can be integrated into people's daily lives. In Adrian's case, the ladder (even after fixing it) was too dangerous to be used by others. It still lives with him but he will soon move out and might pass the ladder to someone else. Mike lives in a co-housing project in which repaired object can more easily find a new owner. Adrian's example also demonstrates that some objects do not really fully get repaired. Some functions might be recovered but not all.

The fixing process does also not always end well. The object does not work or is even more 'broke'. This does not necessarily mean that the citizen scientists get rid of them. They are often stored away, waiting to be thrown away or fixed. Dedicated repair and storage spaces in people's home usually encourage such practices of keeping objects in need of repair. One of the organizers of a Repair Café explained that often, people would not necessarily be unhappy if their object could not be fixed in the Café. People were glad to know that an 'expert' tried to fix it but also failed. The object was truly 'broken' and could therefore be thrown away with a good conscious.

Conclusions

This paper presents first insights from our citizen science research, investigating the dimensions of repair in everyday life and changes to human object relationships: How is repair performed in everyday life and how does the human-object relationships change through repair? Repair activities often follow particular phases, starting with the (possibly very long) phase of pre-diagnosing/ diagnosing the object in need of repair, followed by the fixing process that is not always straightforward, and finally, if fixing was more or less successful, the re-integration of the object in everyday life. These phases are not necessarily performed in a linear and/ or chronological way.

So far, our results have revealed several relevant dimensions for performing repair in everyday life: 1) condition of object in need of repair, 2) socio-material arrangements for repair in people's homes, 3) repair skills, experiences and competences in the household, 4) object in need of repair as part of performing everyday life, 5) socio-temporality of practices associated with object in need of repair, and 6) socio-spatial arrangement of object in everyday life. Such dimensions might be of interests to scholars working on repair for several reasons.

First, pre-diagnosing can occur daily and way before any kind of fixing is taking place. During this phase, socio-spatial arrangement of objects and socio-temporality of practices associated with the object seem to play a key role for whether repair is performed (or not). Depending on how often people perform daily practices with an object (such as brushing teeth with an electric toothbrush), they have the possibility to scrutinize its current condition and value i.e. pre-diagnosing it. Objects do not only help people to perform daily practices, they also demand 'caring' practices to be performed for them: cleaning, storing, etc. Such practices can often lead to quick fixing activities (such as sewing on a button). One preliminary finding is that people seem to fix quite a few objects in their daily life. These might not be 'serious' fixes but they still require time, resources and care.

Second, fixing an object in need of repair often also relies on how they are integrated in the performance of daily practices. If an 'invisible workhorse' (e.g. washing machine) breaks, the need to repair the items in order to keep routines up might be so great that rather a new object is bought to replace the broken one. Other objects (such as bikes) are usually repaired within a few days. Quick or half fixes often become an option. Other objects (such as memory objects or collections) can usually stay longer in a 'waiting to be fixed' phase, considering that the 'deterioration' is part of keeping up the memory. Such temporal rhythms are therefore key when thinking about the relations between objects and repair activities.

Third, the research also shows that early socialization processes that help to gather repair experiences play an important role for repairing in later life. Besides practical repair know-how that people might gain through early experiences, they are able to build a sense of self-efficacy and courage towards opening up objects where regular repair can become the norm throughout people's life.

As part of our future research into repair in everyday life, we will deepen these first insights and develop an understanding of the interlinkages between repair in community-based workshops and people's home. So far, our conceptual approach that puts emphasis on materiality and bodily performances proved to be appropriate to study repair as a practice.

Although our chosen methods have not been the focus of this paper, we would like to point out that the citizen science approach enabled the team to investigate the research topic in unexpected ways. Moreover, it sometimes created tensions on how to conduct the analytical work in a rigorous way i.e. according to existing social science standards. After some initial irritations with the methodology – likewise for the academics and citizen scientists – the probes facilitated a fruitful stimulus for self-reflections and proved to be a well-working visual and textual trigger for analytical discussions in our research workshops.

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”Doing value“ – Modelling of Useful Life Based on Social Practices

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Keywords: Lifetimes of Devices; Replacement; Grounded Theory; Theories of Practice; Sociology of Valuation.

Abstract: The extension of product lifetimes is discussed as an important aspect of sustainable consumption. So far, models explaining lifetimes of devices are predominantly user-oriented and are based on a methodological individualism. Systemic interrelationships are underestimated due to an overemphasis on individual room for manoeuvre. This paper presents a model to explain the useful life of devices, which – with recourse to practice theory – is taking technological change, the context of use and the setting of actions into account. The model is based on qualitative interviews that were analysed using grounded theory. At the core of the model are valuation processes that are located in the interactions with the devices and carried out against the background of context of use. Based on sociology of evaluation, it is explained how the value of a devices is produced, reproduced, increased or decreased until they are replaced. Using mobile phones as an example, two types of forms of practice are presented and it is it derived how longevity might be promoted.

Introduction

Long lifetimes of consumer goods are discussed as an important element concerning sustainability (e.g. van Nes & Cramer, 2006). This paper presents a model for explaining the duration in use of devices that takes systemic interrelations into account instead of overemphasis on the freedom of action. The model is developed based on qualitative interviews which were analysed using Grounded Theory.

In the following, the current state of research on the topic of lifetimes is briefly outlined and practice theory is described as the major conceptual background of this study. This is followed by a description of the methodological design. Then the main construct "doing value" is explained with reference to sociology of valuation, before the model is described and its usability is outlined. In conclusion, the potential of the model and its transferability to other product groups are discussed.

Literature review

Since the end of the 1970s and the beginning of the 1980s, research has been carried out into product lifetimes, replacement and the handling of garbage in various predominantly social science disciplines such as economics, marketing, design, psychology, sociology, anthropology and cultural studies (Cooper, 2010). The studies focus more on decisions and cognitions (purchasing, investment, marketing, design decisions), sometimes also on emotional attachment, and less on the practical handling of consumer goods. With regard to study design, quantitative methods predominate, whereby the statistical relationships between the useful life and the device category, sociodemographic characteristics, the expected lifetime, as well as intentions and attitude such as environmental awareness are often investigated (Echegaray, 2015; Gnanapragasam, Cole, Singh, & Cooper, 2018; Jaeger-Erben & Hipp, 2018; Knight, King, Herren, & Cox, 2013; LE Europe et al., 2018; Siddharth, Dehoust, Gsell, Schleicher, & Stamminger, 2016; Wieser, Tröger, & Hübner, 2015). In these studies, the user is predominantly conceived - whether implicitly or explicitly - as a benefit-maximizing subject according to methodological individualism and rational choice, who would act independently and self-controlling. However, the fact that only a small part of behaviour can be explained by attitudes and intentions is much discussed in attitude-behavioural research (Hassan, Shiu, & Shaw, 2016; Sheeran, 2002; Sheeran & Webb, 2016; Shove, 2010). The inconsistency between user attitudes and behaviour was also found in relation to lifetimes of devices (Evans & Cooper, 2010). Praxeological approaches, on the other hand, take structure of society into account and may provide impulses for research on (non-)sustainable use of electronic products (Jaeger-Erben, Winzer, Marwede, & Proske, 2016).

Practice theories

By drawing on practice theories, the separation between actor and structure often found in the social sciences is overcome conceptually and methodically (Schatzki, Knorr-Cetina, & Savigny, 2000). Social practices are set as the place of the social and the smallest unit of analysis, and routines are thus embedded in social contexts and settings that determine the meaningfulness of action supraindividually (Shove & Spurling, 2013). Practice theory emphasizes the materiality and physicality of social activity, artefacts are understood as important elements of the formation of practice. Individuals are conceived as carriers of practices that make meaningful (mental) use of artefacts (materiality) (Reckwitz, 2002), for which they need specific competences. Social practices are performed within a setting (see Figure 1). Interrelated concatenations of social practices are referred to as forms of practice in the following, taking Hillebrandt (2014) as a reference.

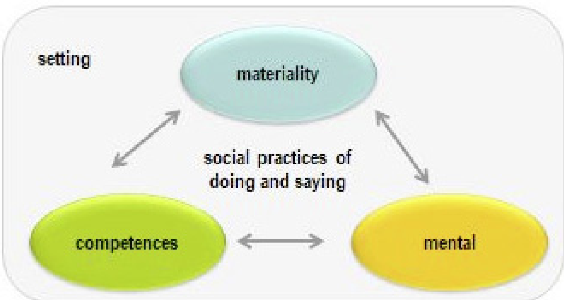

Figure 1. Elements of social practices © Own illustration based on Jaeger-Erben 2016.

A practice-based approach enables the perspective that people do not consume in order to meet needs, but that social practices require consumption in order to be carried out (Warde 2005; Røpke, 2009; Shove, 2007). Thus the questions arise for what the devices are used for and how and why they are replaced and no longer used for performing these practices.

Methodological approach

A qualitative approach was chosen for the investigation of the handling of devices. Both the sampling and the analyse were carried out by using (reflexive) grounded theory (Breuer, Muckel, & Dieris, 2018; Bryant & Charmaz, 2011; Strauss & Corbin, 1996), since this methodology is suitable for generating theories. To date, 15 guideline-based in-home interviews, each lasting approximately 2 hours, have been conducted, and more are planned. The interviewees from different social segments are between 14 and 79 years old and live all over Germany. The data material was analysed using the tool ATLAS.ti.

The focus of the interviews was on mobile phones and washing machines. For both devices, it was recorded how many of these devices were used in life and how the devices were replaced. During the analysis it became apparent that reference was often made to a "value" of the device and that this value seems to be constitutive for many practices in dealing with devices.

Conceptualization of valuation processes

The empirical material suggests that a dynamic, relative value of the devices is produced in and through social practices. A recourse to the sociology of valuations provides the theoretical foundation for the reconstruction of these predominantly just implicit valuations. Although so far only a few attempts have been made to combine practice theories and sociology of valuation (Arnould, 2014), this might be fruitful, since part of the heterogeneous field of the valuation sociology also deals with how valuations are carried out operationally and which practices are connected with it (Lamont 2012; Kjellberg & Mallard 2013). If practices are seen as an ontological basis, the combination with practice theories is possible (Schatzki, 2016). Thus the importance of materiality is also emphasized in the sociology of valuation (Meier, Peetz, & Waibel, 2016).

Value is decoded as something that is produced in interaction – in contrast to economics, which locate it in the object, or psychology, which locate it in the subject (Ramírez, 1999; Simmel & Frisby, 2004). In short: "(...) value emerges from what people do" (Arnould, 2014, p. 130). The value of a device is thus produced, reproduced, upgraded or devalued in and by the social practices in which the device is involved or related to the device. The valuations do not have to be conscious of the acting subject or be intended by him; instead, they are produced and varied in their use of the device – against the background of context of use and setting. In order to emphasize the performative character of this valuation process, in the following this process is referred to as "doing value". "Doing value" is thus conceptualized as a main construct, as implicit order schemata, which encompasses both the processes of emotionally founded value attribution (Krüger & Reinhart, 2016, 2017) differentiated in the literature and the comparison-based weighing of values (Bowker & Star, 2000).

In the sociology of valuation, often only single moments of valuation (methodological situationalism, Knorr-Cetina & Cicourel, 1981) are in focus. In order to analyse how the replacement of a device occurs, however, concatenations of valuations must be considered. The model of the evaluation constellation (German Bewertungskonstellation) of Meiers allows us to analyse the transsituative character of valuations. Therefore, elements[1] of this concept are adopted to elaborate the characteristics of "doing value" (Meier et al., 2016):

1) Valuations are interlocked with positions and relations that have specific structural characteristics. The valuation of a device takes place against the background of the context of use, i.e. the suitability to do certain things with it or to be able to represent the symbolic values required. Furthermore, the valuation takes place in relation to the technological change and the concrete setting. A device is valuated relationally in comparison to another device.

2) Valuations have rules with transsituative validity. Valuation rules indicate what the situation is about, which indications are used and which logic is followed in the valuation. With regard to the model, this can mean, for example, "practicability" or "less effort".

3) Valuation processes require materiality. In relation to the useful life, this is on the one hand the material composition of the device used (quality, functions, operability, etc.) and on the other hand the wear and tear and defects.

This characterization of the valuation processes forms the basis for the developed model.

Practice based model to explain useful life of devices

In the literature, the lifetime of a device is divided into the phases of acquisition, use, and give away[2] (Murakami, Oguchi, Tasaki, Daigo, & Hashimoto, 2010). My interviews suggest that this order does not correspond to the logic of social practice. Which device is purchased does not arise from "nothingness", but is related to handling experience with a previous device in the specific context of use. Also, the passing on of a device is often not to be explained exclusively with reference to the device itself (e.g. not repairable defect), but takes place in relation to a potentially new device or its positive valuation and accessibility. The potentially new device thus serves as a reference standard, which forms the basis for the valuation of the current device. According to my interviews, even the first personal purchase of a device is shaped by experiences of using other devices (e.g. using washing machine at parents' house), the use of devices with similar functions (e.g. experiences with the computer are transferred to the smartphone) or stories told by friends and relatives. Accordingly, I model the usage phase as the beginning, which explains the product give away associated with the purchase of a new device. The model is illustrated in Figure 2.

The value of a device is permanently reproduced, increased or decreased by social practices

A device is integrated by the user into the design of everyday life, for example a smartphone for communication, entertainment and information retrieval. Social practices are also carried out in which the device is not a substantial part of it, but which are related to the device, for example by talking about the device or looking for information about the product. All these social practices of doing and saying in the context of use, give away and purchase are linked to valuations of the device. With each of these social practices, as well as with the omission (e.g. no care practices), the value of the device is produced, reproduced, increased or decreased. The performatively produced value of the device is rarely reflected, but it has a meaningful character.

[1] The model of the valuation constellation is based on a methodical subject-object division. Therefore, only those aspects of its model are used that are also based on a practice-based approach.

[2] There are various definitions of product lifetime and duration in use. With regard to duration in use, an additional distinction is often made between storage and repair phases. For reasons of limited space, this article does not go into this further, although storage and repair were also part of the interviews.

The valuation processes takes place with regard to various characteristics such as functionality, quality, usability, modernity, design and emotional attachment. Due to these different dimensions, the revaluation or devaluation can also be contradictory. For example, the usability can improve due to the habituation during the usage phase, while the valuation of functionality and aesthetics can decrease due to wear and tear. Overall, the gradual devaluation of the current device is predominantly carried out during use in parallel with the gradual upgrading of a desirable new one.

The valuations manifest themselves in the elements of social practices

Production, reproduction and changes in value are evident in the three elements of social practices: Materiality, meanings and competencies and are intertwined.

With regard to materiality, the devaluation of the current device may be related to technical (partial) defects, optical wear or the lack of innovative applications, for example. These can occur successively (e.g. battery slows down, scratches) or spontaneously caused by events (e.g. device falls down).

The meanings associated with the valuation processes can be related both to the device itself (e.g. emotional attachment, careful handling to maintain functionality, enjoyment of design) and to the everyday life (e.g. time management). Regarding the upgrading of the replacement device, the attractiveness of novelty respectively the enthusiasm for new devices plays a major role (see Frick, Jaeger-Erben & Hipp, this volume).

The competences refer to the ability to handle the device (e.g. know-how regarding care practices, repair). They are either to be assigned to the wearer of the practice or they are conveyed via media or friends and relatives.

"Doing value" takes place within a specific setting and is related to the context of use.

The evaluation processes takes place within a specific setting. The setting describes the environment in which the social practices take place and thus reflects not only milieu-specific circumstances (e.g. household size, mobility, financial resources) but also social (e.g. conventions, values, role attributions) and technological change (e.g. product innovations). The setting thus influences social practices and their elements.

The setting also shapes the context of use, i.e. for what purpose (e.g. communication, entertainment, information) and how intensively a

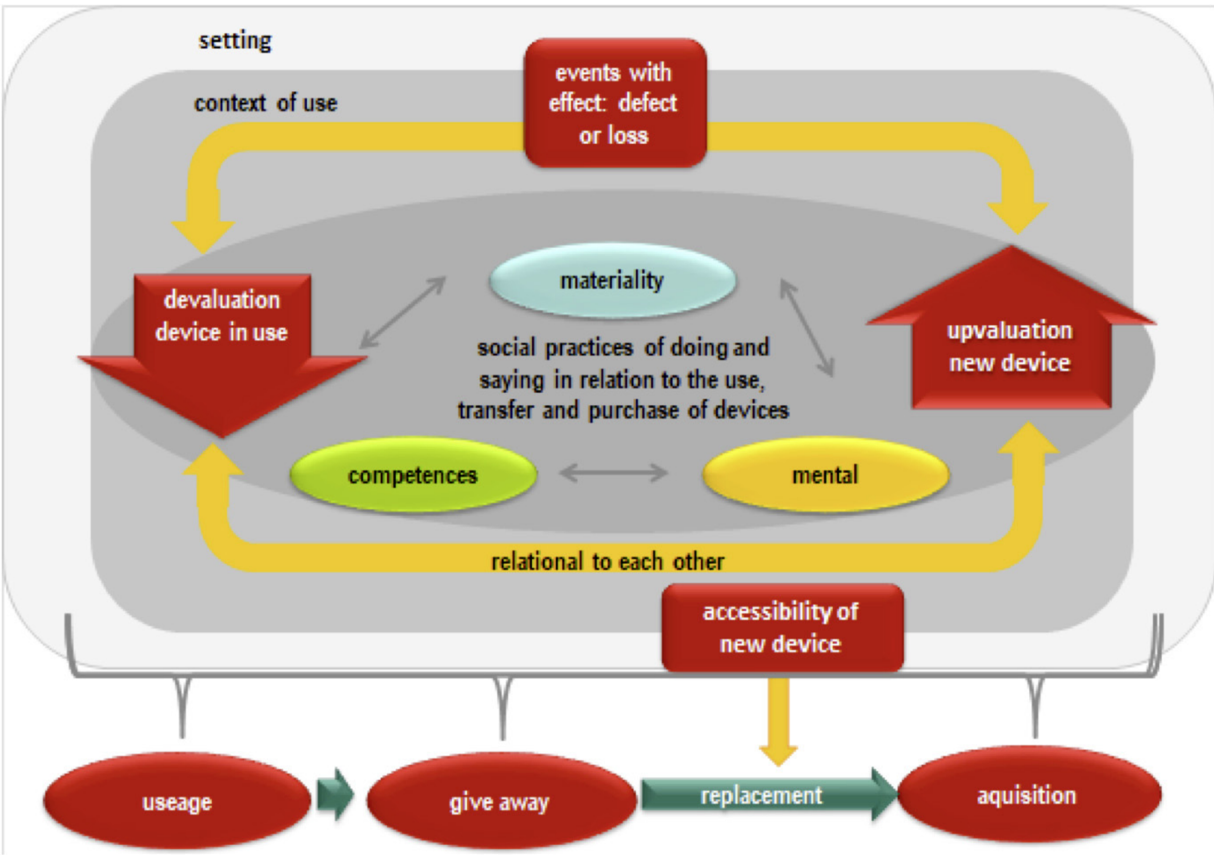

Figure 2. Model of "doing value".

device is used. The context of use describes the integration of the device into everyday life and thus serves as a benchmark for the valuation processes. Whether the value of a device is reproduced, increased or reduced in the performance of the social practice is thus measured by the usefulness of the device for the design of everyday life, together with the specific social practices carried out by the user. Setting and context of use are to be understood dynamically. Changes in the setting (e.g. move, illness, new job) affect the context of use, which may involve changes in the practices performed and may affect the valuation of the device.

The exchange depends on the relationship between devaluation and upgrading and the accessibility to a new device.

Replacement comes closer the more the current device is devalued and a potentially new device is upgraded. The product exchange is therefore based on the relation of the "doing value" regarding both devices. As is customary the "doing value" takes place gradually over time. An abrupt revaluation – usually devaluation – can also be caused spontaneously by events, such as a defect. The unintended loss of the device (stolen, lost) is understood here as a special case, which represents practically a spontaneous "complete devaluation", since the device is no longer usable.

In addition to the "doing value", the accessibility of a new device, which is materialized in the setting (e.g. new releases on the market, as well as the offer of a relative), is decisive for the act of replacement.

Applicability of the model

This model can be used to analyse what limits the useful life by examining the role of elements. This can be linked to hypotheses about how longevity might be promoted.

With regard to mobile phones, the practice form most frequently found in empirical data is "antagonistic valuation". This means a successive devaluation of the current device over the period of use due to partial defects (e.g. lack of software updates, slower battery capacity, crack in the display) or social meanings (fear of failures, etc.) and parallel to this an antagonistic revaluation of a desirable new device with other product characteristics (more functions, design). The exchange of the devices is usually planned and takes place through a concrete opportunity, such as a new release on the market, a special offer or an open gift. This form of practice is associated with a rather average use phase. A special case of the "antagonistic valuation" is "gaming affinity": Here the valuation of the device is based on being suitable for gaming. Therefore characteristics such as processor performance and battery capacity can be decisive for the devaluation, if a new game with higher requirements is launched. According to these criteria, a new device is upgraded in parallel. The intensity of use and therefore also the wear is above average. The use time is below average.

In order to promote longevity, it seems plausible to slow down the devaluation of the current device and the valuation of a new device. How this can be done could be addressed in further research; it could be presented in public discourse to upgrade used equipment (meanings), to make repair services easier to access (materiality) and to promote the diffusion of relevant know-how (competences).

One form of practice that is specific to mobile phones is the exchange according to regular rhythms of a contract. In the practice form of "contract logic", the device is automatically devalued independent of the context of use. The devaluation is thus largely decoupled from the functionality, but is initiated by the setting and gets manifested in the meaning, too. The useful life is usually two years. In order to promote longevity, contract options could be designed that guarantee the functionality of the device through service and provide replacement devices in the event of repairs.

Conclusions

The "doing value" model presented here to explain the useful life pursues the aim of representing real practice as accurately as possible and is therefore necessarily comparatively complex. Nevertheless, it can be broken down into the operation of product valuation, which takes place through the performance of practices against the context of use. It was developed using grounded theory for analyzing qualitative interviews. The theoretical basis is provided by practice theories and sociology of valuation. With regard to the mobile phone, two exemplary forms of practice were presented and starting points were deduced how longevity might be promoted. Accordingly, it could make sense to slow down the processes of devaluing used devices and upgrading desirable new devices, which could be implemented, for example, by offering services that promote longevity. With regard to materiality and in the sense of a circular economy, a modular device could also be developed which would slow down the devaluation of the device due to the interchangeability of (defect) components, design diversity and "space for something new" (Proske & Jaeger-Erben, 2019).

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Framing Organizational Dynamics towards Circular-sufficiency Value Creation Systems

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Keywords: Circular Economy; Organizational Change; Circular Business Model; Sustainable Business Model; Sustainability Transitions.

Abstract: Practitioners from politics, economics, and the civil society, but also scholars increasingly recognize that business contributions to a circular oriented transition of the society are founded in new business models. However, most research in this field remains theoretically conceptual and offers a rather static view of a complex and constantly changing reality. This study strives to contribute to the shift in the circular business model debate from its definitional and motivational aspects to the understanding of organizational dynamics connected to the efforts of firms that experimenting with circular oriented business configurations. Based on eight problem-centered expert interviews with business consultants, the study provides a set of propositions on how they are framing corporate transitions towards circular-sufficiency value creation systems. It reveals starting points for understanding patterns of circular change in firms, which may simultaneously serve as impulses for future research investigations.

Introduction

In light of climate change, massive biodiversity loss rates, or growing natural resource scarcity, just to highlight a few ecological persistent problems, a fundamental reorganization of our social structures seems inevitable in order to move towards sustainability. In particular, the production and consumption patterns of the Global North, which have been expanding in other parts of the world over the past few decades, put tremendous pressure on nature. It is evident that business-as-usual cannot be sustained (IPCC, 2014; Schubert et al., 2011; Steffen et al., 2015). A profound shift in the purpose of corporations and almost every perspective on how they are conceived and arranged is necessary to shape the conditions for a livable future (Bocken et al., 2018).

One possible economic transition corridor that gained growing popularity among corporate representatives, politicians and scientists is the idea of a circular economy (CE). In the CE discourse, innovative business models (BMs) play an outstanding role by perceiving them as a catalyst for a sustainability transition of the contemporary unidirectional (linear) industrial economic logic (Hofmann, 2019). Under certain circumstances, novel BMs have the ability to trigger a “process of industrial mutation” (Schumpeter, 1976: 83), as they couple multiple social actors, and link the production and consumption spheres (Bidmon and Knab, 2018).

Nevertheless, the following paper adopts the concept of value creation system (VCS; Rüegg-Stürm & Grand, 2016) as an analytical unit in order to approach corporate renewal in the context of a CE. It must be emphasized that a VCS goes beyond the usual notion of a BM. Current BM thinking largely assumes a mechanistic approach in which a firm can be understood by analyzing the core components, in this case BM elements (such as value proposition, value creation & delivery, value capture; Foss & Saebi, 2015). The notion of system, in contrast, accentuates “that the whole is greater than the sum of its parts and that the behavior of the whole thus cannot be understood from the properties of its parts” (O’Connor, 2008: 315). It is precisely this interdependent interaction that gives a system a certain structure, which in turn enables specific functions (Kieser & Ebers, 2019). The function and central characteristic of firms as organizations is a unique kind of value creation that can be understood both as a result (products and services that can appear as vehicles of values) and as a process (dynamics of activities, resources, networks) that leads to this result. In other words, firms are at heart sequences of organizing that constitute and stabilize themselves as VCSs (Rüegg-Stürm & Grand, 2016; Weick, 1979). Hence, there are three conceptual conditions of VCSs that differ from the BM perspective: (1) VCSs assume a plurality of values, while the connotation of "business" models imply the focus on financial rationalities solely. This distinction is important because it highlights the complexity of the challenge involved in integrating principles of circularity and sustainability in corporations (such as new performance measurement indicators). (2) Enterprises as VCSs are steadily evolving: they are in a constant state of flux. The dynamic related perspective of VCSs emphasizes the importance of the time dimension and therefore the associated process of transition (Weick, 1979). (3) The ability of the firm to change their BMs is influenced by communication structures, decision patters, roles, power constellations, belief reference frames, dynamic capabilities, etc. The rotational searching, experimenting, and learning sequences to stimulate BM renewal can only be explored by incorporating the organizational dimension. In a nutshell, VCSs combine the BM perspective with the process of organizing.

A circular-sufficiency based VCS connects firstly, circular business configurations focusing on result- and performance-oriented product-service-systems; manufacturing and offering durable, reliable, modular, and repairable products; practicing conscious sales (slow fashion, slow travelling etc.); and adopts an economic long-term view of operating (based on Bocken & Short, 2016; Bocken et al., 2016; Dyllick & Hockerts, 2002; Young & Tilley, 2006). And secondly, the consumption side of business, which includes responsible (non-)consume activities, such as repairing instead of buying new products; second hand purchasing; sharing; or buying locally and regionally manufactured products that can be summarized as "sufficiency". Therefore, circular-sufficiency-driven VCSs attempt to reduce the absolute overall natural resource consumption by moderating demand through education and consumer engagement, making products that last, extending product lifetimes to slow down disposal and replacement rates through changes in sales and marketing practices (Bocken & Short, 2016).

Research in the CE field at the corporate level has primarily developed in two main tracks addressing two sets of questions: why should or should not companies adopt circular value creation architectures, and what makes a corporation more circular? Answering "why"- or "why not"-questions accentuates motivational aspects (such as decoupling growth from natural resource consumption or to become more autonomy and independence from international commodity markets) or studies of drivers, challenges and barriers of integrating CE core principles into daily business routines (e.g. Linder & Williander, 2017; Nußholz, 2017; Rizos et al., 2016; Sousa-Zomer et al., 2017; Tura et al., 2019). Research on "what"-questions focusing on the constitution of circular BMs, the description of properties and features of individual circular BM elements or circular BM design strategies that can be summarized as conceptual debates (e.g. Bocken et al, 2016; Bressanelli et al., 2018; Lewandowski, 2016; Lüdeke-Freund et al., 2018; Manninen et al., 2018; Planing, 2018; Urbinati et al., 2017). Despite, and in part because of, the discourses on the definitional ("what"), motivational ("why"), and risks ("why-not") issues, there is still missing a significant investment in scientific knowledge production, apart from a few exceptions (e.g. Antikainen et al., 2017; Bocken et al., 2018; Heyes et al., 2018), on questions according to the dynamics through how incumbents trying to navigate a circular transition of their VCS. In other words, the CE research field benefits from directions in exploring corporate practices of organizational discovering, experimenting, and learning to stimulate circular change.

This study follows the few tentative investigations that have been conducted so far addressing the "how"-questions. It provides a set of propositions on how consultancies as direct advisory agencies of firms framing organizational transitions to circular-sufficiency VCSs. This allows outlining starting points to (1) reveal patterns of circular renovation of incumbents, (2) identify contradictions and shortcomings of CE narrations in real-life contexts, and (3) highlight future research directions.

Research approach

The research approach of the study is both qualitative and explorative, examining on how business consultancies narrate, frame, and draft transition processes towards circular-sufficiency value creation logics at corporate level. The data was collected through eight semi-structured, problem-centered expert interviews. The interviewed persons hold different positions (two junior consultants, one senior consultant, one department head, one chief operating officer, two chief executing officers, one managing partner) in six international operating business consultancies that offer consulting services for circular organizational change. They were detected through extensive web searches and personal expert recommendations. The selected individuals were assessed as particularly knowledgeable and experienced about the topic of interest. The duration of the interviews varied between 55 and 89 minutes, which were conducted in German between March 2019 and May 2019. All interviews were recorded and transcribed word by word.

The obtained data in the form of written communication was processed and interpreted with the use of both open and axial coding according to Straus (1978). The objective of the data analysis was the rotational deconstruction of the transcripts to firstly, open up new dimensions of meaning behind the obviously perceived surface of the text, or in other words to break up the manuscript into sub-textual interpretation categories. And secondly, based on this, to formulate a preliminary set of propositions on the object of research to approach the observed phenomenon.

There are several reasons why business consultants were chosen as experts. They are advisory bodies that use their expertise, experiences, networks and abilities to influence corporations and therefore contribute to certain developments and arrangements of markets and industrial sectors. Consequently, they are relevant to social negotiation processes as economic authorities and should thus be able to indirectly or directly affect the thinking and actions of corporations. As they have a certain degree of interpretive sovereignty on socio-economic developments, it seems sensible to examine their ideas and deliberations on circular business development in order to draw conclusions about contemporary and potential future VCS formations. In addition, there is still no research on circular change at the corporate level that specifically uses experiences and narrations of business consultancies as source of knowledge.

Framing organizational dynamics towards circular-sufficiency VCSs

Framing comprises the process of embedding occurrences and phenomena in interpretative schemes. This allows intricate information to be selected, structured, and complemented in a meaningful way to handle the complex reality. “To frame is to select some aspects of a perceived reality and make them more salient in communicating text, in such way as to promote a particular problem definition, causal interpretation, moral evaluation, and/or treatment recommendation for the item described” (Entman, 1993: 52).

Circular-sufficiency reinventions are determined as substantial, architectural, and complex organizational changes of incumbents as already existing VCSs that are embedded in their own past, in different social spheres, and in interrelated ecosystems. To be capable of acting and not to be paralyzed from the faint of complexity and uncertainty of the future, selecting and prioritizing specific constructed realities is necessary to absorb uncertainty (March & Simon, 1958). Consequently, selecting and prioritizing certain issues of corporate transition processes opens up spaces for action. Due to interpretative schemes the diffuse openness of evolution pathways can be reduced to make recommendations and decisions about future operations (Luhmann, 2002). The following subsections introduce a set of four propositions how the individuals interviewed embedding organizational dynamics towards circular-sufficiency VCSs into their interpretative schemes.

Proposition I: Circular-sufficiency reinventions as organizational black boxes that lead to perplexity

The management of circular-sufficiency based VCS reinventions and its dynamics is ambiguous and opaque. In this context, corporate management appears in many ways to be a black box, and this despite of the tremendous importance of navigating and evolving today's firms against the backdrop of the anthropocene. Black boxes are simplified representations of complex systems, which processing specific stimuli to possible responses, without knowing how the inner structures and spaces are designed and organized. It is a construct consisting of both entrance and exit, but its inner architecture is opaque and declared as irrelevant. Hence, a black box ensures a specific functionality, but its manner of functioning is unknown (Baecker, 1999).

The core principles to integrate circular-sufficiency VCSs into daily practices or, in the language of the black box metaphor, the input factors to stimulate implementation are known and discussed widely. Applying new technologies, especially of digital ones, involving relevant stakeholders in the VCS design process, collaborating within value creation networks; and reorganizing producer-consumer-relationships are frequently mentioned premises for the development and successful realization of circular-sufficiency VCSs both in the conducted interviews and in the scientific literature. The expected behaviour patterns of circular-sufficiency VCSs (black box output) can be aggregated in the modes of value creation and offerings to slow resource loops (e.g. Lüdeke-Freund, 2018; Hofmann 2019). These include, for example, repairing, maintaining, refurbishing of products and components, managing reverse logistic systems (modes of value creation) or providing product functions and performing services (modes of offerings). But so far there are no answers or concrete solutions on how to orchestrate the core principles of integration. What does this mean for the organizational dimension of incumbents? How do communication structures, decision-making patterns, hierarchies, power constellations, and key performance indicator matrices change in order to generate the imagined output? The lack of knowledge and the resulting uncertainty find their expression in the perplexity and paralysis of corporate decision-makers. This kind of faint may leads to inertia and stall substantial firm transitions, which seem necessary to identify and figure out potential pathways for overcoming persistent problems, such as climate change or resource scarcity. "There is a great helplessness on how to implement this (CE) and, in particular, how to implement it in companies" (interviewer A).

Proposition II: Circular transition as a reactive concept for heteronomous VCSs

The narratives about circular corporate transitions start predominantly by emphasizing on key external competitive and social compulsions. "In my opinion, there are two or three main pressure points that lead companies to think about the topic (circular reinventions) at all" (interviewer B). Enterprises are driven and determined by price volatility on raw material markets, climate change, legislative modifications, customer needs, shareholders, price fights, digitalization, the own chief financial officer, concentration of power and monopolies, etc. In other words, they can contribute solely to socio-economic developments if stakeholders provoke them. This is in line with the stakeholder approach, which implies causality thinking based on unidirectional power of the environment that affects the architecture and logics of VCSs. Thus, firms are constructed as externally controlled administrative organizations: as passive and reactive social agents that merely adapt to the environment (Schumpeter, 1976). They are triggered, driven and chased by foreignness, and fight with their backs to the wall trying to pursue economic, social, and ecological trends with elaborated strategic plans. From this point of view, circular corporate reinvention is articulated as a reactive concept for heteronomous VCSs.

Proposition III: The need for provocateurs and troublemakers

Where does circular-sufficiency change arise at corporate level? How does dynamism emerge in seemingly stable systems? Taking into account the axiom that VCSs as social systems cannot exist without humans (human "resources" as strategic importance of corporations), it can be inferred that employees are essential origins of irritation and inspiration who scrutinize the existing VCS. The data indicate that intrinsically motivated, usually influential persons initiate circular-sufficiency reinventions, who encounter resistance with intrepidity and courage. They become role models of renewal through their attitudes and behavior. Other employees perceive them as idealized paragons of progression, as the personification and leading figure of change. They reinterpret the rules of the game, even try to reformulate them, and critically reflect routines and thus the logic of the contemporary VCS. They irritate existing communication structures and make non-conform decisions. Thus they confront the “establishment”; act against power and hierarchy pyramids, or use them for their ideas.

Nevertheless, it must be considered that individuals are not able to directly control and deterministically influence organizational dynamics (Luhmann, 2002). Corporations as VCSs are not just representations of visionary ideas of self-confident and sovereignly performing top managers. The interfering impact of individuals depends on situational occurrences, on the interaction of a multitude of experiences, identities, expectations, and is determined by communication processes.

Proposition IV: Circular-sufficiency VCS reinventions begins in the minds of flexible and versatile employees

Circular-sufficiency transitions of VCSs are radical and highly uncertain projects of incumbents that gradually begin to emerge in the minds of creative and unconventional thinking individuals, whose ideas must stabilize in organizational communication and decision-making processes. The accumulation of new and situation-specific knowledge is needed amongst the employees that they attain through practical and experiential activities. Unidirectional (take-make-dispose) and unidimensional (merely in monetary terms) economic thinking and acting are deeply anchored in current value creation logics, so that circular-sufficiency VCSs cannot even be imagined. It is argued that CE-based VCS transitions start at the optimization of product functionalities or due to the modifications of product materials, e.g. recycled materials substitute the use of primary natural resources. These incremental variations may elicit a new efficiency revolution, but they do not automatically provoke the prevailing business rationales that cause the persistent problems we face. Even if changes of product configurations and value creation patterns like recycling waste into new forms of value are important for restructuring consumption and production systems, greater efforts are needed to design VCSs that flourish within planetary boundaries. But how can incumbents radically rethink their actual VCS and explore new appropriated approaches? One possible option is safe and autonomous physical “playgrounds” where there are no bans of thinking. Open spaces to imagine entirely new corporate objective dimensions. Arenas of freedom decoupled from everyday settings to test, negotiate, reflect and evaluate new game rules and course of actions in order to build up transformative knowledge assets and expertise.

Discussion and Conclusion

Through qualitative and explorative research, eight business consultants were interviewed focusing on how direct advisory agencies of enterprises narrate, frame, and draft transition processes towards circular-sufficiency value creation logics at corporate level. The introduced set of propositions proposes tentative insights for understanding patterns of circular-sufficiency reinventions; identify contradictions and shortcomings of CE narrations in real-life contexts; and highlight future research directions.

VCS conceptions must go beyond efficiency and consistency strategies to address the challenges of the anthropocene. No question, “what is truly required to reduce environmental impact is less production and less consumption” (Zink & Geyer, 2017: 600). But how does this insight influence enterprises in their everyday routines, in their assumptions of economic activities? Obviously, circular-sufficiency transitions of VCSs are radical and highly uncertain projects representing a black box, not only for incumbents and business consultancies, but also for the scientific community. The resulting state of faint shows us that there is an enormous lack of theoretical and practical knowledge about such immense processes of renovation. This nebulous uncertainty is reinforced by narrations that conceptualize and articulate CE transitions as a reactive response to stakeholder strains. We should rather emphasize the ability of corporations to proactively contribute to solutions for climate change, biodiversity loss, etc. Among other aspects, this also means further conceptual development of the stakeholder approach. A key insight from the data is that circular-sufficiency VCS transitions begin with unorthodoxly thinking and behaving employees, and not with novel product designs and business models as often highlighted in scientific literature (e.g. Moreno et al., 2016; Planing, 2018; Urbinati et al., 2017).

Among other issues, future research should focus the intra-corporate experimentation process, e.g. through case studies, ethnography and longitudinal studies, to obtain knowledge about organizational learning topics and how the above-mentioned thought and action "playgrounds" of freedom must be constructed for creating compatible and fruitful outcomes.

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Circular Economy of Plastics: Analysis of Plastic Flows and Stocks in Europe

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Keywords: Circular Economy; Material Flow Analysis; Dynamic Modeling; Stocks; Plastics.

Abstract: Plastic production is continuously growing and accumulated in the socioeconomic system. Plastic in the stock has the potential to become plastic waste in the future, contributing to waste generation or secondary plastics supply. This research applied material flow analysis(MFA) which provides one-year snapshot of the system to then build a dynamic MFA model to estimate the future plastic waste change from 1960 to 2040.

The results show that around 66.27±15.4 million tonnes(MT) plastic polymers production in the EU, and about 69.99±11.8 MT consumed across packaging(31%), construction(18%), transport(13%), electrical and electronic products(9%), textiles(6%) and other(23%) applications in 2014. The recycling rate was around 38% but only 9% of this was used as secondary plastics to produce new products. According to the stock modelling, total inflows and outflows are expected to increase in the future, which accounts for 178MT inflows and 131MT outflows in 2040. The amounts of in-use stock in this scenario continue increase and reach to 1282MT in 2040. Construction dominates the stock-in-use for a long time due to its long life span.

These results highlight the large quantities of plastics have accumulated in the societal stock and leakage to natural systems. This study provides decision-makers an evidence-based model to plan plastic circular economy strategies. Future research is suggested to combine these results of the stock model into different scenarios which can help in gaining insights about possible future outcomes of plastic circular economy strategies in the EU.

Introduction

Plastic products are omnipresent in human lives and are extensively used in different sectors. The production of the plastic is continuously growing and accumulated in the socioeconomic system. Geyer, Jambeck, and Law (2017) estimated that 8300 million tonnes(MT) plastics have been produced since the early 20th century. In the global plastic value chain, the EU plays an instrumental role, contributes to 20% of the global production and 17% of global consumption (Plastics Europe, 2017). However, large quantities of plastic materials and products have accumulated in the societal stock or leakage to natural systems, given that lifespans of plastic components vary significantly. Plastic in the stock has the potential to become plastic waste in the future, contributing to waste generation or secondary plastics supply. Transition to more circular use of plastics requires an understanding of plastic in the stock in order to project infrastructural needs for future processing of plastics and supply of secondary plastics. In 2015, the European Circular Economy Action Plan (European Commission, 2015) identified plastics as one of five priority areas for action. The European Commission (2018) has established a strategy for moving plastics towards a circular economy by 2030. The concept of a circular economy has attracted considerable business and policy attention, thus, it is crucial to assess both plastic flows and stocks. Geyer et al. (2017) estimated that in-use stock of plastics may account for 2500 MT globally, while analyses such as Ciacci, Passarini, and Vassura (2017) focused on European PVC flows and stocks. Kawecki, Scheeder, and Nowack (2018) have recently estimated plastic material flows in the EU but the analysis does not include the stocks. However, comprehensive analyses of the plastic flows and stocks at EU level are still largely missing. This study aims to contribute to fill this gap by proposing a dynamic stock model for plastics, which consider stocks and future plastic waste flows to contribute to more accurate assessment of Circular Economy opportunities for plastics in Europe. The study can also contribute to literature by providing methodological guidelines for the design of comprehensive dynamic models of future plastic flows.

The paper has been structured as follows. Section 2 explains the methodology and data collection. Section 3 analyses the results of the plastic flows and stocks. The article wraps up with discussion and suggestions in section 4.

Methodology

Material flow analysis (MFA) is a systematic approach to assess the flows and stocks through a system that is defined in spatial and temporal boundary(Brunner & Rechberger, 2016). In this study, the system boundary consists of the Europe, according to the EU-28 definition in 2014. The one-year snapshot of the plastic flows used 2014 as a reference year, while the stocks are estimated from 1960 to 2040. This plastic includes resins, plastic materials, and thermoplastic elastomers, based on the definition of the plastics polymers from the NACE rev.2 (Eurostat, 2008), and the plastic fibres are also included.

The plastic flows can be divided into four main phases, including plastic polymer and product production, consumption, plastic waste generation and plastic waste treatment. A wide range of data is needed to establish the plastic flows. Most of the data are extracted from the Eurostat databases, including statistics on the sold production, exports and imports by PRODCOM (production of manufactured goods) list, waste generation and treatment databases. The apparent consumption was calculated as: production + imports – exports. For the fraction of plastic contained in the products, the data was mainly collected from the commodity guide database established by the Swedish Chemicals Agency (2015) and other literature. The net weight per unit of plastic-containing products was collected from different sources (e.g.,Forti, Baldé, and Kuehr (2018), Amazon). The STAN software was used to do mass balance through data reconciliation dealing with data uncertainty and established the Sankey diagram.

Calculation of stocks is based on inflow and outflow characteristics. With regard to the inflows, the equation for projection of plastics consumption has been estimated from the historical data of per capita consumption(Panda, Singh, & Mishra, 2010; Plastic Insight, 2016).

The fact that plastics are embedded in different products (e.g., packaging, construction, transportation, electrical and electronic products(EEE) and other), requires considering lifespans into the calculations of the outflows for each period. The mean plastic product lifetimes are applied by estimation based on other literature (Bakker, Wang, Huisman, & Den Hollander, 2014; Ciacci et al., 2017; Geyer et al., 2017; Patel, Jochem, Radgen, & Worrell, 1998). Thus, we combined the plastic consumption data with the normal distributions of product lifetime to model the time period of the plastic products are used until they reach to end-of-life stage. The outflow depends on the delay of product discards, as shown in the equation (2), where the pdf indicates the probability density function of lifetime model, $\boldsymbol{\tau}$ is the age-cohort. The stock change over time is given by equation (3). The top-down approach is used to derive the in-use stock (see Equation (4)). The plastic stocks before 1960 are ignored in this study.

$$\mathbf{O(t)} = \int_{\mathbf{t_0}}^{\mathbf{t}} \mathbf{I(\tau)} \cdot \mathbf{pdf(T-\tau)d\tau} \qquad (2)$$

$$\frac{dS}{dt} = \text{Inflow}(t) - \text{Outflow}(t) \qquad (3)$$

$$S(t+1) = S(t) + \text{Inflow}(t) - \text{Outflow}(t) \qquad (4)$$

The proportion of plastics used in different application fields are estimated based on the annual reports from Plastics Europe. Results provide projections of future inflow and outflow of plastic in Europe. Thus, the plastic stocks in the EU up to 2040 can be forecasted.

Preliminary results

Plastic flows

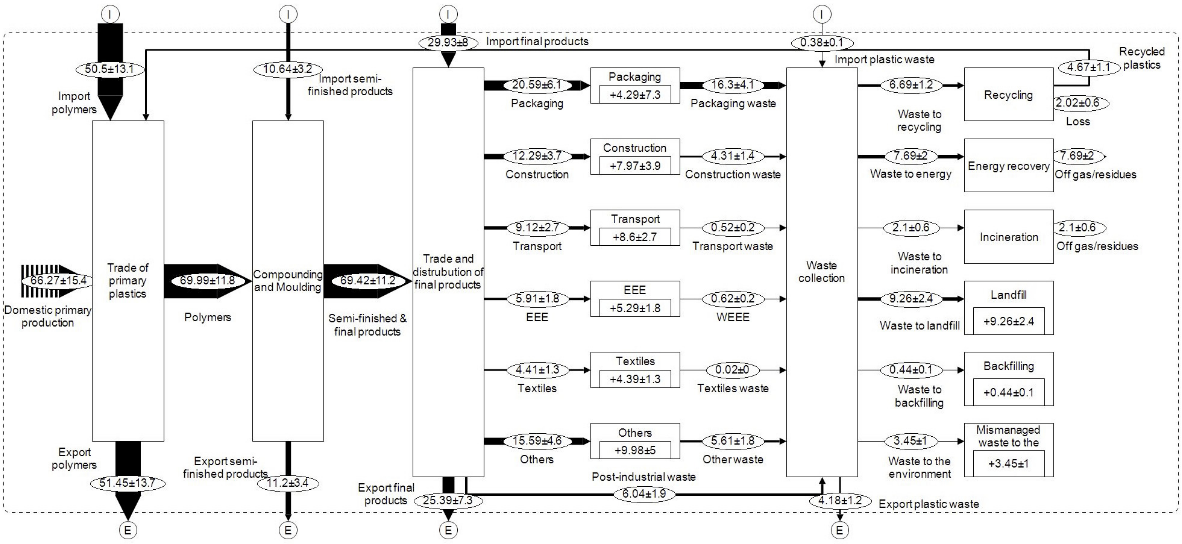

Figure 1. Plastic flows in the EU in 2014.

Figure 1 shows the results of plastic flows in the EU in 2014. The total amount of plastic polymers production in the EU was 66.27±15.4 million tonnes(MT), whilst 69.42±11.2 MT of semi-finished products and final products were produced.

The EU imported 50.5±13.1 MT of primary polymers, 10.64±3.2 MT of semi-finished products, and 11.2±3.4 MT final products, while total exports consist of 51.45±13.7MT of primary polymers, 11.2±3.4 MT of semi-finished products, and 25.39±7.3 MT final products.

With regard to consumption, 69.99±11.8 MT plastic polymers were consumed. The final products were distributed to different application fields. Packaging shows the highest consumption(20.59±6.1MT), followed by others(15.59±4.6MT), construction(12.9±3.7 MT), transport(9.12±2.7MT), EEE(5.91±1.8MT) and textiles(4.41±1.3MT).

In the plastic waste generation and treatment stage, the recycling rate was around 38% which is relatively high compared to the global rate(Geyer et al., 2017). However, only 9% of this was used as secondary plastics to produce new products (4.67±1.1MT). A significant amount of the plastic waste did not return back to the production. This includes relevant losses during the recycling process (2.02±0.6MT), around 9.26±2.4 MT entered into the landfill. Furthermore, around 4.18±1.2 MT plastic waste was exported to other countries, while a substantial leakage to environment, which has been estimated in here at around 3.45±1MT.

Plastic stocks

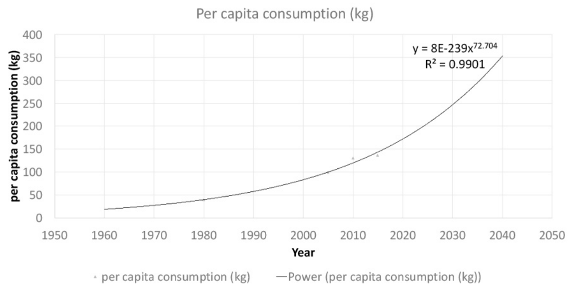

Figure 2. Projection of plastic consumption.

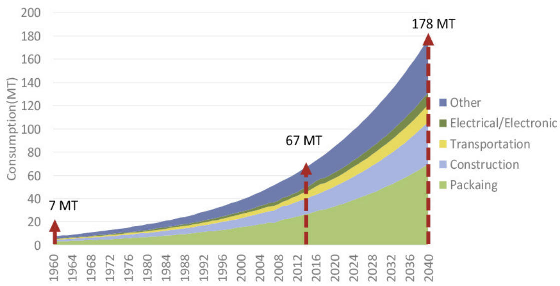

Figure 3. Inflows of plastics.

Figure 2 shows the equation for projection of plastic consumption: $Y = 8E - 239X^{72.704}$, where y represents per capita plastic consumption, while x denotes time. The $R^2 = 0.99$ shows significance between per capita consumption and time change. The plastic consumption in

this scenario is expected to continue growing until 2040.
To be more specific, the plastic consumption in Europe has increased from 7MT in 1960 to 67MT in 2014, and is expected to reach 178MT in 2040 (see Figure 3) The projection of plastic consumption here fits the range of the result from the one year snapshot of plastic flows.

Next, these inflow data combined with the product lifetime distributions for five product application areas can forecast the future waste generation and in-use stocks. Figure 4 shows the product lifetime distributions, whereas Table 1 lists the detailed mean values and standard deviation used in this study. According to our assumption with normal distributions, the means ranging from 0.6 year of packaging, to 41 years of the construction.

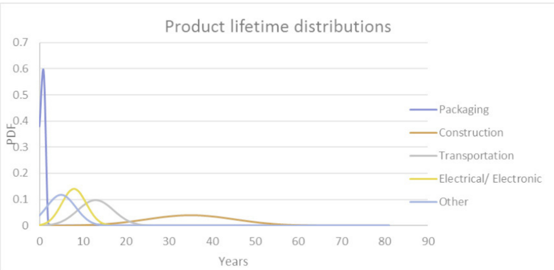

Figure 4. Product lifetime distributions.

Application	Mean (in years)	Standard deviation
Packaging	0.6	0.5
Construction	41	10
Transportation	14	4
Electrical/ Electronic	9	3
Other	6	3

Table 1. Mean value and standard deviation for estimating distribution of product lifespan.

Determining by these lifespans in different application areas, the outflows from the stock are estimated in Figure 5. In 2040, overall outflows are estimated to reach 131MT. Since there is a significant amount of the inflow of packaging and its life span is short, the outflow of packaging is expected to slowly increase, reaching to 67MT in 2040. This means around 51% of the outflow is generated from the packaging application area. The plastic packaging waste remains a significant problem in the future, if we keep extensive using plastic packaging.

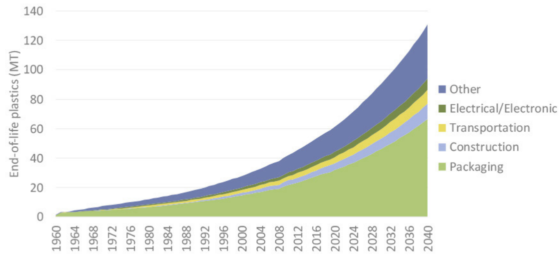

Figure 5. Outflows of plastics.

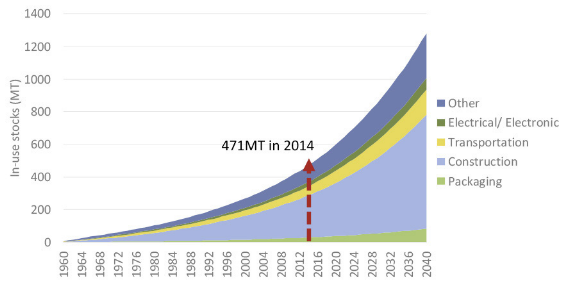

Figure 6. In-use stocks of plastics.

Figure 6 displays the change of in-use stocks of plastics over time. It is clear that the reservoir amounts of plastic will continue to increase and reach to 1282MT in 2040. Namely, the reservoirs are embedded in packaging (82,992kt), construction (698,573kt), transportation (153,937kt), electrical/electronic products (71,775kt), and others (274,540kt). Clearly, construction dominates the stock-in-use for a long time due to its long life span.

As there is no decreased of net additions to plastic stock in the past few years, the plastic in-use stock is not expected to reach saturation by 2040 consistent with Krausmann et al. (2017).

These in-use stocks need to be utilised efficiently, on the other hands, they would be future waste. If these future outflows can enter into the proper recycling system, and also create the demand for recycled plastics within the EU, these plastic waste can be reproduced to be the secondary plastics as the substitution of virgin plastics.

Conclusions

This study provides a comprehensive overview of the plastic flows and stocks in Europe. The dynamic stock model calculates the stock over time by the inflow and outflow characteristics of five application areas.

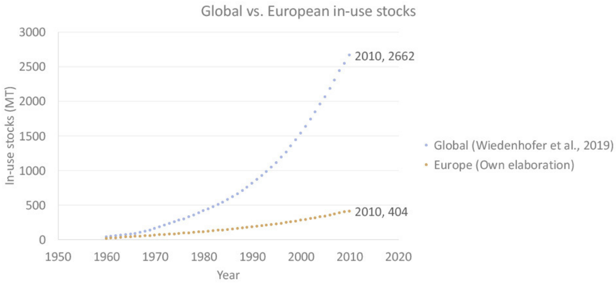

Figure 7. Comparision of global and EU level.

Comparing to the in-use stock of plastics at global level, Geyer et al. (2017) estimated that 2500 million metric tons in-use stock of plastics was accumulated globally, between 1950 and 2015, whilst Wiedenhofer, Fishman, Lauk, Haas, and Krausmann (2019) estimated 2662MT in-use stock of plastics in 2010. In this study, it is estimated that the in-use stock accounted for 404MT in the EU in 2010 and 490MT in 2015 (see Figure 7). All these studies show that the outflows are lower than the inflows, due to the extensive plastics are accumulated in the stocks.

Different from Kawecki et al. (2018), this study applied statistic data to analysis the plastic flows as a whole along the life cycle with more details regarding the possible leakages. Most importantly, this study further estimates the dynamic stock modelling which provides a prediction of future waste generation. These results highlight the large quantities of plastics have accumulated in the societal stock and leakage to natural systems. The main challenges are to reduce the leakage, utilise the stocks and recovery efficiently within the EU.

The results of this study support to further integrating stocks with plastic flows, and provide decision-makers an evidence-based model to plan plastic circular economy strategies. The next step can integrate the product level to assess different plastic products and do comprehensive uncertainty analysis. In this study, the future forecasts other relevant variables, such as per capita GDP, substitution, technology change, and policy change, are as yet not included. Hence, future research is suggested to combine these results of the stock model into different scenarios which can help in gaining insights about possible future outcomes of plastic circular economy strategies in the Europe.

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Product Lifetimes And The Environment

Transforming Berlin towards a Community-led Circular Economy

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Keywords: Circular Economy; Community Engagement; Climate Change; Urban Metabolism; Resource Management.

Abstract: Cities have been starting to adopt Circular Economy (CE) strategies to address resource efficiency and to tackle climate change. Combining sustainability and economic ambitions, municipalities aim to make their urban systems more resilient by giving incentives for closed resource loops in areas such as food, transport or construction. To address CE at an urban or regional scale, it is necessary to take into consideration the complexity of cities including the interwoven socio-ecological processes. This article briefly discusses two concepts for the implementation of CE at city-region level and introduces the Circular Berlin project as a new approach that has a strong focus on bottom-up mobilisation and community engagement. An in-depth description of the process and methods applied in Berlin is provided to demonstrate the effects of local community mobilisation within the context of CE. The Circular Berlin project is an alternative replicable model for CE implementation at city-region level that is based on the societal production of socio-technical systems. In a period of less than two years, more than 150 different organisations have been co-creating the CE agenda in Berlin. A database of relevant CE projects and stakeholders including their resource flows has been created and an active community has been formed that is leading the way in transforming the city and its systems towards a community-led CE.

Introduction

This article uncovers some key features of CE models at urban scale and gives a detailed account of the results obtained from the Circular Berlin project including an introduction of the bottom-up approach for CE urban development in Berlin. The purpose is to provide an in-depth analysis of one urban CE approach to retrace the decision-making processes of the municipality and the actors involved. The objective is to demonstrate the benefits of a community-led approach to CE that makes the involvement of a wide range of stakeholders a strategic focus and the base for defining CE initiatives. The findings of this article are targeted at practitioners in the field and aim to close the gap between theory and implementation by providing a new role model for CE implementation at city-region level that is based on the societal production of socio-technical systems.

Cities are shifting into the centre of attention for applying CE strategies to create resilient urban systems and to promote sustainable consumption in times of climate change. Environmental degradation and the increase of extreme weather events have become major concerns that impact ecosystems, economies and communities around the world (IPCC, 2018; Lehmann et al., 2018; Trenberth et al., 2015). At the same time, the global population in urban areas grew from 30% to 50% between 1950 and 2000 and keeps on growing strongly with a prediction of around 68% by 2050 (UN DESA, 2018). Depending on whether a consumption- or a production-based attribution is used, cities cause up to 80% of the world's Greenhouse Gas (GHG) emissions (Hoornweg et al., 2011). However, studies show that the per capita levels of GHG emissions in cities are lower than the ones in rural areas at similar levels of affluence making urban living more environmentally efficient (Sattherthwaite, 2008). Additionally, cities are seen as having the best potential to address climate change mitigation for at least three reasons 1) urban authorities can set ambitious targets for emission reduction and they have certain types of responsibilities in key fields such as land-use planning, mobility or the enforcement of industrial regulations; 2) the concentration of people and industries in cities allows for symbioses and efficiencies, specifically in the energy sector; and 3) the mix of institutions and actors in cities makes the rapid spread and adoption of solutions and innovations possible that are necessary to curb GHG emissions (Dodman, 2009). Cities therefore have a key role in the sustainability challenge and in affecting the pathway towards limiting the increase of the global average temperature to 1.5 degrees compared to preindustrial levels[1].

To achieve this, municipalities are perpetually adopting the concept of CE at different levels as an opportunity for increasing resource efficiency – combining both sustainability and economic ambitions. Their aim is to create more sustainable and integrated processes to turn their cities into sustainable circular systems. Initially proposed as an approach to improve product design and to promote new business models through effective resource use, the definition of CE has undergone a transformation towards system thinking addressing complex socio-technical systems (Kirchherr et al., 2017). The same authors found that CE definitions mainly focus on promoting economic prosperity with strategies to increase environmental protection but often fall short to take social sustainability aspects into consideration. Others argue that CE is about a fundamental system change that should emphasize societal production and consumption systems (Korhonen et al., 2018). Both findings focus on a systemic transformation including the involvement of a wide range of stakeholders. This shifts the attention of CE implementation from single companies or institutional actors to large communities with the automatic need of scaling solutions to urban and regional levels.

The urgency to effectively address climate change and the conceptual diffusion are two key reasons why CE as an approach to urban resource management is gaining momentum in cities and municipalities. Yet, since the adoption of the CE concept at the urban and regional scale is a very recent field of research, many open questions have been identified. One of the most urgent research gaps is the relationship between theory and practice and the question how urban authorities implement CE to actually contribute to a sustainable society (Petit-Boix & Leipold, 2018; Geissdörfer et al., 2017). In other words, what is the best combination of CE initiatives for a city to support urban sustainability?

City-wide transition towards Circular Economy

To address CE at an urban or regional scale, it is necessary to view the complexity of cities including the interwoven socio-ecological processes and the physical, discursive, cultural, material, and organic flows that are moving in and out of the city through the lens of metabolism. The metabolism of cities brings together the physical dynamics and the social regulatory conditions that continuously transform and produce the urban as socio-ecological landscape (Swyngedouw, 2006). Focusing on materials and substances and the responsible actor-networks is intrinsically linked to the sustainability of a city in terms of resource availability and environmental protection (Brunner, 2007). Taking urban metabolism as a starting point, two concepts have been emerging that give a framework for the transition towards CE: the RESOLVE concept on the one hand and the Circular City concept on the other hand. Developed by the Ellen MacArthur Foundation, RESOLVE describes six key actions, which will help the transition towards a circular economy:

1. **Regenerate**: shift to renewable energy and materials; regenerate the health of ecosystems and return recovered biological resources to the biosphere
2. **Share**: keep product loop speed low and maximise utilisation of products by sharing them among different users
3. **Optimise**: increase performance/efficiency of a product; remove waste in production and supply chain; leverage big data
4. **Loop**: keep components and materials in closed loops (reuse, recycle, recover, remanufacture) and prioritise inner loops
5. **Virtualise**: dematerialise resource use by delivering utility virtually
6. **Exchange**: replace products/services for lower resource-consuming options (Ellen MacArthur Foundation et al., 2015). Since RESOLVE is designed to produce circular practices in businesses or the industrial sector, it focuses on the ecological optimisation of the economic system rather than on the

[1] This is the fundamental goal of the Paris Agreement that was signed by 174 states and the European Union in 2015.

complexity of urban systems. This is insufficient for addressing the transformation to a CE on the urban scale for a number of reasons: 1) RESOLVE focuses on production, rather than consumption, yet cities are centres of both; 2) land will be ignored, which is often the most valuable resource in cities; 3) RESOLVE also does not integrate the fact that infrastructure governs how resources are supplied, managed and consumed in cities; 4) finally, the scale at which resources circulate within districts, city-regions, nationally, or internationally is overlooked (Williams, 2019). In opposite to the RESOLVE concept, WILLIAMS takes into consideration the complexities of urban multi-level governance systems. In the Circular City concept, she outlines that two types of initiatives (circular and supporting) are needed to deliver cities in which resource consumption and waste are reduced, infrastructure adapted and ecosystems regenerated. Three actions are fundamental for the delivery of circular processes: **looping, regenerating and adapting**. Looping reduces resource wastage by closing resource loops through recycling, re-use and energy recovery. In cities, this may manifest for example as waste-to-energy plants, 'remakeries', grey-water recycling, or the refurbishment of buildings. Regeneration refers to the restoration of the urban ecosystem, preservation of natural capital and essential ecosystem services through the implementation of green and blue infrastructure into the urban fabric. For example, permeable surfaces, reed-beds, retention ponds, green roofs, urban farms and forests may be incorporated into the urban environment to encourage the regeneration of the urban ecosystem. Adaptation involves the planning and designing of the city to enable the renewal of existing infrastructure with minimal resource wastage. For example, through the use of flexible buildings, modular systems and meanwhile spaces. Four further supporting actions – optimisation, sharing, substitution and localisation – can be used to reinforce these circular actions (Williams, 2019). In summary, RESOLVE has limitations for the application on the urban or regional scale while the Circular Cities concept of WILLIAMS is a valid starting point for making the CE concept useful for cities and municipalities. Central to her framework is the creation of symbiotic local capital that contains natural, social, financial, human and physical flows, which are interdependent and self-reinforcing at a local level (Curtis, 2003).

Many cities in Europe have adopted CE strategies that create incentives for symbiotic local capital and therefore resemble the Circular Cities approach. In order to identify what materials to keep in closed loops in a city, local authorities are considering what materials are in high demand and create opportunities for their localised production and recovery. Applying that criteria also for cities and towns, Finland developed the first circular economy roadmap. Finland's *Circular Economy Roadmap 2016–2025* sets priorities for industrial transformation across the food, transport and logistic systems, focusing on forest-based and technical loops (Sitra, 2016). Amsterdam, Rotterdam and London have followed suit and are now applying circular economy principles as their cities' economic approach by taking into consideration the metabolism of their local materials. These strategies can be considered as top-down, meaning that governments are taking the lead towards transformation. This is an essential precondition, but „without (…) bottom-up support from the industry or the community, CE initiatives are not sustained" (Winans et al., 2017).

The Circular Berlin project developing a grass-roots perspective to CE

In contrast to the CE strategies mentioned above, there is currently no centrally coordinated approach in place in Berlin, which is typical for the city being both a state and a municipality. The CE landscape in Berlin is coined by a variety of grassroots initiatives and several decentralised testbeds including research projects. Taking into consideration these circumstances, the Circular Berlin project started as an exploratory study in the beginning of 2018 with the idea to establish a coordinated network that connects key stakeholders to have more influence on local policies and regulations in the field of CE. Circular Berlin is an open initiative that aims to support the transformation of Berlin towards a Circular City. Currently, it provides information on Berlin-based CE best practices, offers a platform for local community engagement and knowledge exchange, connects local actors and supports their growth through collaboration. The Circular Berlin project was inspired by an approach called 'Circle City

Scan' developed by Circle Economy that suggests – among others – the incorporation of the following principles:

- Stakeholder collaboration models through joint project work to understand the potential starting points for CE implementation
- Impact analysis of CE industry value chains: reviewing the current industry in the city and its possible impacts in terms of job creation, environment and added value
- Industrial Ecology methods for mapping material flows to understand potential efficiencies through the cross-sector integration of inputs and outputs

The project was subdivided in three phases:

- A desk research exploring Berlin's CE actor landscape including the analysis of existing city strategies, in which CE could potentially be incorporated as well as identifying the main CE drivers and relevant city needs
- In-depth interviews and surveys with identified actors to determine the degree of collaboration readiness and vision for a Berlin-wide CE strategy
- Initiation of a workshop series to bring the CE topic to specific sectors including food, fashion, secondary materials, and construction

Based on the existing city strategies, the main priorities identified for a CE transformation in Berlin are: product reuse, waste prevention, improvement of eco-procurement including material use, the link between CE and energy efficiency, eco-construction, food and bio waste, and place-based actions. The next step of the desk research was to identify local projects that could become part of the Berlin CE network. Initiatives were selected according to the following aspects in order to validate their maturity level of CE: design, processes, business model, waste as resource and product life extension. Then, they were mapped according to their existing material flows regarding input and output resources. This helped to identify industrial value chains at city level and enabled to link local CE initiatives and their core competencies across value chains. Altogether, 86 projects were identified that are dealing with the topic of CE. Those were further described as micro case studies with detailed information on their operation, material usage, achievements and associated partners. The analysis of the projects helped to prioritise four main industries for further focused work: built environment, textile and fashion, food and agriculture, materials and products.

The second phase used interviews and surveys as methods to inform a feasibility study about a city-wide CE approach in Berlin that aimed at:

- Understanding the current involvement of different organisations in CE practices
- Identifying the main challenges and barriers for those organisations in the context of CE.
- Gathering requirements for a centrally coordinated CE strategy in Berlin.

During the second project stage, 22 interviews were conducted and an online survey was filled in by 28 different local actors including district authorities. The main outcomes of the interviews were the desire for intensified collaboration among the CE stakeholders and an improved visibility and representation in the city. There was a strong interest in the topics of understanding city material flows that go beyond waste flows, understanding cross-industry practices, a platform within the city to promote the topic, and increased information and knowledge sharing. According to the results of this stage, the limited knowledge about the implementation of CE concepts remained the biggest challenge that also prevents innovation development in the field. The most selected answer on how to raise awareness about CE concepts was to create a demonstrator project to showcase the potentials and practical advantages of the functionality of CE.

The third phase of the project contained four sector-specific multi-stakeholder workshops. The sectors chosen were: built environment, textile and fashion, food and agriculture, materials and products as determined in the stakeholder analysis. This was the most time-intensive and significant step for the Circular Berlin project. These workshops aimed to identify current gaps for implementing CE by bringing together local stakeholders. They had the opportunity for discussion and co-created potential next steps to advance CE in each sector. Three significant points were addressed in this phase:

- Envisioning Berlin-specific industrial CE loops and identifying the necessary contribution of the stakeholders
- Identifying gaps in the current CE industry loops and defining the areas of future work for the administrative bodies and local partners
- Identifying local strategic partners and front runners who are ready to act ‘now’ to support the CE development.

The workshops attracted altogether around 150 different stakeholders including local NGOs, initiatives involved in CE industry work, open workshop spaces, academic partners, design and funding institutions, and municipality representatives. The strategic partners that helped to design the workshops were public private partnership organisations that aim to bring together the city needs and local industry development.

The key outcomes of each workshop varied by sector. The built environment and construction workshop brought the following results:

- Need for the development of a model to start using buildings more flexibly via participatory approaches
- Need for involvement of future tenants in the planning process
- Business models need to be based on life cycle analysis and life cycle models
- High demand for educational training for municipalities
- A city material database and a catalogue of secondary materials should be established using an appropriate central space

These were the key results of the second workshop for materials and products:

- Strong interest to focus on reuse / remanufacture of wood, textile, and fair-waste.
- Recycling centres should additionally generate knowledge about materials but also serve as a multiplier for CE in the city
- Proposition of a physical warehouse with pick-up area for companies for material bundling, sorting and creating an inventory

The challenges of food waste, unsustainable agriculture and alternative ways of using biomass were addressed during the third workshop with the following results:

- Many initiatives identified regarding food waste prevention but no substantial improvement
- Potential to explore the nexus of biomass and agriculture
- Lack of connectivity between food producers and consumers identified

The last workshop on textile and fashion came to the following conclusions:

- Challenges to access sustainable and circular materials
- No advanced practices on collection and separation in Berlin
- Overproduction and overstock of the global industry leading to local waste problems
- Lack of economic incentives to start production locally

Conclusions

This article provides an in-depth account of the CE activities in Berlin by summarising the results of the Circular Berlin project. It becomes evident that the agenda of implementing CE in Berlin is driven by a range of multidisciplinary stakeholders and strong engagement by the civil society. This demonstrates the effects of local community mobilisation and at the same time leads to an active base for the transformation towards a CE. Many relevant projects in different areas and on different scales are already defined or ongoing without having a centrally coordinated strategy. The approach of Circular Berlin focuses on the community-led transformation towards a CE, which can be seen as an alternative model to existing approaches for circular resource management at urban scale. Further research should address the relationship between bottom-up movements in the field of CE and the environmental dimension of sustainability as well as the replication potential of this approach.

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Towards Developing a Framework for Circular Business Model Scalability Analysis: Evidences from Fashion Retail Value Chain

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Keywords: Circular Business Models; Scalability; Fashion.

Abstract: The concept of circular economy and circular business models have received increasing attention in recent years, especially when it comes to innovation and implementation. The scalability aspect of these models is however less explored. This can also be seen in one off the world's most resource draining industries; the fashion industry. In recent years circular economy has frequently been mentioned in sustainability reports and new business models have emerged. This paper aims to create a framework that can be used for further analysis of scalability of circular business models in the fashion industry. To do this we draw on the literature on business model scalability and apply learnings form these papers to a CBM context in the fashion industry. Through a systematic literature review of 25 articles, we find three different themes of scalability: central strategies, supporting activities and required resources. In this paper, we have further explored the central strategies and their different orientations, namely growth, connection, efficiency and adaptability. The implications of these findings are discussed in relation to circular business action points as stated by 94 fashion companies, and reported in Global Fashion Agenda report. Further research is needed to elaborate these themes for understanding scalability of circular business models in the fashion industry, explore the underpinning logics, and prescribe a comprehensive framework on its basis.

Introduction

The concept of circular economy and circular business models (CBMs) has received increasing attention in recent years. Despite this, the logics underpinning the scalability aspects of these models are still lacking (Pal & Gander, 2018). In the linear economy, scalability often builds on the logic of economy of scale in production where the unit cost decreases as volume increases. In circular economy, production is decoupled from consumption (Stål & Corvellec, 2018) in that value can be created without ending up in a take-make-dispose system. The concept of value creation, thus get a wider perspective, which may affect the scalability of these business models (Pal & Gander, 2018). Further study is therefore needed to explore what types of scaling logics apply to CBM, and if new logics need to be developed to fit the requirements.

The fashion retail industry, being one of the world's most resource draining and environmentally stressing industries, has in recent years adopted CBMs at a greater scale. The mention of circular economy and circular business model can be seen in several sustainability reports (Stål & Corvellec, 2018; H&M Group, 2018) and examples of companies engaged in resale of used clothes, take-back services, renting or sharing platforms can be found (Pal, 2017).

Even if many are successful, these are often small-scale initiatives that will not have a large effect on the economy as a whole. The reason for this is in part due to barriers and challenges such as lack of consumer acceptance and absence of regulatory or technical support (Franco, 2017). The "fast-fashion"-focus and functional limitations that the fashion industry offers also add to the complexity when creating and capturing value from CBMs (Stål & Corvellec, 2018; Pal & Gander, 2018).

Knowledge regarding how to overcome these barriers and the underpinning logics for scaling CBMs in the fashion retail industry is still lacking. This could be another reason for the low degree of scalability that we see. Even though a recent report by the Global Fashion Agenda ("*2020 Commitment - Status Report*"

2018) highlights many action points for transitioning the fashion industry towards circularity, there is a lack of a scientific elaboration of these practices.

The purpose of this article is to create a better understanding of how CBMs can be scaled. In order to do this, basic assumptions of different scalability strategies and processes in the literature have been studied.

Method

The paper is based on a systematic literature review (SLR) where papers relevant to the subject of business model scalability were identified and analysed.

The body of literature on scalability of business models in the fashion industry, as well as scalability of circular economy and CBMs, was found to be quite limited. To deal with this limitation, the literature review was widened to cover business model scalability in general (e.g. not limited to a specific industry or context).

A literature search was carried out using Scopus database and the search words "business model" and "scal*" in title, key words or abstract. This search gave 269 papers. After further review of abstracts and in full text, 25 papers were identified that were relevant to the research subject.

In order to analyse the data an inductive method building on thematic coding, as described by Flick (2009), was used. The papers were summarised with focus on scalability, after which the information was coded by all three authors and structured into different themes guided by a process perspective adapted from Van de Ven (1992). In the next step cross analysis was performed to look at patterns within each theme. This was done by one of the authors by using different colour schemes to group similar findings to build clusters. From these clusters the central strategy orientations emerged iteratively through discussion with the other authors.

The findings from the SLR were then applied to a CBM context from the fashion industry. To do this a report from Global Fashion Agenda has been used (Global Fashion Agenda, 2018). The report includes a set of action points on circularity that 94 companies has committed to. The aim is to accelerate the industry's transition to a circular fashion system and the report therefore give a good representation of strategies currently used in the industry.

Findings

When analysing the literature we found that the strategies and processes behind scaling a business model could be categorized from different views and at different levels. Guided by Van de Ven's (1992) perspective of process, this understanding lead to three themes; *(i) central strategies, (ii) supporting activities* and *(iii) required resources*, as described in table 1. In this working paper we mainly elaborate on the central strategies and apply them to circular fashion retail.

Central strategies	The central strategies have direct causal relationship to scaling. They do not explain in detail how scaling is done but map out a direction.
Supporting activities	Supporting activities help the central strategy to be realized. These activities are more detailed and can either be a sequential process, or an individual action.
Required resources	Required resources are fixed entities that a business needs to be able to scale.

Table 1. Definitions of the themes.

When analysing the central strategies, four distinct strategy orientations emerged; *(i) growth oriented, (ii) connection oriented, (iii) efficiency oriented* and *(iv) adaptability oriented.*

The growth oriented strategies revolve around a more traditional understanding of scaling as a process of growing a company in size and market share. For example, Biloshapka and Osiyevskyy (2018) argue that a constant scaling up process of the business model is the principal way to satisfy shareholders' expectation of growth. To do this they discuss increase in sales to existing customers as well as introducing new products and finding new customers as key mechanisms.

The connection oriented strategies builds on relationships between individuals and/or organisations. Building strategic partnerships and collaborations with other industry players as well as policy makers are identified as important for the scaling process (Nielsen & Lund, 2018; Ma, Lan, Thornton, Mangalagiu & Zhu 2018). Ma et al. (2018) also recognise the importance of establishing these connections early on, especially with local governments. If this is not done, it could create barriers that hinder the scaling process at a later stage. Another type of connection is made with the customers, here the literature for example discuss freemium models (Täuscher & Abdelkafi, 2018) and different type of network effects (Stampfl, Prügl & Osterloh, 2013).

There is two different efficiency oriented strategies in the literature. The first is connected to technology and how that can be utilised to automate processes for improved efficiency (Stampfl et al., 2013; Makides & Anderson 2006). Nielsen and Lund (2018) discuss another, more general area, that deals with overcoming capacity constraints. They argue that scalability can be achieved by identifying and removing traditional capacity constraints related to the specific market that the business operates in.

The last of the four orientations that was discovered is adaptability. To achieve scale, a business model should be able to adapt to market needs, which also includes identifying unmet needs as opportunity to scale (Mohan & Potnis 2010). It is also important to adapt to the customers' existing knowledge for easier adoption (Stampfl et al. 2013). Another area is adaption to different laws or policies, either when entering new markets or changing regimes in current markets (Stampfl et al., 2013).

Implications for the context of circular fashion retail

In this paper we focus on the four CBM strategies identified by the Global Fashion Agenda (2018) as tactical areas where the fashion industry need to achieve scale in the transition towards circularity. Below we will discuss these tactical areas in relation to the scaling orientations that were identified though the SLR, i.e. those related to growth, connection, efficiency and adaptability.

Design for recyclability

Designing for recyclability could be an important step toward adapting to a circular business model. Depending on the product and the business model, this could include designing for functional durability and repair to prolong the garments life, and/or designing with material recycling in mind by using mono-materials. The companies involved in Global Fashion Agenda report that the barrier they face in this area is lack of knowledge. According to the report (Global Fashion Agenda, 2018), circular economy is still a rather new concept, which means that suitable tools and training material still need time to be developed.

The strategy that the companies have to increase recyclability through design, builds on *adaptability oriented strategies*. By educating design and development teams in circular design strategies and include circularity into their design briefs, they aim to adapt their current strategies to the new context and what they believe will be the future market need. Furthermore, some companies have explored new business opportunities such as repair services. This requires a flexible organisation that can adapt to new business opportunities as they develop. In our findings, we also saw that *adaptability oriented strategies* refer to adapting the offer to customers' existing knowledge for easier adoption (Stampfl et al. 2013). This could be an important aspect to consider, since adoption will be slower if the switching cost from conventional offerings is high.

Garment collection

Building garment collection systems is another important area to achieve circularity. Perhaps it is also the CBM area in the fashion industry that has been scaled the most at this point (Stål & Corvellec, 2018). For example, in 2018 H&M collected 20 649 tonnes of garments in their take-back service (H&M Group, 2018). This is however only a fraction of new garments sold.

The companies in the Global Fashion Agenda generally follow a *growth oriented strategies* where new distribution channels are added, or already existing expanded, to reach new markets and more customers and thereby increase the collected volumes. In- store collection, where existing infrastructure is utilized, seem to be the most common practice even though other initiatives also exist. Marks & Spencer are for example exploring home collection as an alternative (Global Fashion Agenda, 2018).

In addition to this, the companies in the Global Fashion Agenda have activities involving customer engagement. These activities, as described in the report, also follow a *growth oriented strategies* where advertising and pop-up stores are used to achieve customer awareness. There seem to be an opportunity here for more *connection oriented strategies,* where stronger relationships with the customers can be built to achieve engagement. These types of activities might exist but not as well-known or well represented cases, hence not evidenced through current reports.

However, *connection oriented strategies* are prescribed when it comes to influencing legal regimes and creating a more efficient system overall. Collaboration between brands, NGOs, local authorities and other stakeholders is suggested for developing a more efficient garment collection system (Global Fashion Agenda, 2018).

Resale and reuse

Resale of clothes is not a new concept, but a new take on it is perhaps needed for the transition to CBM to succeed. The most scaled method mentioned in the report is collaboration with partners who already have the distribution channels needed. For example, H&M work with both international sorting companies and national charity organisations for the resale of their collected garments (Global Fashion Agenda, 2018; H&M Group, 2018), this shows the use of *connection oriented strategies*. Finding a suitable match would be vital for a large global company like H&M. They would need a partner able to handle the large volumes in their garment collection service as well as working with international solutions.

Other companies use *growth oriented strategies* and add resale as an additional sales channel. Seeing a positive outcome they have then expanded this channel using traditional *growth oriented strategies* such as market development and penetration. Eileen Fisher have for example set goals to increase resale by both opening a new resale store and expanding resale in their normal stores (Global Fashion Agenda, 2018).
The challenge with resale is the unpredictability when it comes to availability and quality of the collected garments. In addition, the Global Fashion Agenda report (2018) also identifies the costly handling including shipping, sorting and repair as major barriers to scale. This can be related to what we found in the SLR where Kohler (2018) for example, discusses how managing a growing crowd can lead to diseconomy of scale when each task needs specialized coordination. Even though he discuss this in the context of crowdsourcing it could be true for the resale of fashion with its high degree of customization in common. It could therefore be interesting to look more into how *efficiency oriented scaling strategies* could help this process forward.

Recycled post-consumer textile material

The last area that was identified by the Global Fashion Agenda (2018) is to scale up the use of recycled post-consumer materials. Companies report that the biggest barrier for this is that the supply of material does not meet the demand. Consequently, to find a solution to scaling up the use of recycled material the supply must first be solved. This is however primarily identified as an industry problem rather than a company problem.

Some companies have adopted *connection oriented strategies* where they identify key partners to collaborate with, or invest in, to develop and test new technology. In this way both the company and the industry at large will eventually be able to scale the use of recycled materials. However, the report also mention that regulatory incentives and further involvement from policy makers is needed.

Conclusions

This paper contributes to the understanding of CBM scalability by identifying three themes of scalability from a strategy-activity-resource perspective. From the themes we have also found four different scalability orientations that can be used when scaling business models. We have further applied this prescribed framework to a CBM context in the fashion industry.

The framework needs more elaboration along the other two themes identified within business model scalability literature. In the future, this framework could be used as a starting point, and for assistance, when locating right strategies for fashion retail business looking to scale their circular models. Another approach could be to explore the combination of the framework with the value mapping tool by Bocken, Lenssen, Short, Rana & Evans (2013) in order to investigate what values are scaled, using which scalability strategy, for multiple stakeholders. Case studies can conducted to explore these aspects of CBM from the fashion retail industry.

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Optimizing Second-hand Clothing Stores Based on Consumer Preferences

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Keywords: Second-hand Fashion Stores; Fast Fashion; Sustainable Behavior; Consumer Preferences; Sustainable Fashion.

Abstract: The use of second-hand clothing can reduce the sustainability impact of clothing. It is a prerequisite of second-hand clothing shops to attune to consumers' needs to significantly increase the sales of second-hand clothing shops. In this paper, the consumer preferences with respect to second-hand clothing shops are researched using a conjoint experiment. Four store characteristics were manipulated, namely the quality of clothing, clothing availability, warranty, and brand. The study shows that participants prefer second-hand clothing stores that offer branded clothes, offer a wide assortment of good quality clothing, and even provide consumers with a 6-months warranty. Such shops are comparable to the omnipresent fast-fashion shops. It is advised to build a brand for second-hand clothing shops, e.g. using a franchise strategy to increase the diffusion of these shops. However, the limited availability of large quantities of high-quality second-hand clothing might hinder such a diffusion.

Fast Fashion

The impact of product consumption is one of our deepest cultural fissures. The fashion industry has played a major role in this by creating the so-called fast-fashion concept. Fast fashion can be defined from an industry point of view as the selling of trendy, fashionable products that are universally affordable and continually changing (Cachon and Swinney, 2011). The supply of fast fashion requires flexible and cheap production and distribution processes. Indeed, omnipresent fashion retail chains, like H&M and Zara, sell low cost products, are very flexible in product design and excel in speed to market (Bhardwaj and Fairhurst, 2010). By building on the fast-fashion business model these companies have grown to become the largest apparel companies in the world (Caro and Martínez-de-Albéniz, 2015).

From a consumer's point of view, fast fashion is associated with relatively low product prices that are combined with an acceptable level of quality, a broad and deep assortment and the frequent renewal of collections (Gabrielli, Baghi and Codeluppi, 2013). Fast fashion has influenced the meaning of clothing for consumers. Buying clothes has become part of a lifestyle. The adoption of fast-fashion products by young consumers is motivated by their limited financial resources and by the fact that trendy and socially visible fast-fashion apparel plays an important role in socializing at this stage in their life (Joung, 2014). Unfortunately, today's treasures are tomorrow's trash (Joy, Sherry, Venkatesh, Wang and Chan, 2012). Indeed, a strong negative side effect of the constant urge to buy the newest fashion items is the discarding of items that were bought just a month before. The fashion industry, more than any other industry in the world, embraces obsolescence as a primary goal (Abrahamson 2011). This is highly unsustainable (Boström and Micheletti, 2016) as most discarded clothing is still send to landfills (Gwordz, Steensen Nielsen and Müller, 2017).

Second-hand clothing and sustainability

More sustainable consumption of products requires product longevity by the first user or through reuse (Mugge, 2017). This applies strongly to clothing. Farrant, Olsen and Wangel (2010, p. 726) showed that "the reduction of impacts resulting from collecting 100 garments for reuse range from 14% decrease of global warming for the cotton T-shirt to 45% reduction of human toxicity for polyester/cotton trousers." Clothing is often reused by being passed on to family members, donated to charity, but also by being sold through second-hand clothing shops. We will focus on shops in this paper.

Second-hand clothing stores

Second-hand clothing shops have seen rapid growth in the past decades (Giout and Roux, 2010), but they still only make up a small fraction of the clothing market. Buyers of second-hand clothes are motivated by two different motives. Either they shop for fashionable reasons, e.g. searching for highly fashionable items (unique, rare) or they shop for low-price related reasons (Williams and Paddock, 2003; Cervellon, Carey, and Harms, 2012; Ferraro, Sands and Brace-Govan, 2016). This means that consumers shop for vintage items and/or shop for what is mostly referred to as second-hand items. In the market, shops can be found that are targeted at vintage shoppers and shops that are more focused on the price-seekers. As indicated above, the fast-fashion industry is highly unsustainable. It would be beneficial if the percentage of clothing bought by consumers in second-hand stores grows significantly for sustainability reasons. However, such a growth can only be realized if consumers' demand for second-hand clothing increases significantly.

How to optimize second-hand clothing stores?

In marketing the idea is key that market success relates strongly to the ability of companies to provide products and services that fulfil consumers' needs and wants (Kotler, & Armstrong, 2010). A relevant factor towards an increase in demand for second-hand clothing therefore will be the availability of second-hand clothing shops that attune to consumers' needs and wants as much as possible. Second-hand clothing stores also need to optimize store attributes in order to be able to compete in the market. This is especially important as the fast-fashion industry has been able to create strong consumer demand by optimizing marketing elements like branding, positioning, store placement, pricing and advertising. In this paper, we will research the following question, How should second-hand clothing shops be designed to better attune to consumers' needs and wants? In doing so, we will limit ourselves to the second-hand clothing shops (and exclude shops that mainly sell vintage clothing) as we believe that a much larger effect on sustainability can be expected by an increase in sales of highly available items.

Research method

To answer our research question, we calculate the preferences of consumers for stores that vary in four relevant store variables. As indicated above, an important reason to buy second-hand clothing are the relatively low prices of items. However, fast fashion is also characterized by relatively low prices. This means that the financial advantage of buying second-hand clothing is small. Next to price, other store attributes such as product assortment, warranty, product quality, travelling distance, etc. determine consumer preference (Chernev, 2012). Research (Paulins and Geisffeld, 2003; Visser, Janse van Noordwyk and Du Preez, 2006) has shown that consumers' store preference is mostly based on the products that are sold in store (e.g. merchandise, type of clothing). Other store attributes, like availability of parking spaces, influence preference to a (much) lower extent.

Based on these insights, we define four attributes of second-hand clothing stores in this paper, namely clothing quality, product availability, warranty, and branding. We selected these four clothing store attributes because of their relevance for consumer preference. The first two variables are directly related to merchandise on offer and type of clothing. Clothing quality is a measure of excellence of the offered clothing. Product availability indicates the amount and sort of items found in store. Warranty and Branding are variables that are included because of their value in the "normal" fashion store preference. Warranty is a guarantee promising to repair or replace a product. Branding is defined by a design and a name used in order to create an image that identifies a store and differentiates it from its competitors.

A conjoint experiment

It is widely assumed that product or store preference is related to the perceived utility of a number of relevant variables, such as brand name, price, etc. Consumers are expected to make a choice for the product or store that has the highest utility. In this study, a conjoint experiment was used to assess consumers' preferences. In conjoint analysis it is assumed that consumers build their preferences by considering several attributes with different levels (Green and Srinivasan, 1990). In this research, four attributes with two levels each were used, namely brand: high-end, low-end; quality: high, low, availability: extensive, limited, warranty: no, 6 months. By combining these attributes (levels), 16 scenarios were defined that describe a second-hand clothing shop. 50 TU Delft students participated who were aged between 19 and 21, with 66% female and 34% male participants. 72% of the participants buy second-hand clothing. Participants ranked the scenarios to answer the following question; What shop would you prefer to buy your second-hand clothing from? A regression model was used to calculate the relative utility of the attributes and their levels. These utilities are expressed in terms of their relative importance: the higher the importance of a variable, the more it influences the choice of the consumer in a positive way. To conclude the experiment, participants completed an online questionnaire to assess their concern for sustainability, and preference for product uniqueness.

Results

The relative importance value (higher percentage equals higher importance) indicates how important every attribute is regarded. The results show (importance values: Product quality 21.3%; Brand 24.9%; Product warranty 29.7%; and Product assortment 24.0%) that all four variables have about the same importance value, with warranty being slightly more important. This means that the participants have roughly the same preference for these four variables; it is important that a second-hand clothing store is branded, offers a wide assortment of good quality clothing and even provides consumers a 6-months warranty.

Next, based on the questionnaire assessing participants' concern for sustainability, and preference for product uniqueness responses were clustered; cluster 1 consists of 33 participants, and cluster 2 consists of 15 participants. The only difference between these two clusters is that the value that participants attach to sustainability when buying second-hand clothing is slightly (but statistically significant) higher in the second cluster. We again calculated the mean importance values, but now for the two clusters separately. The analyses show that in general the results of the two clusters are similar. The only difference is that in the smaller cluster, participants value the availability of warranty somewhat less.

Conclusions

Our study indicates that consumers perceive all four variables relevant for a second-hand clothing store; they prefer a store that offers high quality, branded items, shows extensive availability of items, and provides consumers with an extended warranty. The results are only slightly different for the two clusters of participants that could be formed on the basis of concern for sustainability, and preference for product uniqueness.

Our results indicate that consumers prefer to buy branded products in second-hand stores. However, second-hand stores usually sell products of different brands and therefore the brands are less prominent. It is advisable that second-hand stores develop their own brand, by using a brand name and being visible on social media, thereby building consumers' trust in the store and merchandise. Indeed, at the moment a well-established brand of second-hand stores seems to be lacking as most stores are small and have a name, but not in the sense of a “brand”. Therefore, a brand, combined with a franchising strategy might be an avenue to growth in this market.

Overall, the research indicates that consumers want second-hand stores that offer propositions that resemble those of mainstream (fast) fashion stores. Only in this way second-hand fashion stores are probably able to compete with mainstream fashion stores on a much larger scale than they do now. (This of course is less relevant for the vintage clothing stores that sell more on basis of uniqueness of products.)

It is, however, questionable whether second-hand fashion stores can supply enough high quality and diverse products to satisfy large groups of consumers. Maybe a cooperation of second-hand stores with large (fast-) fashion companies is needed to really increase the availability of second-hand clothing. In this case, product quality might be an issue, since fast-fashion companies usually do not provide high quality, durable clothing. Next, it is interesting to research if a chain of second-hand clothing stores under the heading of a brand can be a good alternative to fast-fashion stores and under what conditions this can be the case.

Our study has some limitations, like the small number of mostly young participants. Other target groups should be taken into account in future studies. Next, different ways to assess consumer preferences like Likert–based items can be thought of, as the present method provides relative preferences only.

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Product Lifetime Labelling and Consumer Preferences for Product Longevity: Conceptual Model and Preliminary Findings

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Keywords: Choice-based Conjoint Analysis; Electrical Appliances; Product Lifetime Labelling, Consumer Preferences, Structural Equation Modelling.

Abstract: The article studies the influence of product lifetime labelling in the context of electrical appliances. Based on a conceptual model that combines the consumer theory of Lancaster with the theory of reasoned action, motivational drivers of preferences for product longevity are also investigated. Using choice-based conjoint analysis, experimental survey data is collected from a population-representative sample of 499 German consumers. Preliminary results from Hierarchical Bayes utility modelling suggest a decreasing positive effect of the label on purchase decisions and a deterioration of the purchase influence of existing brands compared to new brands. Preliminary results from structural equation modelling show that the preference for a long product lifetime is fostered by the positive attitude and the subjective norm towards purchasing long-lasting electrical home appliances. However, the attitude only exerts a substantial influence if it is driven by personal rather than environmental gains. It is further documented that biospheric values enhance, while stimulation values inhibit, both attitude types. Hedonic values only enhance the attitude based on personal gains. Based on the preliminary results, politicians are informed about the label's potential to stimulate the supply of, and demand for, more durable electrical home appliances. Business practitioners should focus on business models for product longevity which account for product variety and up-to-dateness, and communicate the personal benefits of product longevity.

Introduction

The past debate on sustainable consumption has focused on substituting conventional products and services with more sustainable ones, rather than on reducing consumption as such (Prothero et al., 2011). Consequently, the extension of product lifetimes has received relatively little attention in research and practice (e.g. Bakker et al., 2014; Van Nes and Cramer, 2005), despite its considerable potential for limiting negative environmental impacts (e.g. Cooper, 2010; Prakash et al., 2016). Product lifetime refers to the period from acquisition to disposal of a product, and is determined both by the consumer's willingness to keep the product in use and by the product's functional durability (Cox et al., 2013). There is empirical evidence that the lifetime of products in Europe has reduced over time. Study results from the German electrical appliance industry, for example, show that the average product lifetime of some product categories has decreased from 2004 to 2013 (Prakash et al., 2016). The main reason for replacing electrical home appliances has been technical failure (Hennies and Stamminger, 2016). As a result, improving the lifetime and, in particular, the durability of products has recently become an objective of environmental and consumer policy in the European Union (European Economic and Social Committee, 2013). One of the most discussed measures in this respect is the introduction of a product lifetime label for electrical appliances. The underlying idea is that greater transparency for consumers about expected product lifetimes will stimulate supply of, and demand for, long-lasting products (e.g. Montalvo et al., 2016; Sircome et al., 2016).

However, due to a lack of previous research, it remains largely unclear how consumers would react to the introduction of a mandatory label indicating the expected lifetime of a product. There is also a lack of in-depth knowledge about how psychographic antecedents such as attitudes and values influence purchase decisions towards long-lasting products. Addressing these research gaps, this article investigates what influence a product lifetime label exerts on purchase decisions (1st research question), and what motivational drivers precede consumer preferences for product longevity (2nd research question). The research questions are addressed using the example of electrical appliances.

Theoretical Framework and Hypotheses

Interdisciplinary Approach

For addressing the research questions, this study follows an interdisciplinary theoretical approach (see Nocella et al., 2012, for a similar approach). By combining the consumer theory of Lancaster (1966) with the theory of reasoned action (TRA) (Ajzen and Fishbein, 1980; Fishbein and Ajzen, 1975), two complementary frameworks from economics and social psychology are merged. Lancaster's well-established economic theory postulates that consumer preferences are not directed to a product or service as such, but to its characteristics (Lancaster, 1966). The theory is therefore well suited to examining decision-making processes in multi-attribute choice contexts (Nocella et al., 2012). It thus provides a sound basis for measuring consumer preferences for certain product attributes such as product lifetime. Lancaster's consumer theory is, however, less useful in explaining potential heterogeneity in preferences (Nocella et al., 2012). For this reason, the TRA is consulted, which belongs to the most prominent social-psychological theories in research on sustainable consumption (see, e.g., Joshi and Rahman, 2015; Liobikienė et al., 2016). According to the TRA, intention for a specific behaviour is determined by the attitude towards the behaviour and the corresponding subjective norm (Ajzen and Fishbein, 1980; Fishbein and Ajzen, 1975). Due to the TRA's lower predictive power in choice contexts (Sheppard et al., 1988), Lancaster's consumer theory was chosen as the main theoretical framework and enriched with elements of the TRA. Consequently, attitude and subjective norm are defined as direct psychographic antecedents of consumer preferences for product longevity. In the following, hypotheses for both research questions are developed.

Hypotheses

The studies recently commissioned on product lifetime labelling predominantly show that a mandatory label can have a positive effect on purchasing electrical home appliances (e.g. Artinger et al., 2018; Sircome et al., 2016). However, previous research suggests that consumers may be afraid of missing progress on certain product features such as design, performance or energy efficiency if they commit to product longevity (e.g. Cooper, 2004; Cox et al., 2013). Based on this rationale, the first hypothesis is formulated as follows:

H1 The positive influence of a product lifetime label on purchase decisions for electrical home appliances decreases with an increase in product lifetime.

Consumers rely heavily on brands when assessing the durability of electrical home appliances at the point of purchase (Cox et al., 2013). It is therefore argued that the introduction of a product lifetime label can lead to a reduction in quality signals conveyed by existing brands. New brands, however, may remain unaffected as they have not yet been able to build trust in terms of durability. The following hypothesis transfers this logic to the choice context:

H2 The introduction of a product lifetime label negatively affects the influence of existing brands − compared to new brands − on purchase decisions for electrical home appliances.

In line with the theoretical framework, it is reasoned that consumers' preference for a long lifetime of electrical home appliances is determined by their positive attitude and subjective norm towards purchasing long-lasting electrical home appliances. Moreover, consumers may be motivated by two different types of potential gains when purchasing long-lasting products: personal gains, such as saving money (e.g. Brook Lyndhurst, 2011; Maitre-Ekern and Dalhammer, 2016), and environmental gains, such as protecting resources (e.g. Cooper, 2010; Prakash et al., 2016). The hypotheses are thus phrased as follows:

H3a The positive attitude towards purchasing long-lasting electrical home appliances based on personal gains positively influences the preference for a long lifetime of electrical home appliances.

H3b The positive attitude towards purchasing long-lasting electrical home appliances based on environmental gains positively influences the preference for a long lifetime of electrical home appliances.

H4 The subjective norm towards purchasing long-lasting electrical home appliances positively influences the preference for a long lifetime of electrical home appliances.

To gain deeper insights into the underlying motivational structure of consumers' preference for a long lifetime of electrical home appliances, the values of consumers are also examined. Studies on pro-environmental and prosocial behaviour predominantly conclude that self-enhancement values inhibit, whereas self-transcendence values enhance pro-environmental and prosocial attitudes (e.g. Jacobs et al., 2018; Schwartz, 2010). As explained above, the attitude may be driven by personal and environmental gains, which reflect similar individual interests as self-enhancement and self-transcendence values, respectively. Furthermore, the following hypotheses account for Steg et al.'s (2014) empirical distinction between two value clusters each for self-enhancement values (egoistic and hedonic values) and self-transcendence values (biospheric and altruistic values). Furthermore, due to the specific nature of the environmental consumption behaviour in question, it is reasoned that stimulation values are by nature likely to undermine activities that aim for long product lifes. Consequently, three sets of hypotheses are formulated:

H5a Egoistic values positively influence the positive attitude towards purchasing long-lasting electrical home appliances based on personal gains.

H5b Hedonic values positively influence the positive attitude towards purchasing long-lasting electrical home appliances based on personal gains.

H6a Biospheric values positively influence the positive attitude towards purchasing long-lasting electrical home appliances based on environmental gains.

H6b Altruistic values positively influence the positive attitude towards purchasing long-lasting electrical home appliances based on environmental gains.

H7a Stimulation values negatively influence the positive attitude towards purchasing long-lasting electrical home appliances based on personal gains.

H7b Stimulation values negatively influence the positive attitude towards purchasing long-lasting electrical home appliances based on environmental gains.

Figure 1 summarises the hypothesised relationships within a conceptual model developed to explain consumers' preference for a long lifetime of electrical home appliances. All hypotheses of this study are tested empirically by means of choice-based conjoint analysis and structural equation modelling.

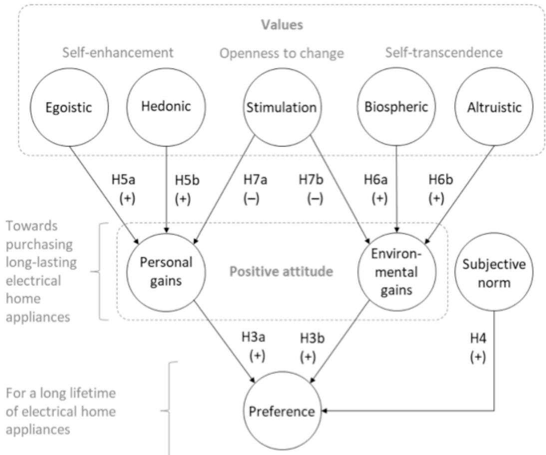

Figure 1. Conceptual Model.

Methods

Using choice-based conjoint (CBC) analysis, experimental online survey data was collected from a population-representative sample of German consumers. The respondents were recruited via an online panel in May 2019. After the deletion of speeders, a total of 499 usable questionnaires remained for subsequent analyses.

In consumer research, conjoint analysis refers to a bundle of multivariate methods used to examine the structure of consumer preferences for combinations of attributes that form products or services (Rao, 2014). The consumer theory of Lancaster (1966) provides a theoretical framework for conjoint analysis. The fundamental principle of traditional conjoint analysis is to decompose a consumer's overall preference judgments for multi-attributed alternatives into separate attribute-specific utility values (Green and Rao, 1971). Instead of analysing preferences expressed by rating product or service profiles, the more recent CBC analysis examines stated choice data collected under hypothetical purchase decision scenarios. CBC analysis is considered more realistic than rating-based techniques. The process of making trade-offs among competing attribute level combinations and of choosing the most preferred alternative is closer to actual market activity (Rao, 2014). CBC analysis is currently considered the most widely used type of conjoint analysis (Sawtooth Software, 2017). A computer-assisted CBC questionnaire was designed for each of two consecutive CBC exercises to compare consumer preferences before and after the introduction of the product lifetime label. For each choice task, respondents were asked to choose one out of three washing machines that differed in their levels of a number of attributes. The attributes chosen are price, brand, energy consumption, equipment version and, only for the second CBC exercise, the product lifetime label.

To analyse the stated choices, Hierarchical Bayes (HB) utility modelling was used. It is considered the state-of-the-art approach in analysing CBC data since it accounts for heterogeneity in respondents' consumer preferences by estimating individual-level utilities (Orme and Chrzan, 2017). In addition, the conceptual model (see Figure 1) was tested using structural equation modelling.

Preliminary Findings

The primary objective of this quantitative, population-representative study was to explore the influence of a mandatory product lifetime label on purchase decisions for electrical appliances. By testing a conceptual model built on the consumer theory of Lancaster (1966) and the TRA (Ajzen and Fishbein, 1980; Fishbein and Ajzen, 1975), motivational drivers of consumers' preference for a long product lifetime were also investigated. Based on CBC analysis, two HB utility models and a structural equation model were estimated. The preliminary results based on HB utility modelling indicate a strong positive, but decreasing effect of the product lifetime label on purchase behaviour. They also suggest that introducing such a label leads to the purchase influence of existing brands becoming less favourable compared to that of new brands. Furthermore, the preliminary results based on structural equation modelling indicate that the preference for a long product lifetime is fostered by a positive attitude and a subjective norm towards purchasing long-lasting electrical home appliances. However, such an attitude only exerts a substantial influence if it is driven by personal rather than environmental gains. It is also documented that biospheric values enhance, while stimulation values inhibit, both types of attitude. Hedonic values are found to only enhance the attitude based on personal gains.

Based on the preliminary results, politicians are informed about the label's potential to stimulate the supply of, and demand for, more durable electrical home appliances. Business practitioners should focus on business models for product longevity which account for product variety and up-to-dateness, and communicate the personal benefits of product longevity.

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Circular Society – From a Self-Destructive to a Self-Sustaining Metabolism

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Keywords: Metabolism; Value Creation; Innovation; Obsolescence; Circular Society.

Abstract: The current SCP (SCP) create value by externalising costs, overusing natural resources and depriving future generations of their livelihoods. A major driver is the reductionist definition of value and innovation that creates a reinforcing surrounding for the constant and accelerated production of economically successful novelty, i.e. new products and services. . Circular Economy practices provide a solution to overcome resource scarcity and environmental crises but stick to the existing economic value creation system and innovation paradigm. Based on a thorough characterization of the self-destructive metabolism of current SCP the paper outlines some basic ideas on a more holistic, socially sustainable version of the Circular Economy: The Circular Society.

Introduction

Technology-driven interferences into nature and society have let to transformations that threaten to extract humanity of its natural livelihoods. These transformations are characterized by such complex and multi-levels interrelation and interactions that they might reach beyond human understanding and control. At the same time current sociotechnical regimes support an economic paradigm whose logical grounds are astoundingly simple. On main assumption is that nature can be both, a generous donor of cheap resources for humanity and a humble drain for all its residual emissions and left-overs. Taking the example of a smartphone, this paper starts with an exemplification of how the pretended value creation in modern systems of production and consumption is accompanied by a constant creation of damage, both ecologically and socially. The paper argues that a main requirement for the creation of transformation knowledge – i.e. knowledge on how to solve these multifaceted problems and foster a more sustainable production and consumption – is to enrich the system knowledge on how humanity "got into this mess". Based on theoretical reflection and exemplified on empirical cases an outline of a cultural theory is presented that mainly evolve around the dialectical relation between obsolescence and innovation.

Based on this holistic understanding the paper offers an alternative view on the role of a circular economy approach to transform current systems of production and consumption.

The mindset of the linear economy and its self-desctructive metabolism

A central cause of current environmental problems and scarcity of resources lies in the linear logic that characterizes global production and economics today. Linear logic, that means: Resources are taken from nature and earth and processed and used in such a way that they can't be returned to natural cycles and usually pollute nature in the form of waste or emissions (from waste incineration). An example: Smartphones are now ubiquitous and an almost natural part of everyday life. There are now 57 million smartphone users in Germany, which is almost 80% of all citizens (Source: Statista and Bitkom). On average, a new device is purchased every two to three years, whereby the usage time can vary greatly depending on the user: Some people use their devices for up to 9 years, others exchange them at least every year (Jaeger-Erben / Hipp 2017).

If one traces the "life" of a smartphone from "birth", ie the production over the trade and the usage time to the end of life at a landfill or in the recycling, then not only a value creation, but also a substantial "damage creation" can be determined along the so-called value chain (among other things Hütz-Adams 2002).

In business and politics, the so-called value-added chain is often talked about when it comes to the production of consumer goods. The idea is that by processing resources into a marketable product, a value can be created that can be quantified in monetary terms, that is, in hard cash and thus in profit. At the time of sale, the value is the highest, it decreases continuously with the use. After the purchase, the new owner can no longer sell the product at the original price. Even for consumers, a new product often has a greater value, not only financially, but also ideally: new is often valued more than old. At the end of the life cycle, the value is destroyed, the product is dumped, incinerated or, at best, recycled. The value for manufacturers and consumers is thus approaching zero again. It does not take into account that, in principle, the resources in the product, even before they have been used to manufacture the product, and after the product has reached the end of its life, are in principle very valuable. Especially if they occur rarely or in small quantities and the stock is slowly coming to an end. Against this background, it is particularly fatal that there is still no established material cycle for electronics, which allows the recycling of the built-in materials in a confined space.

The fatal thing about the harmful effects of a product life is that it does not return to zero at some point, just like the value added. The damage caused by the destruction of the environment, the overuse of resources, the social and health consequences of production and disposal remain for a long time to come, and some are even irreversible. The following figure shows this graphically.

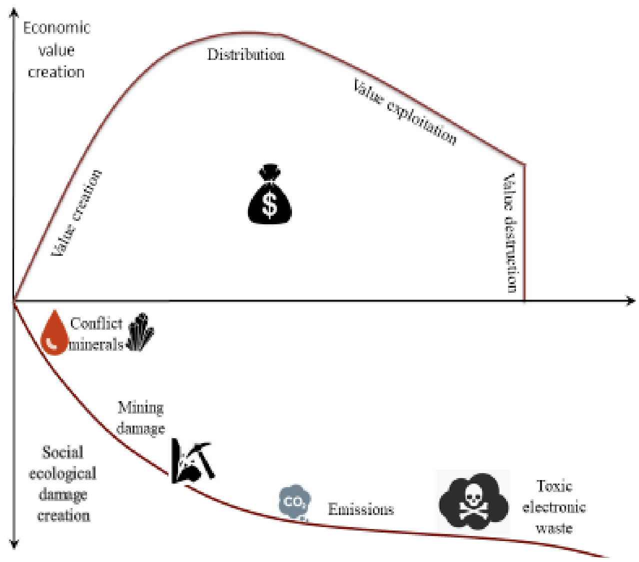

Figure 1. Value creation vs. damage creation in the lifecycle of a smartphone.

Thus, the damage creation outperforms the value creation immensely and the long term ecological and social effects of for example chemical water pollution from Indonesian mines or the burning of electronic waste in Agbogbloshie are still far away from being fully understood.

The current systems of production and consumption have evolved into a self-destructive "waste metabolism" where flows of resources, materials and energy are organised in formations of take-make-dispose-chains that in the long run devastate the society-nature-relationship.

We describe the relation between the current system of consumption and production and the overarching ecosystem as a metabolism to highlight the paradoxical nature of our current situation. A metabolism consists of interrelated dynamic processes and flows of matter and energy, which is life sustaining and self-regulating. The human metabolism, for example, processes food to produce energy and reproduce cells. It keeps the body in homeostasis. But sometimes it happens that metabolic responses become self-destructive: A critically ill body provokes adaptive reactions in such an exaggerated way that a metabolic self-destruction is triggered. Similarly, the take-make-dump-chains in the industrialised market society consume and transform matter in such a way, that the ecosystems reactions are likely to destroy the whole organism.

The fatal cause of the evolution of a self-destructive metabolism is an unholy alliance of three force that characterizes today's global SCP;

1) Reductionism and one-dimensionality in the definition of value
2) Externalisation and imperialism in the creation of costs and damages
3) Non-reflectivity and path-dependency in economic practice and progress

Reductionism and one-dimensionality in the definition of value

The linear economic model sees nature above all as a supplier, which provides cheap raw materials for the production of the "real" value in the form of a product. The raw materials themselves have a certain value, because they generate costs when they are extracted or purchased. In the case of finite resources such as gold or oil, however, this does not take into account how nature has created this value within the framework of processes that are sometimes millions of years old and that this value can hardly be restored to this form and to that extent (Dunn 1993). The ever-increasing rates of natural and even finite resource extraction (UNEP 2016, 2013) are more evidence that this fact is neglected.

In the further course of the value creation process, nature and the environment play a more indirect role: production, trade and eventually the use of the product cause an increasing amount of emissions that are brought into the atmosphere and hydrosphere. The smartphone manufacturing alone consumed 968 TWH of energy between 2007 and 2016 (Jardim 2017) mostly generated by finite resources with the associated emissions. These "externalities" are usually not “priced in”, i.e. neither manufacturers nor consumers have to pay for pollution and littering. Thus, the assumption behind that is that natural systems can permanently act as a generous donor of cheap resources and a humble sink of emissions and waste from production and consumption. But these “services” and the associated damaged are not valued, not even in monetary terms. There are some efforts to estimate the so called “ecosystem services” monetarily, but these evaluations stick with an economic perception of nature and ecosystem that mainly are of value if exploited.

Imperialism and externalisation in the creation of costs and damages

The previous considerations are primarily related to the natural environment, but the damage assessment also represents social consequences and damage in all phases of (economic-monetary) added value. The exploitation of people in the production process, endangering the health of those who reduce the raw materials processing or processing the electronic waste under questionable conditions - these externalities are also tolerated or ignored (Lessenich 2016, Amnesty International 2016). The assumption behind this is therefore analogous to the assumption of cheap available nature (resources): "Human labor and psychosocial health are available cheaply and may be consumed." Another fatal assumption relates to the distribution of value created and damage done globally and unevenly distributed along the value chain. On the one hand, raw materials are mined mainly in countries of the South, for example on the African continent, but the resulting products benefit mainly consumers in industrialized countries in the northern hemisphere (Brand/ Wissen, 2018, Ortega/ Ulgiati 2004). And the profits from the extraction and trading of raw materials are also distributed extremely unequally within the raw material-producing countries if they are not already generated by a globally operating company and do not stay in the country at all (Oxfam International 2018/ 2015). So, the value of the product and its value in the product benefits only very specific people and groups of people, while others suffer considerable harm (Amnesty International 2016). For example, child labourers in Congolese cobalt mines inevitably suffer this damage, but often unwittingly, in order to earn at least a little money. That is, they also receive some profit, but wage and employment are a very short-term and fleeting value, while the damage to health and psyche and to child development is long-term. Organizations such as Amnesty International have, inter alia, closely monitored and interviewed the workers in Cobalt Mines in southern Congo, and noted a plethora of human rights violations, such as child labour, physical exploitation and ill-treatment, in addition to an almost total absence of protective equipment and clothing in and around the mines (Amnesty International 2016). Thus, there seems to be a more radical connotation to the last assumption, that supports the linear economic model and it reads: "some people (groups) are worth more than others.", Because they can use and consume more resources, benefit more from value creation processes and Satisfying their profit or consumption needs is worth more than the health and well-being of others. Brand and Wissen (2018) describe this as the “imperial mode of living” of global elites whose consumerism is mainly based on maintaining a global divide between those who mainly take and those who mainly give.

Non-reflectivity and path-dependency in economic practice and progress

Many stakeholders now - including business representatives (WTO 2011, WEC 2015) - are quite clear that the assumptions mentioned before are actually mistakes and that humanity deprives itself of its natural basis of life in the long term.

The sociologist Ulrich Beck has described this insight and the resulting reactions and activities for the reduction of environmental damage with the term "reflexive modernization" (Beck 1996). This means that the modernization of society through industrialization, technological development and economic growth brings with it consequences that are increasingly visible in their fatality and threaten progress and modernization in itself. So, in its future development, society must first and foremost focus on limiting the current losses of its past development. The linear growth model has thus become a vicious circle.

But reflexivity is not the same as reflectivity. Trying to minimize or compensate the damage does not get to the root of the damage. Changing the mind-set of the current linear economy is not only a cognitive work, it is inscribed into globally distributed, highly connected and complex material infrastructures and supply chains, which creates an enormous path dependency. This can be exemplified by the deep connection between innovation and obsolescence. Today's interpretation of innovation is mainly due to the economist and political philosopher Joseph Alois Schumpeter. Starting from the question of which essential factors make economies more dynamic, Schumpeter diagnoses that there is only one primary driving force that drives economic development: the process of 'creative destruction' by the creation of novelty. He said, "The fundamental drive that sets the capitalist machine in motion is the new consumer goods, the new methods of production or transportation, the new markets, the new forms of industrial organization. ... a process that incessantly destroys the old structure and unceasingly creates a new one" (Schumpeter 1947: 137 f., translation by author). This kind of dialectic force has become independent and got accelerated. The old is regarded as an attribute of backwardness, antiquity, and dispensability. The notion of innovation has become the main promise of unprecedented human progress (Gronemeyer, 2000), it marks the dominance of the new over the old, the hope of unimaginable possibilities. "The new wants to be ... not an option, but a necessity that excludes everything else" (Liessmann 2000: 8, translation by author). This strive for innovation and the superiority of the new against the old is driven be a constant production of obsolescence. The premature obsolescence of the “created values”, i.e. consumer goods and products, is a central mechanism in these formations. Obsolescence and innovation are interdependent processes that are constantly reproduced in social practices of valuation and devaluation, of highlighting and neglecting, of overprotection and dilapidation. Obsolescence is a major condition of innovation, and the modern societies’ constant strive for innovation in turn creates an abundance of obsolete materials.

Thus, a major condition to overcome path dependencies would be to change current innovation regimes and the material and communicative practices of how value is created.

Circular Society – a vision for a self-sustaining metabolism

A decarbonisation and dematerialization of the current system of consumption and production seems inevitable if livelihoods of present and future generations are to be preserved. A much-discussed concept for designing a sustainable economy is the Circular Economy. It intends the cyclical and cascading use of products and materials following the principle of circularity of ecosystems. Economic thinking and action should aim to keep extracted natural resources in use as long as possible and to preserve the maximum value of products through reuse and recovery strategies. The main objective of the concept is to decouple economic value creation from nature degradation.

So far the Circular Economy approach has mainly been conceptualized as an ecological modernization project of the economy to increase natural resource efficiency. Circular business model development, supply chain management, circular product design and the adoption of new digital technologies are primarily considered as enablers for a transition to more ecologically sound ways of living, manufacturing, and consuming. But progress measures are still mainly focused on creating monetary value. Circular Economy thinking so far strives to overcome resource scarcity and environmental crises but sticks to the current economic value creation system and the current innovation paradigm that mainly focus on new technological and economic inventions and new types of products.

But ecology and social issues must be considered equally, both when it comes to a comprehensive analysis of the damage creation and to the establishment of a sustainable economic model that also overcomes the other forces in the unholy alliance: Reductionism and externalisation/ imperialism.

While the distinct focus of Circular Economy concepts is to solve the ecosystem damage of current systems of production and consumption, their social damage remains a blind spot. Thus, greater efforts are needed for a transition towards solidary, inclusive and open societies that flourish within planetary boundaries. In addition to the strategies and patterns of the Circular Economy already discussed, we need solutions that proactively broaden the definition of value to a multidimensional and holistic construct, where society and nature flourish in balance. Therefore, the transition is not mere a question of new business models or consumer choices, but requires a fundamental reorientation and reorganization of practices and processes in all areas of life - from nutrition, mobility, energy use to work models and housing concepts. Our proposition is to frame this holistic version of Circular Economy as the 'Circular Society'.

The principles of the Circular Society draw back to the roots of circular economy thinking where a system perspective was prevalent, that considers the complex ways in which nature, society and technologies are interdependently interacting on a local, regional and global level. The target of the first circular economy thinkers was to create a resilient system taking the need for regeneration of natural capital into account. This emphasis needs to be broadened to take the "social capital" and the resilience of societies, locally and globally, into account. The balance of techno- and ecosphere that are mainly focused in circular economy approaches need to be complemented by the sociosphere.

On the one hand, the focus is on the question of how economic action can consistently and exclusively serve social well-being and how circular economy strategies, models and methods can be combined with the human pursuit of meaning, community, effectiveness and quality of life. On the other hand, it deals with the question of how society can be "circularized", that is, what society can learn from the basic principles of the circular economy. The term "sociosphere" refers generally to all human spheres of life and the cultural practices and social relationships found therein. It is used, among other things, in geographic research to distinguish the sphere of human activity as a cultural earth sphere from more natural spheres, such as the lithosphere (the stone shell of the earth). Here we use the term not only in this descriptive sense (marking the area of socio-cultural action), but also to emphasize some normative aspects, that is, aspects oriented to a particular value or goal.

A core idea is to replace prevalent principles and meanings of economic practice by alternative narratives, which are rooted in current discourses on social sustainability, sustainable development, social justice and solidary quality of life. The following principles are proposed to form the core of the Circular Society:

Accessibility and transparency can be seen as central prerequisites for participation in the social and economic practices of a Circular Society. These include both access to natural resources and land or housing, as well as to education and health services and consumption and production processes. Knowledge is not monopolised but accessible and can be shared; political and economic action is subject to the duty of transparency. *Democratization and empowerment* should create unconditional opportunities for participation and engagement in political, economic and cultural processes. Participation opportunities are linked with strategies for activation, capability boosting and empowerment. Production processes are supposed to be accessible and participatory allowing consumers to co-create the satisfiers to their needs. These prerequisites can foster *communality, collaboration and solidary practices*. The guiding principles for social relations in a Circular Society are communication, collaboration, social trust and reciprocity. Nature and culture are jointly managed as 'commons' that is, as a common heritage, and it is negotiated on an equal basis, which economic, political or cultural action can be regarded as adequate against the background of intra- and inter-generational justice. This can provide a fertile ground for *social innovativeness and creativity*. Experimental and creative spaces are provided to try out different, local solutions to sustainability challenges and to foster the emergence of political, economic and cultural innovations. The experimental spaces enable people to experience self-efficacy and thus the ability to proactively face new challenges.

Conclusions

The Circular Society still is a sketchy idea. The term and the conceptual ideas behind it are supposed to push the discourse on Circular Economy further and embed it more thoroughly in research and action for social-ecological transformation. It should highlight that the principle of linearity in consumption of nature is so deeply rooted in the economic structures and lifestyles of industrial societies that the mere introduction of new business models or changes in consumer disputes will not solve the socio-ecological crisis.

There are many good ideas, examples and a number of political, economic and civic actors who promote circular thinking and action.

The open source movement, solidary economy, commons-based peer production, collaborative consumption, micro-energy cooperatives, eco-villages and co-housing projects… there is a growing number of cases where the aforementioned principles are put into practice.
The idea Circular Society aims to establish a participatory, solidarity-based and circular consumption and production system as a possible fruitful and encouraging framework within which these initiatives can flourish. But it can also mean a major material loss for industrialized nations concerning comfort, status (through material possessions) and the seemingly endless consumption options that might get lost. It also means a significant loss of power for those who benefit excessively from today's linear economic structures, while others, formerly niche players, are becoming more important, such as cooperative initiatives for self-production, circular enterprises and communities of use.

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Engaging with the General Public on Critical Raw Materials through the Medium of Electronics Repair Workshops

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Abstract: The issue of Critical Raw Materials (CRMs) and potential interruptions to their supply and availability due to concerns such as shortages, trade restrictions or geopolitical considerations are topics that are relatively unknown to the general public. Education and the dissemination of this information amongst the general public has been promoted as a key factor in addressing this and enabling the transition towards a circular economy. By and large, the general public are unaware of the existence of CRMs, their importance in our world and how they contributes to this issue. Educating people about these issues is one way to redress this shortcoming in modern society.
Electronic repair events, repair cafés and repair workshops have been gaining momentum at national and international level as a means of addressing the perceived waste inherent in the current linear consumption model. Repair events have existed for quite some time throughout Europe and around the world. When considered in conjunction with the problem of CRM education, they provide an innovative and novel platform for the dissemination of knowledge and the education of the general public on CRM issues.
However, at present electronic repair events and workshops lack the capacity or knowledgebase to educate the public about complex issues such as CRMs and their importance. Raw Engagement for Electronics Repair (REFER) is a KIC Raw Materials project that seeks to address this gap and use platforms such as electronic repair workshops to educate the general public and the wider society about CRMs through engagement in such events.
The project will host 60 Restarter Party events across 6 different E.U. member states, engaging with up to 6,000 members of the general public directly on matters of repair, re-use and CRM importance. A set of educational resources has been developed to support these engagements and related referrals through social media, word-of-mouth and website interactions.

Introduction

Nowadays, the world is experiencing an ever-increasing demand on its finite resources such as CRMs, in line with increasing global demand for consumer electronics.
For the European Union (EU), CRMs are materials assessed to have a high risk to supply while being important to the EU economy (EU Commission, 2019). In 2011, the EU released its first list of 14 CRMs, which has grown to include 27 materials in its third iteration in 2017, including rare earth elements.
These CRMs are considered to be of paramount importance to a modern, technological society and potential supply interruptions due to geopolitical issues, trade restrictions, unsafe working environments or other factors would be very disruptive to both the economy and the society which depends on them.
CRMs are crucial to the European economy and essential to maintaining and improving the quality of life of its citizens going forward. For the general public, the quality of life which people have come to enjoy and the enabling technologies and devices which support this are all reliant on access to a growing number of these raw materials in ever increasing quantities.

One of the largest contributors to this problem is our linear usage model of manufacture-use-discard, which means that this increasing demand transfers into a direct increase in Waste Electrical and Electronic Equipment (WEEE). Bakker et al., 2014 and others have shown that product lifetimes are currently decreasing with factors such as fashion trends, styles and public perception all contributing to this problem. The problem is further exacerbated with increasing difficulties encountered in maintaining or repairing these products due to the lack of durable or reusable product designs.
The subject of CRMs, their mining, recovery and recycling is both complex and is often underrepresented in modern society. In addition to the importance of the materials for our technology, related factors such as geopolitical issues, social aspects such as unsafe/dangerous working conditions and more responsible sourcing for some of these minerals also need to be mentioned.

One response to this problem lies in educating the general public about CRMs and their importance in the modern world. People in general are largely unaware of these problems and how their usage and consumption patterns/behaviours compound the issue. This is only one facet of a complex problem, but serves to highlight the need to redress this lack of understanding amongst the general public.
The REFER (Raw Engagement for Electronics Repair) project seeks to address this gap. The project aims to use repair and reuse of electronic appliances as an outreach avenue in order to educate the general public about CRMs and these associated issues. This KIC-funded project is working across 6 countries (Germany, Sweden, Italy, Belgium, Ireland and the UK) to increase public awareness about CRMs using the novel model of active participation in electronic repair events and workshops.
Education, discussion and engagement around these topics with the general public is facilitated through the unique opportunity presented by these repair events. The project offers people the opportunity to fix their own appliances and devices during the course of a series of repair workshops. These repair workshops create an engaging dynamic, facilitating discussion and discourse over the repair and reuse of technology, the issues of CRM and their importance to all modern electronics. A series of educational resources have been developed to complement this, highlighting the role of CRMs, their scarcity and actions people can take to get involved in stages of the process. The project plans to use these repair events as a platform to show how our growing reliance on technology is placing an inordinately high demand on these scarce resources and pose some of the questions associated with addressing the issue.

The remainder of this paper is organised as follows. Section 2, Literature Review, considers some of the research and findings documented in the literature relating to CRMs and the rise of repair cafés and repair events in recent years. Section 3 introduces the REFER project, the group partners, the projects goals and aims. The REFER Project workshops and restarter events, the main channel for CRM education amongst the target general audience are described here. Section 4 presents some findings, observations and feedback on these events and workshop events, in particular identifying some of the key factors necessary for a successful event. Finally, Section 5 concludes the paper with a summary of the key points presented herein.

Literature Review
CRMs are an increasingly important topic in scientific research, but still relatively unknown to the broader audience of the general public.
The definition of what constitutes a CRM is already difficult because 'criticality' depends on more than just the physical existence of a material, but also on different, rapidly changing associated considerations such as the political stability of a country/region, the technical feasibility of exploitation, etc. Hofmann et al., 2018 consider CRMs, introducing the topic of materials criticality and observing how the criticality of raw materials is perceived and handled. The authors present examples of critical raw materials in advanced technologies, summarize some definitions of criticality, outline the topic of critical raw materials by highlighting relevant outcomes of a survey on critical raw materials for materials scientists, and present a literature research on "Critical Raw Materials" and "Criticality".
Consider, for example, the case of the smartphone in modern society. A typical smartphone can use up to 75 different kinds of minerals and metals in its construction (United States Geological Survey, 2017), including CRMs that provide it with key functionality, connectivity, light weight and compact form factor. At the same time, society is highly dependent on many CRMs to deliver green technologies such as solar panels, wind

turbines, electric vehicles and energy efficient lighting systems in our cities and countries (Grandell et al., 2016; Kim et al., 2015; Gielen et al., 2016).

As a visualisation for CRM mining and extraction, Bertrand et al., 2016 presents the Critical Raw Material (CRM) Map of Europe produced by EuroGeoSurvey's Mineral Resources Expert Group in 2014, following the second revision of the CRM list by the EU. The map shows EU mineral deposits from the EU FP7 ProMine project database, as containing critical commodities, according to this list of CRM published by the European Commission.

Due to concerns over the sources of supply, inefficient use of many of these materials and poor collection and recycling rates, securing reliable access to these raw materials is becoming a growing concern within the EU at an official level (EU Commission, 2019). Some research publications have focused on emerging technologies and methodologies for recovering CRMs from resources such as WEEE. Işıldar et al., 2018 consider the recycling of end-of-life devices and WEEE as a secondary source of CRMs. Current technologies employed include pyrometallurgical processes; however, these are deemed imperfect, energy-intensive and non-selective towards CRMs. The paper considers alternatives such as biotechnologies, presents the current frontiers in CRMs recovery from WEEE using biotechnology, the biochemical fundamentals of these bio-based technologies and discuss recent R&D activities, including biologically induced leaching (bioleaching) from various matrices, biomass- induced sorption (bio-sorption), and bio- electrochemical systems (BES).

In spite of their importance to the EU economy and society, the concept of CRMs, their supply situation and associated issues are topics that are unfamiliar to many business leaders and product designers (Whalen, K.A., 2013; Köhler et al., 2013), let alone the general public. This is evident in the behaviour and actions of the general public regarding these devices and appliances. For example, many people see no problem with putting such devices into "long term storage" in drawers, shelves, spare rooms and sheds. However, such behaviour impedes the collection, recycling and recovery of materials while these products are "hibernating" (Wilson et al., 2017). Research has also shown that product lifetimes are decreasing (as in Bakker et al., 2014), which further compounds this issue.

Buchert et al., 2012, for example, describe the findings from the German project "Recycling critical raw materials from waste electronic equipment". The project's aims included the production of a life cycle inventory of the occurrence of the critical raw materials in four selected groups of electronic devices – flat screens, LED lights, notebooks and smartphones – and the development of recycling options for the waste equipment to recover the critical raw materials. The study found that many of the critical metals examined, especially the rare earths (lanthanides plus scandium and yttrium) as well as tantalum, gallium and indium, show total end-of-life recycling rates of less than 1%. The recycling situation for precious metals (platinum, palladium, gold and silver) and cobalt was significantly better with rates above 50%, though the quality of some of these secondary material streams is still an issue of debate (EU Commission, 2019).

Like many scientific issues, the existence of CRMs and associated concerns such as environmental issues can appear as abstract problems to the general public, who perceive them as being unrelated and having little relevance to their day-to-day life. In particular, the public do not seem to associate the nature of their consumption/use of electronic appliances with these issues. The OECD cited outreach and public engagement as a vital factor in the implementation of change to address global challenges such as energy production, e-waste, climate change, raw materials and the associated economics (OECD, 2012). Traditionally, according to Funk and Rainie, 2015, engineers and scientists frequently lack the appropriate vehicles with which to engage the general public on these issues. Often people's only previous experience with science and technological issues was through school, and traditional school science frequently fails to tackle current and relevant issues (Hofstein et al., 2011).

Electronic Repair Workshops and Repair Cafés have also been widely considered in the literature. Repair, as defined in Rosner and Turner, 2015, may be thought of as 'the process of sustaining, managing, and repurposing technology in order to cope with attrition and regressive change.' Charter and Keiller, 2014, analysed the motivations of 158 volunteers in repair cafés in nine different countries as part of a quantitative study, They found the top three reasons why participants engage in repair to be:
- 1) encouraging others to live more sustainably,

2) providing a valuable service to the community and 3) being part of the movement to improve product reparability and longevity. The authors draw the conclusion that volunteers act altruistically and that their personal gain is not important to them.

Kannengießer, 2018 also considers repair workshops and cafés and the driving motivation behind them, identifying them as a new format of events in which people meet to work together on repairing objects of everyday life such as electronic devices. While repairing is an old practice, argues the author, what is new is that the act of repairing becomes public in such events, with the actual repairing as well as the repair events being staged as societal actions which strive for cultural transformation aiming at sustainability. The author considers a range of related questions, such as why do people participate in repair cafés and repair items? What do these events and the practice of repairing mean to the participants? And what relevance do the participants see in the Repair Cafés for society?

About the REFER Project

The main objective of the REFER project is the creation and establishment of an international network of educational-driven, repair-based events which focus on raw materials. These events aim to function as a vehicle for general public engagement with these complex scientific and societal issues. The events allow people to bring their electronic devices such as computers, phones or small household appliances to be repaired. Attendees sit down with expert repair volunteers and staff to understand how the technology works, identify the problem and repair their device.

Supported by a range of educational resources developed for the project, these interactions allow discussions on the nature of the technology, the range and amounts of CRMs and other scarce resources used and what can be done to address these matters.

Electronic devices are an excellent conduit through which to approach the general public about abstract topics such as CRMs. WEEE is the fastest growing waste stream in Europe, growing at 3-5% per year (Eurostat, 2018). Electrical and electronic equipment are the products with the highest concentration of CRMs in the marketplace, embedded in a complex multi-material matrix. A number of EU projects and research such as Chancerel et al., 2015 have highlighted the fact that no technological solution or market drivers to the complete recovery of CRMs from WEEE are expected for at least 15 years.

The REFER project therefore works to increase public awareness about CRMs using this novel model of active participation through the medium of these repair events and workshops.

Repairing products is also a strategy for addressing CRMs by enabling people to repair and maintain their own appliances going forward, thereby slowing material loops as part of a transition to a circular economy (Dominish et al., 2018). People not only learn about the issues, but are actively engaging in strategies to address them.

The REFER project is hosting repair workshops/cafés in 6 different E.U. member states. By the end of the project it is expected that this will allow direct engagement with approximately 6,000 members of the general public with an associated multiplier effect of 10-20 times based on the social networks (physical and virtual) of the participants. An accompanying website is hosted by the project with additional information, educational material, links, videos and supporting content for interested parties. The project aims to "educate the educators", which in the case of REFER are the people, hosts and repairers coming to the events. These people are already motivated to repair, re-use and explain sustainability aspects to others in their vicinity and social circles, so a key goal of the project is to enable this behavior and provide them with the tools and knowledge to do so.

At the events, participants engage in the repair process, gain a better understanding and appreciation for the roles of raw materials and CRM recovery in electronics and effect a change in their perspective towards CRM and the circular economy as well as the repair/recycle/re-use of electronic appliances within society. Figure 1 shows a selection of photographs from various repair workshops hosted across the different project partner workshops.

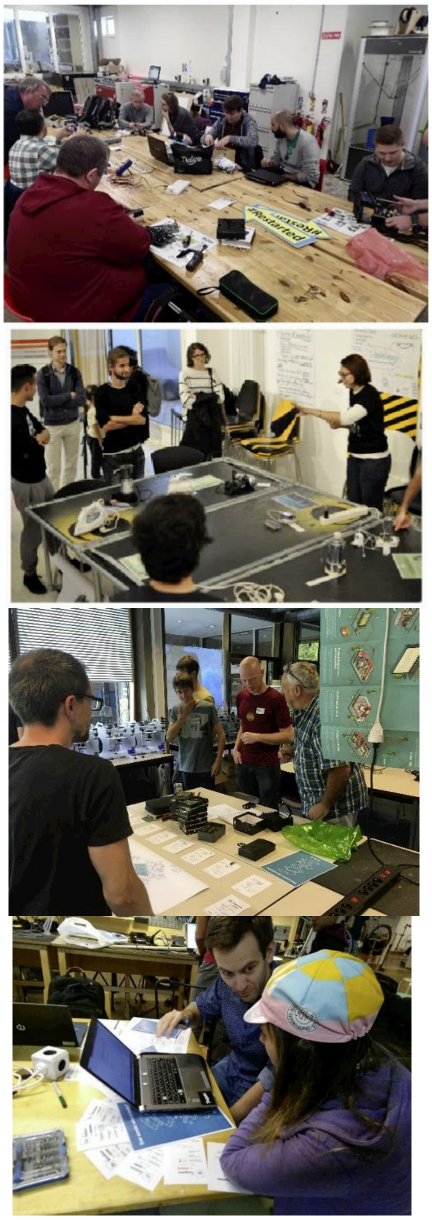

Figure 1. Selection of the REFER Repair Workshops/Restarter Parties.

Some of the key points identified for the development of the project's educational resources included the increased use of CRMs and other scarce metals and resources in modern-day consumer products. The low recycling rates of CRMs at present and the reasons behind these, including new approaches and technologies being developed in this regard also need to be considered. Furthermore, the low collections rates for WEEE in general at national and international levels also need to be highlighted, including discussion on why this is so important and what can be done about it. Finally, the use of extended product lifetime, repair and reuse as a means to conserve CRMs was also included. A selection of the educational resources developed by the project are shown in Figure 2 and may be accessed from the REFER website.

Figure 2. Selection of the REFER Project Educational Resources.

From the use of these resources, the main teaching moments at the repair events were categorised as either "repair augmentation" or "hands-on experimentation" activities. "Repair Augmentation" categories focused on the repair operation itself, and comprised learning and interactive activities with potential to enrich the actual repair moment. The "hands-on experiments" comprise activities which are distinct or separate from the act of repair itself e.g. disassembly of old/broken smartphones during the events, opening up HDDs to extract magnets, etc. In addition, demonstration kits and materials such as partially dismantled

electronic devices or raw material samples are also used.
These activities typically happened around the repair process and are meant to help demystify the act of repair by engagement, such as familiarising participants with tools and components of electronic repair.

REFER Workshop Events Feedback & Observations

To-date, a number of repair events and restarter parties have been hosted across the different project locations, namely Ireland, Sweden, Germany, Belgium, Italy and the U.K. It is envisaged that approximately 70 repair workshops/events will be held across these 6 different E.U. countries over the 18 months of the project.
At each location, personnel have been recruited or volunteered for the key event personnel roles identified and highlighted, such as fixers, hosts and educators. These people have been instrumental in implementing the actual workshops and repair events at the various venues internationally, and their importance, commitment and contribution to the successful execution of the repair events cannot be over-stated.
It has been critical that a sufficiently large and capable number of volunteers for each role are recruited, as not everybody will be able to attend every repair event. Redundancy in the forms of extra personnel and volunteers is highly recommended. Event personnel have been recruited from local repair groups, university students, hobbyists and other interested parties, through advertising, promotional events and word-of-mouth.
The scheduling of the actual events has also been an important organisational consideration. Depending on the number of volunteers available and the existence or not of a pre-existing repair network in the locations, an average of 1 event every 3-4 weeks has been scheduled for the project. Consideration for holidays and other time-related events on the annual calendar should be included in the scheduling process.
A final point of consideration has been the venue chosen for the REFER events. Ideally, the location should provide good access for members of the general public to bring along their broken appliances, be centrally located and easily accessible. The venue should facilitate a waiting area for people when they arrive, with tea/coffee facilities and a relaxed environment. The repair space should be separate and distinct from the waiting area and should include ample power outlets and Wi-Fi access for the appliances. A selection of repair tools and kits should be available to the repairers to handle the different types of appliances which may be brought in.
To augment the reach and scope of the project, the educational and outreach materials have been made available through the project website, which contains additional information on all of the topics discussed at the repair events, as well as all of the educational material developed for the project, including videos, links and supporting content for interested parties.
Promotional activities preceded each workshop and are important to advertise and publicise the events. These have included advertisement of the events through social media (Facebook, Twitter, website, etc.) and local channels such as posters, flyers, etc.

Conclusions

There is a need for raising public awareness and understanding of CRMs needed for modern society as well as actions, such as repair of electronic products that can alleviate some of the pressures on critical material loops in a circular economy. This paper has presented an overview of the REFER project, currently being hosted across 6 different countries within the EU. The project attempts to address these issues through both development of educational resources and the dynamic collaboration and atmosphere of public electronic repair events. This model using electronic repair events as an interactive medium for CRM education and dissemination can be useful for other repair activities and actors seeking to raise awareness about CRMs issues and strategies for addressing them.

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Circular Design of Composite Products: A Preliminary Framework Based on Insights from Literature and Industry

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Keywords: Design; Circular Economy; Composite Products.

Abstract: Composite materials are an attractive material choice as they enable lightweight, low maintenance products with a long lifespan. But closing the loop for these materials in a Circular Economy (CE) is challenging, especially for thermoset composites. In a CE, products should be designed for minimal impact while preserving their environmental and economic value for as long as possible. However, design strategies for composite products in a CE are currently largely unexplored.
Insights from literature on design for a CE as well as on composites recovery are combined to create a set of design principles for composites in a CE. In addition to well-known long life, lifetime extension and product recovery approaches, literature indicates the potential value of structural recycling. Structural recycling preserves most of the functional value of the product, which is largely lost in materials recycling. Experts from composites industry were interviewed in focus groups to further explore CE strategies and design principles for a set of reference products, such as car interior components. The resulting framework connects Circular strategies to design principles for composite products and supports design of new composite products for use, reuse and recycling in a CE.

Introduction

The current rate of consumption puts dangerous pressure on our global ecosystems, depleting resources and generating waste. The Circular Economy (CE) offers a promising alternative to lower the environmental burden. The CE aims to prevent waste by design and to preserve economic and environmental value (Balkenende et al., 2017). Products, components and technical materials are kept in the system by repairing, refurbishing, remanufacturing and recycling. Potential value gains are largest when the product remains as close as possible to its original state. This retains most of the energy, material, labour and capital that are embedded in the product (Bakker et al., 2018).

In a CE, products have to be designed for a low environmental impact, long lifetime, and recovery of products, parts or materials at the end of life. Composites (fibre reinforced polymers, (FRP)) are an attractive materials choice for designers, as they enable lightweight structures with a long lifespan (Yang et al., 2012). Yet, these materials present opportunities as well as challenges for use in a CE. Composite materials can reduce impact during the use phase (Mangino et al., 2007), enable long product lifetime (Jensen & Skelton, 2018; Job et al., 2016; Yang et al., 2012) and provide opportunities for lifetime extension (Beauson & Brøndsted, 2016; Nijssen, 2015). However, closing the loop remains challenging (Job et al., 2016; Yang et al., 2012).

Composites reaching their End of Life (EoL) are a growing concern for industry and policy makers. Approximately 12 million tons of composites were produced in 2017. Annual production rates increased by 5% (glass fibre composites) up to 10% (carbon fibre composites) (Effing, 2018). No clear solution has yet been found for the increasing volume of composite waste; all recovery processes severely degrade materials, making recycling economically barely viable (Job et al., 2016). Thus, the majority of composite material is landfilled or incinerated, losing material properties and the potential for reuse (Mativenga et al., 2017).

Opportunities for recovery and reuse of composites, key aspects of the CE, will increase when addressed in the initial design stage (Jensen & Skelton, 2018; Perry et al., 2012; Yang et al., 2012), and new policies are expected to stimulate this (Cherrington et al., 2012). Still, design of composite products for a CE remains largely unexplored. Although examples of composite product reuse can be found (Beauson & Brøndsted, 2016; Jensen & Skelton, 2018), this is generally not addressed in the initial design. It needs to be investigated to what extent CE strategies are applicable to composites, and how circular design principles can address the challenges found when developing composite products for a CE.

Approach

The focus of this research is on design strategies that enable long life, lifetime extension and closing the loop for composite products, specifically for FRP. As shown in figure 1, first the design framework for preserving product integrity (Den Hollander, 2018) is adapted to designing composites in a CE. Literature from the field of design for a CE as well as composites recovery is studied to identify strategies and design principles that prolong the product life or facilitate recovery of composite materials in a CE. Then, these strategies and principles are further explored by interviewing experts from companies using composites in a focus group setting. Finally, the paper concludes by proposing a design strategy framework which connects CE strategies to actionable design principles applicable to composite products.

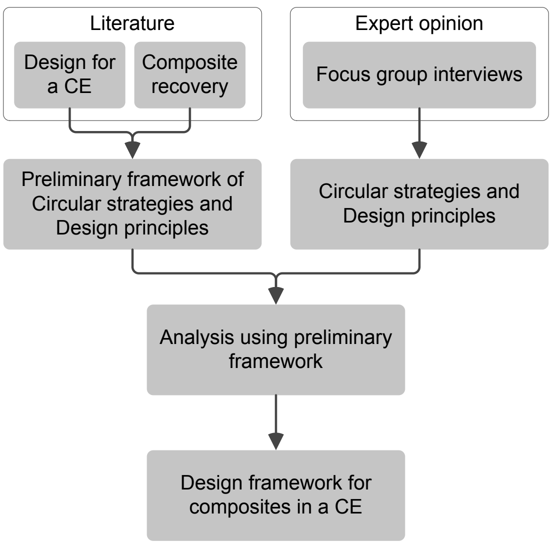

Figure 1. Research approach.

Literature background

Product integrity is a key concept in the circular economy. Maintaining product functionality has preference over materials recovery (Den Hollander, 2018). Product value can be preserved through long life, lifetime extension and product recovery approaches. Material value can be preserved through recycling.

In the case of composites this scheme can largely be followed as far as product integrity is involved. However, recycling routes for composite materials show some distinct aspects (Yang et al., 2012).

Composite materials can only be recycled to a limited extent by mechanical (shredding), thermal and chemical processing. Thermoplastic composites can also be remoulded (Yang et al., 2012). Thermal processes range from oxygen-rich combustion, recovering energy and ash (e.g. by co-processing in a cement kiln), to pyrolysis in an inert environment, recovering (damaged) fibres and generating fuel or organic feedstock. Chemical recycling, solvolysis, aims for full recovery of fibres and chemicals from the matrix, but still has not passed pilot scale (Job et al., 2016). In all cases the loss of material functionality and the deterioration of material properties is considerable.

More interesting, and specific to composites, is structural recycling. This preserves material quality with relatively little effort (Asmatulu et al., 2014), for example by resizing and repurposing composite parts in such a way that their unique properties as determined by the combination of material composition and structural design is maintained (Jensen & Skelton, 2018). This is considered a promising approach to preserve value for relatively little investment of energy and resources, and has been demonstrated on a small scale (Beauson & Brøndsted, 2016; Jensen & Skelton, 2018).

To generate a framework for actionable design guidelines, the CE strategies have to be connected to design principles and the business context wherein the product operates. Design principles address product realisation and for example include modularity and disassembly, which are directly related to choices with respect to materials and connections (Balkenende et al., 2017). A generic framework for CE strategies and design principles was derived by Den Hollander (2018).

Expert opinion

Experts were interviewed in focus groups to explore circular strategies and design principles for products containing composites. This study was done in the context of the H2020 project Ecobulk, a large scale demonstration project for composites in a CE. Ten groups of 6 to 8 participants were asked to explore opportunities for circular redesign of different products representing various industry sectors: a car interior part (automotive), a bookcase or bed (furniture), and outdoor panels or bars (building), respectively. The participants were stakeholders from the respective product value chains, including material suppliers, Original Equipment Manufacturers (OEMs) and recyclers.

The discussion was guided by a moderator. During the discussion, notes were taken and added to a shared worksheet. Afterwards, the notes were transcribed and categorised using the CE strategies and design principles from literature.

Results

Based on the literature and focus groups, a framework connecting CE strategies (columns) and design principles (rows) for composite products in a Circular Economy was derived. This framework is shown in Table 1. The table fields show where a specific combination of CE strategy and design principle was found: in the studied literature (LIT) or focus groups (FG).

		Design for preserving product integrity			**Design for recycling**	
		Long life	Lifetime extension	Product recovery	Structural recycling	Material recycling
		Reuse Long use Physical durability	Repair Maintenance Upgrade Adapt	Refurbish Remanufacture Parts harvesting	Repurpose Resize	Remould Mechanical Thermal Chemical
Concept design	Accessibility		LIT	LIT		
	Adaptability	LIT, FG	LIT, FG	LIT, FG	FG	
	Dis- and reassembly	FG	LIT, FG	LIT, FG	LIT, FG	LIT, FG
	Fault isolation		LIT	LIT		
	Interchangeability		LIT, FG	LIT, FG		
	Keying		LIT, FG	LIT, FG		
	Modularity		LIT, FG	LIT, FG	LIT	LIT
	Sacrificial elements	FG	LIT	LIT		
	Simplification	LIT	LIT	LIT		FG
	Standardisation		LIT, FG	LIT	LIT	LIT, FG
	Function integration	FG	FG			FG
Embodiment	Material selection	LIT, FG	LIT, FG	LIT, FG	LIT	LIT, FG
	Surface treatment sel.	LIT, FG	LIT, FG	LIT, FG		LIT, FG
	Connection selection	FG	FG	FG	LIT	LIT, FG
	Manufacturing		FG	FG	FG	LIT, FG
	Structural design	LIT, FG	LIT, FG		LIT, FG	LIT, FG
Realisation	Identification	FG	LIT	LIT, FG	LIT	LIT, FG
	Malfunction annunciation	FG	LIT	LIT		
	Documentation	FG	LIT, FG	LIT	LIT	LIT
	Monitoring	LIT, FG				

Table 1. Design strategy framework for composites in a Circular Economy. Showing circular strategies, design principles and where a combination was found: literature (LIT) or Focus group (FG).

Most design principles were identified for long life, lifetime extension and product recovery. Less design principles were found for material recycling, while structural recycling was incidentally encountered. Findings from literature and expert consultation showed considerable overlap.

Literature

Based on insights from literature, the circular design framework proposed by Den Hollander (2018) is adapted to composite product design:

- Structural recycling is added as intermediate strategy between product recovery and material recycling, preserving part of a product's functional value (Asmatulu et al., 2014).
- Five design principles are added, notably 1) manufacturing process selection, 2) structural design, 3) selection of connections 4) documentation of product specifications and 5) in-use monitoring. Manufacturing, structural design and connections determine to a large extent the processability of the product at the end of use (Jensen & Skelton, 2018; Perry et al., 2012; Yang et al., 2012), while documentation and monitoring enable better estimation of residual quality (Jensen & Skelton, 2018).
- Three design principles are omitted: 1) animacy, 2) redundancy and 3) ergonomics. Composites are predominantly used in aerospace, automotive, furniture, construction and wind energy industry for their lightweight properties (Perry et al., 2012; Yang et al., 2012). This type of applications does not call for animacy – making the product behave as if it were alive– or weight increasing features like redundancy. Ergonomics was omitted as this relates to generic product design criteria, but has no special significance in relation to designing for lifetime prolongation or recovery in a CE.
- Two principles were merged: functional packaging and modularity, as both aim to create readily replaceable subassemblies by grouping e.g. parts, functions or materials (Den Hollander, 2018).

Expert opinion

In the focus group sessions materials selection, dis- and reassembly and adaptability were mentioned most, and a new design principle, function integration, was found.

- Material selection was mostly regarded as a means to make the product better recyclable. For example, participants suggested to "Create materials with inherent aesthetic properties", to avoid coatings and thereby material contamination in the recycling process.
- Dis- and reassembly as well as connection selection were discussed for all Circular strategies except long life.
- Adaptability was predominantly recognised for long use and lifetime extension. For example by enabling the user to adapt furniture to changing needs.
- Function integration was suggested as additional design principle, as integrating functions will increase a part's value and mass. The first may provide an incentive for product recovery, and the latter for material recycling. When applied to a car dashboard component, this could incentivise dismounting of the complete component for refurbishment or recycling the materials.

Both literature and expert consultation

EU regulations, product lifecycle planning, repair technology and information exchange in the product value chain were noted in both literature and by experts. However, these are not directly part of the product design process as such, but should be aligned to it to develop a circular product. They are therefore not added to the design strategy framework, but should anyhow be considered in the early stage of new product development.

Discussion

In the framework, design principles are grouped using the stages of the product innovation process (Roozenburg & Eekels, 1998): concept design, embodiment and realisation. Grouping the principles in this way shows how they relate to the design process at large. In the early stage, a product strategy is formulated, addressing EU regulations and the product lifecycle plan. Then, principles like modularity and standardisation are used to find conceptual design solutions. In the next stage, the concepts are embodied to a detailed product design by, for example, material selection and structural design. Finally, documentation and identification provide stakeholders along the value chain with the information needed to use and recover the product according to the product strategy.

In the product innovation process, product design runs parallel to market development, i.e. the product's business and societal context. Thus, it becomes evident that, in addition to design principles, business model development as well as (development of) repair technology play a role in a Circular design process.
Most of the design principles were encountered by both literature and experts. However, two design principles were only encountered in literature: accessibility and fault isolation. Although not mentioned by the experts, both should be considered as an important factor to facilitate lifetime extension and product recovery.
One design principle, function integration, was only mentioned by the experts. Function integration is a new contribution to the field of design of composites for a CE. It serves to increase a part's recovery incentive by expanding its functionality (for parts harvesting and structural recycling) or mass (for material recycling). Function integration seems to conflict with the design principle of dis- and reassembly, which is relevant to all CE approaches. However, it may align with modularity, as function integration can be used to create a single-material module. For example, integrating multiple functions into one car dashboard component reduces the number of parts, connections and materials used. Which facilitates disassembly and avoids material contamination in the recycling process.

Recommendations

The framework is considered as a first step that provides insight in available design strategies and tools, to support designers developing new composite products for a Circular Economy. However, the framework might need further expansion as the selection of focus group participants and design cases was limited. Also, attention should be given to addressing the trade-offs in product design. For example, materials selection for recycling may conflict with materials selection for long product life.
Implementation of the framework in the product development process, as well as alignment with the product's market context has to be further detailed. As shown, the product design process should have a clear and strong connection to its business and societal context to realise a circular product. The relevance and application of design principles and CE strategies depends on this product context like recovery actions and business case.
Further research, building on design studies with composite products, will be carried out to validate and build upon the framework.

Conclusion

This study found that composites provide opportunities for the design of products in a CE. The material is often applied to minimise product weight, thus reducing materials used, and ensure long product lifespans. However, closing the loop remains a challenge and design of composite products for a CE is largely unexplored. This paper set out to explore design strategies for products containing composite materials in a Circular Economy. CE strategies and design principles found in literature and expert interviews were categorised into a framework.

The circular approaches found in CE literature are extended by introducing structural recycling. The approach, positioned between product recovery and materials recycling, has the potential to preserve composite material value for relatively low cost. A new design principle, function integration, was added to the existing body of knowledge and included in the framework. This is expected to increase the recovery value of parts as well as materials. On the other hand, some design principles found in literature were not mentioned by the experts and further expansion of the framework might be needed.
The framework is a first step in the development of strategies and tools, to support design of new composite products for a Circular Economy.

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Appendix

Descriptions of design principles

Design principle	Description	Quote
Accessibility	Ensuring (internal) parts can be reached for e.g. maintenance or repair operations.	related to the way in which parts are shaped, grouped and connected [1]
Adaptability	Enabling changes and adjustments to be made to the product during its life.	Changing the furniture to a user's changing needs
Dis- and reassembly	Facilitating (manual or mechanical) disassembly and reassembly of the product.	Design for disassembly by using screws or reversible snap fits
Fault isolation	Facilitating fault finding for e.g. repair.	Assuring that a… malfunction can be traced to the part … requiring replacement [2]
Identification	Using labels, tags etc. to facilitate recognition of the product and/or its specifications	Use markers for materials to facilitate separation
Interchangeability	Making parts or subassemblies of the product readily replaceable	Replaceable panels for damaged sections
Keying	Using product shape to facilitate alignment, e.g. holes and pins	use "slotted assembly" where the product is fixed from the ends into a groove.
Malfunction annunciation	Indicating (imminent) product failure	Inform user of bad use
Material selection	Selecting matrix, reinforcement, connections and other materials	Create materials with inherent aesthetic properties
Modularity	Grouping features within the product to create separable sub-assemblies	modular upgrades … to refresh design with minimal intervention.
Sacrificial elements	Defining replaceable components to take up wear and damage, thus protecting other parts	Grading and categorising parts which are likely to have most wear tear
Simplification	Minimising the complexity of the product, by e.g. appearance, assembly or materials	adopt essential lines and shapes … neutral colours such as scales of white and grey
Standardisation	Using standard components, processes, dimensions etc. in the product design	Same assembly system along time and models
Surface treatments	Selecting coatings and other surface treatments appropriate for the use and recovery of the product.	glass or aluminium replaceable covers in order to protect coatings during the whole life cycle
Connection selection	Selecting connections for the use and recovery actions during product life	use "pane type of roofing" … to avoid unnecessary fasteners nor use of sealants
Documentation	Providing information about the product to stakeholders in the value chain	Make it easy for customers to return at end-of-life --> info attached to product,
Manufacturing	Selecting and optimising the process to meet the material, shape and recovery criteria	… techniques that can at least partially use the recycled fibres instead of only new
Monitoring	Measuring (and storing) product properties while in use.	Lifetime monitoring … necessary to ensure the safety of re-using the blade [3]
Structural design	Optimising the shape to get the best structural quality.	Structure made of linear components like truss structures so [parts] could be re-used
Function integration	Combining multiple functions and (sub)components into one part.	Easier [Dis]assembly … due to the reduction of parts for a multi-functional component.

Table 2. Description and examples of design principles, quote from experts in this study and literature. From [1] (Balkenende et al., 2017); [2] (Den Hollander, 2018); [3] (Jensen & Skelton, 2018).

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Online Collaborative Clothing Consumption = "Business as Usual"? A Look at Female Practitioners of Online Redistributed Ownership

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Keywords: Collaborative Consumption; Sustainable Consumption; Clothing; Online.

Abstract: The advent of collaborative consumption (CC) has brought a renewed sense of hope among sustainable consumption scholars. Current CC clothing platforms conjure some skepticism about the capacity to meaningfully boost sustainable consumption, as these platforms are often positioned similarly as fast fashion outlets The purpose of this study was to understand the extent to which the practice of online redistributed clothing ownership aligns with the fundamental arguments that implicate CC as a model for sustainable consumption, using practice theory as a framework for inquiry. These fundamental arguments include utilization of secondhand goods that reduces demand for new products, mitigating premature disposal, and self-organization and peer-peer interaction that facilitate the development of shared values and personal identity via sociality that, consequently, changes consumption behavior. Phone interviews were conducted with 24 female participants from age 18-40. Constant comparative technique was utilized to identify emergent themes, and then these themes were categorized into performances, knowledge, and meanings characterizing the practice of online redistributed ownership. Evidence in the study supports the conclusion that the current practice only loosely supports fundamental aspects of how CC facilitates sustainable consumption. Meaningful product longevity and a culture that values secondhand exchange is largely absent from the practice among young women who use these online platforms.

Introduction

The advent of collaborative consumption (CC) has brought a renewed sense of hope among sustainable consumption scholars. The emergence of this new economy was partly driven by concerns around over production and waste, and "sharing" resources rather than buying new and accumulating seems attractive in light of increasing environmental issues (Hamari, Sjöklint, & Ukkonen, 2015). To be sure, any value proposition that increases the utilization of a product, prevents disposal, and decreases dependence on new production is an environmental gain (Botsman & Rogers, 2010; Leismann et al., 2013). However, current CC clothing platforms conjure some skepticism about the capacity to meaningfully boost sustainable consumption, as these platforms are often positioned similarly as fast fashion outlets (Joyner Armstrong & Park, 2017).

Though secondhand trade is not new, technological advancements have transformed this exchange into a broader landscape (Barnes & Mattsson, 2016), making the cost and ease of interaction between numerous buyers and sellers much easier (Barnes & Mattsson, 2016; Hamari, et al., 2015; Tsui, 2016). Park and Armstrong (2017) propose two primary categories of online CC in the clothing industry; those that provide only utility, without ownership (e.g., renting) (Reim, Parida, & Ortqvist, 2014), and the redistribution of secondhand goods (Botsman & Rogers, 2010). This study focuses on the latter: the procurement of still-valuable secondhand clothing, the redistribution of under-utilized garments to new owners. Compared to traditional methods of secondhand exchange, such as consignment and resale stores or swap meets, online platforms such as Poshmark, Mercari, and ThredUp represent a substantive marketplace for used clothing and provide opportunity for product life extension by increasing the utilization of clothing items. Yet, questions exist about aspects of these platforms that could negate environmental advancements (Reim et al., 2014), such as packaging and transportation requirements (Leismann, et al., 2013), low levels of peer-peer interaction (Jaeger-Erben et al., 2015; Mont, 2004), and the positioning of platforms (Baumeister, 2014).

The purpose of this study was to understand the extent to which the practice of online redistributed ownership aligns with the fundamental arguments that implicate CC as a model for sustainable consumption, using practice theory as a framework for inquiry. Research questions included: What are the key performances that characterize the practice of online redistributed ownership of clothing? What are the key knowledge areas requisite to an effective practice? How do practitioners understand the practice?

Background

Clothing is redistributed via online consignment, auction, or swapping in which used goods are resold to become owned once again, and the access period is undefined (Botsman & Rogers, 2010). Redistributed ownership will soon top $33 billion in annual sales, a sector that is growing 20 times faster than traditional retail outlets and five times faster than off-price retail, which has previously outpaced other retail outlets (Weinswig, 2017). Undoubtedly, this growth is a consequence of technological advances making it easier and less costly for an expansive network of users to connect, interact, and exchange goods (Barnes & Mattsson, 2016; Weinswig, 2017), especially among younger consumers (Weinswig, 2017).

The brass ring of sustainable clothing consumption is product longevity (Cooper, 2010), which is influenced by aspects of design and production (Gil, Lopes, & Kaye-Smith, 2016; Cooper, Hughes, & Claxton, 2015) as well as consumer practice (Laitala & Boks, 2012; Norum, 2018). Some fundamental arguments linking CC with sustainable consumption point to two ideal cases. The first case is when the utilization of secondhand goods reduces the demand for new products and when premature disposal is mitigated (Leismann et al., 2013), without rebound effects (e.g., transport requirements) (Reim et al., 2014), for which current clothing-related redistribution CC models undeniably yield (Joyner Armstrong & Park, 2017). However, clothing-related CC businesses also emphasize the economic benefits of accessing new fashion for cheap in quantity, similarly to fast fashion outlets, promoting concomitant consumptive behaviors. Certainly, *how* practitioners of CC utilize these platforms begs for illumination.

The second case is when self-organization and peer-peer interaction facilitate the development of shared values and personal identity via sociality that, consequently, changes consumption behavior (Jaeger-Erben et al., 2015; Mont, 2004). Sociality is crucial for developing a sense of community around a behavior, which can even lead to political consumerism, observed often in non-clothing related swapping and renting practice (Albinsson & Perera, 2012; Binninger, et al., 2015; Philip et al., 2015). Jaeger-Erben et al. (2015) argue that the more self-organization is permitted within CC by involved and engaged consumers, the more viable an alternative consumption practice can become. Further, other research implicates CC in the development of social capital that empowers practitioners to more fundamentally modify their behavior to sustainable aims (Chou, Chen, & Consley, 2015; Jaeger-Erben et al., 2015). Online clothing-related CC platforms embody relatively low levels of peer-peer interaction and features that could foster community, driving skepticism about its potential to buoy sustainable consumption behavior. As an aside, it arguably remains a question as to whether clothing-related CC is, in fact, an alternative consumption behavior.

From a practice theory perspective, behavior is motivated by everyday concerns in life, and people seek to become competent practitioners. For research inquiry, importance is placed on understanding the practicalities of consumption, actual behaviors included in the practice (Hargreaves, 2011). Warde (2005) contends that engaging in a practice, rather than a cognitive decision, is often what shapes behavior, not the other way around. Hargreaves (2011) argues that practice theory offers more mechanisms for behavior change than simply altering attitudes or values. Here, barriers to behavior change become more apparent by examining how ordinary life is organized. For instance, many authors have argued that environmental consciousness is an important influence in the decision to engage in CC (Becker-Leifhold & Iran, 2018; Hamari et al., 2015; Parguel et al., 2017) while other studies attempt to identify variables that explain the context of that decision (Lang & Joyner Armstrong, 2018), especially when environmental consciousness is disappointingly found not to be significant. Notably, within the few studies available about clothing-related CC, the theory of planned behavior, has dominated (Becker-Leifhold & Iran, 2018; Johnson, et al., 2016; Lang & Joyner Armstrong, 2018). The chief downfall of such a tact is that variables like attitudes or values that are determined to influence behavior in one context are often erroneously assumed to influence behavior in all other similar contexts, an implausible feat (Hargreaves, 2011). Røpke (2009) urges the use of a practice lens to understand the practices that people carry out, not because of environmental intentions, but due to everyday interests. Practice theory moves beyond economic theories rooted dependent on a rational actor as well as theories that seek social- or identity-related explanations for behavior by looking at the actual behaviors involved in a consumptive practice; shifting the focus of concern from consumer to practitioner (Fuentes, 2014). By understanding practices, changes in collective action can be identified (Hargreaves, 2011).

Methods

Since current CC platforms for clothing are predominantly used by female consumers (Wu, 2015), a mass email was sent to 5000 female faculty, staff, and students enrolled in or employed at three campuses that are part of a large Southwestern university in the U.S. Though sourcing participants through a university prohibits generalizability to some extent, for an exploratory study of this nature, it was appropriate. Those who were interested in participating in the study completed a brief screening survey. The interview questions consisted of two primary topics: what prompted their initial choice of CC as well as how and why they have used the features of CC platforms (e.g., website navigation, financial arrangement, interaction with other users). A $15 cash incentive was provided to participants. Phone interviews were conducted until a saturation in user experience was reached, which included 24 participants from age 18-40, with most participants in the 18-22 age range. Though most participants were young, online CC has received some of its highest engagement among younger consumers (Weinswig, 2017). Røpke (2009) suggests a method for analyzing consumption studies in accordance with practice theory to initially include three broad interrelated categories: material, meaning, and competence. Constant comparative technique was utilized to identify emergent themes related to the basic performances involved in the practice (e.g., the routines) and then to code the aspects of these routines across these three categories (Strauss & Corbin, 1998). Røpke (2009) argues that these aspects belong to the practice, not the individual, which is what characterizes a practice by a social group. The use of practice theory in a CC context is inherently challenging because the practice is not monolithic but rather highly diverse, with many different platforms available; not all created equal. Thus, an effort was made during data analysis to identify the overarching performances or behaviors that reflect the practice of CC, regardless of platform.

Findings and Conclusion

Four key performances were found to comprise online redistributed ownership of clothing: buying, selling, interacting, paying, and distributing. Each performance included knowledge areas or know-how considered requisite by participants to effectively practice online redistributed ownership; for example, site navigation techniques, knowing what sells best, items most ideal to purchase, products to avoid, vetting buyers and sellers, and the navigation of fees were commonly cited as important competences. Meanings identified during analysis highlight that users understand the practice of online redistributed ownership as akin to online shopping and shopping generally (e.g., convenient, affordable). Additionally, these platforms represent a way to recoup value for their unused items and an ideal disposal method for unwanted clothing. It is concluded that this current practice only loosely supports the fundamental arguments of CC that support sustainable consumption via product longevity and a culture that values secondhand exchange is largely missing from the practice among young women who use clothing CC platforms.

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Modularity as One Principle in Sustainable Technology Design – A Design Case Study on ICT

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Keywords: Modularity; Sustainability; Critical Design; ICT; Mobile Phone.

Abstract: Within design of information and communication technology (ICT) we need to first shape and then follow a vision to take responsibility for the futures that design materializes. Although research and literature on both sustainable technology and sustainable interaction design grow significantly, both fields with their (im)material character, are less often thought together and seen as mutually shaping. Hence, this paper examines the state-of-the-art in modularity as one sustainable design principle for the mobile phone and related ICT, utilizing a review of design (concept) cases in form of their multimedia representations. Matching the findings from the concrete exemplars with generic scientific research results within modular designing informs a discussion on value preservation (promotion of reuse over recycling and the like), portraying nowadays insufficiencies on the one hand and desirable, meaningful futures on the other. It describes both the employment of and the confidence in modularity for accomplishing sustainability, digital materiality or the soft matter, and the demandingness of modularly upgradable architectures. Supposedly by help of the critical design practice in an academic context - which translates to fundamental creativity-based research driven by envisioning new possibilities - further research shall build on the insights gained here. Our vision may thus be called sustainable technology and interaction design, which as an acronym gives STaID.

Introduction

We have proposed to engage more with the politics of technology through preceding research into societal views on the phenomenon "Planned Obsolescence" (Junge & van der Velden, 2018). By means of a critical discourse analysis, we addressed overcoming the persisting view of 'technology as neutral'. This study on ICT carries on with technology as the manifestations related to this discourse (Jäger, 2001). Modularity is for this paper chosen to represent one principle within sustainable technology design. An in-depth study was reasonable to apply due to clear boundaries for what is considered modular, the good literature base and the amount of design cases found. I draw on sustainability related design frameworks, such as Critical (Malpass, 2017) and Transition Design (Tonkinwise, 2015) as they represent the vision to take responsibility for the futures that design materializes. Modularity may show in how far a design principle can counter commercial design, whose job seems to remain "building alternatives in response real-time analytics, rather than to pursue a vision" (Tonkinwise, 2015, p. 88).

Approach to a modularity review

To identify the state-of-the-art in ICT design and thus characterize its design space, a review of cases was conducted. It started out in the academic literature, where certain examples of technology to describe and argue are frequently used. A follow up search for design cases was initiated, outside academic literature in multi-media resources of economic/entrepreneurial, educational or entertaining kind: video-channels, (non-)commercial websites, blogs, popular science and engineering publications etc. Through the nature of such media the search was conducted in a snow-balling manner leading to many design cases that characterize the potential design space. Though the review spans wide, it does not claim to be complete.

Results and discussion of the design case review

The collected design cases within modularity (see Figure 1) have been clustered to cover: i) definite modular phone concepts, published in the recent decade, that only reached a prototype phase with no market entry (yet); ii) marketed (semi-)modular phones or components, that have passed the former's prototype stage; iii) related modular ICT in R&D or early market. Besides promoting modularity in a more or less profound manner, every design case has its unique feature(s). What often distinguishes them is their origin, their development history, story and creators. The distinguishing features shall be highlighted in and through the following discussion of modularity as a sustainable design principle.

What all cases have in common is that devices consist of components and at least all main components are easily switchable modules. Module means a structurally independent element, i.e. a part, component or sub-assembly that has non-permanent interconnections (interfaces) to other modules (Schischke, Proske, Nissen, & Lang, 2016). Modular devices most often have a base unit and can be upgraded in terms of a new screen, CPU, GPU, camera, battery and RAM (main units of ICT) simply by switching out individual modules. Some sort of mounting mechanism holds the modules tightly so they usually will not disconnect even under impact or fall.

Nevertheless, the definition of 'module' is vague as different devices have different demarcations of those. The liveliest description of demarcation is for the Puzzlephone speaking of the three main modules as the Spine (display, speakers, microphones), the Heart (battery) and the Brain (main electronics). For the Fairphone 2 one speaks of the transceiver (or core) unit, the display unit & the receiver module and the rear camera module & speaker unit. These distinct and cascading orderings show how much room for interpretation there is, involving several factors, making the demarcation a complex endeavour.

Modularity's main capacity, in terms of sustainability in the use-phase, is to extend the useful lifespan of products through easier repair, maintenance and upgrading (Sonego, Echeveste, & Galvan Debarba, 2018, p. 200). The Fairphone 2 is again an example here, as thanks to its modular architecture anyone should be able to do basic maintenance.

Important measures to establish modularity are achieving interchangeability between modules, by independence between components and/or their lifecycle processes, as well as fostering that components and processes in a module are similar. It creates functional independence, due to which modularization "has been called the goal of good design" (Gershenson, Prasad, & Allamneni, 1999, p. 1), as Fry ("Good Design / Inkahoots," n.d.) and Rams ("Dieter Rams 10 Principles of 'Good Design' | ArchDaily," n.d.) promote. There is a body of literature systematically reviewed in (Sonego et al., 2018), which is concerned with modular repairability and modular upgradability (Agrawal, Atasu, & Ülkü, 2016) in particular. It seems to exist a widespread belief in modularity as a "sure way to achieve sustainability" (Sonego et al., 2018), as the literature promotes the benefits stronger than the limitations associated with it.

Several have issued modular design concepts, in particular for the smartphone in the middle of the current decade. Examples are the LG G5 with its accessory slot at the bottom, which allows users to remove the battery and to swap in different modules. The ZTE Eco Moebius has a similar sliding track design and it also envisions various screen sizes available by three different frames all capable of utilizing the same (besides the LCD) modules for the device. The Facebook's XBEAM concept's strategy is also to facilitate for different sized and shaped display units. On a general basis Phonebloks, an early initiative within modular phone conceptualizing (Hankammer, Jiang, Kleer, & Schymanietz, 2016), continues promoting the strive for modularity in consumer electronics. Fonkraft must be mentioned for its special mounting mechanism for a tight holding display that can only be removed by pushing a frame button whereof a special slider under the display unblocks all the modules, hindering unintended disconnection (impact or fall). More such issued concepts would fit here, but will follow later.

Some concepts were even published together with modular design frameworks, such as the three evaluation charts by (Ishii, 1998) exemplified on hand of a hypothetical family of inkjet printers. Since little had reached market entry, research started examining why and how modularly upgradable designs would not become valued and widely adapted (Agrawal et al., 2016). It found that generalizing empirical observations and extrapolations onto new

modularization cases bear the risk that qualitative details are overlooked, for example when transferring modularly upgradable architectures prevalent in industrial markets (Agrawal et al., 2016) to the consumer electronics industry where such architectures have yet to be proven a strong concept.
One specialty that comes in with consumer electronics is software, for example in form of the operating system (OS). When we see OSs as modules, then modular repairability and upgradability also come into play for the soft matter. Vsenn with its modular smartphone proposal envisioned the possibility to swap operating systems and to promise four years' worth of guaranteed software updates. Also BLOCKS Project OpenWatch proposed to try the idea of a modular Android-software open to system developers of wearables. This stands in contrast to earlier experiences within smartphone evolution, examined by (Farman, 2017), who brings up issues around nine major releases of iOS between 2007 and 2014, where especially apps "rarely preserve[d] backward compatible versions for older iOSs" (Farman, 2017, p. 21). "Older iOSs", synonymous to older devices, i.e. hardware, are characterized as not even "allowed" to have the latest version installed or running.[1]
Not only but also such technology-evolutional issues remind us that modularization is "not necessarily the most sustainable design option" (Schischke et al., 2016). The two concepts overlap, but are not completely congruent. For one, modularity demands more material in the first place, since additional sub-structures become necessary or the product increases in volume when a "maximum potential configuration" (Schischke et al., 2016, p. 1) is incorporated. An example for a "maximum potential configuration" is Microsoft's Surface Phone (Andromeda): Its hybrid, foldable form factor with a modular hinge allows for independent units (i.e. devices) to be used together (when folded or unfolded) or separately (when unfolded and detached). Modularity is also "demanding" more material and volume when a fit to possible future technologies is anticipated. Here modularity overlaps largely with future-proofing, another design principle in the larger scope in my research.
Besides the described demandingness it secondly depends on the intention of users (and producers) whether actually broken modules are replaced or rather frequently exchanged "to keep pace with latest technology features" (Schischke et al., 2016, p. 4). Google project ARA started out like this without promoting sustainability as a core aim or reason for modularization. Compared to ARA, the announced (and never released) Xiaomi Magic Cube concept pictures only a more asymmetric layout of modules in a smartphone. In fact, there seems to have been a 'run' on modularity among tech-developers in the sense that it is invested in extra material & functionality to raise turnover and/or profit [19] or just to show willingness to follow this tech-trend. In the case of Moduware (Modular Smartphone Case), a community of developers has quickly come up with 300 ideas for extra-functionality modules as add-ons. The distinction here is that it was open to a large community of developers to contribute, not a single large cooperation profiting from a resulting large product portfolio.
Yet, such intentional frequent introduction and replacement of modules causes accelerated obsolescence (Sonego et al., 2018) and thus bears the risk to cause significant rebound effects: The limiting factor can be soon recognized when in particular the aforementioned interfaces and sub-structures trigger an increased consumption of critical or scarce raw materials (Schischke et al., 2016). An example here could be the design of the module-interface as click-on mechanism with strong magnetic surfaces able to hold the modules tightly together (as for Google project ARA). It might encounter problems like much more neodymium necessary than resources provide (Möller et al., 2014). Given that with such rebound effect "the greatest environmental impact can be generated" (Sonego et al., 2018, p. 202), it is worrying how understudied the user and the use phase in respect to modularity and sustainability is.
Further disadvantages the literature finds in modular designs span across: redundant structures, overdesigned products with

[1] By contrast, one of the newest releases, namely the September 2018 issued iOS 12, promised to make older phone hardware workable again, which would mean a major shift in backward compatibility [48]

sacrificed performance, that are perceived less durable, difficult to use and onerous to maintain, less reliable and safe (Schischke et al., 2016; Sonego et al., 2018). In addition, it is considered that modularity might not promote an increase in the product's lifespan but rather reuse and recyclability of parts of the product, such that products can profit from future efficiency gains (Sonego et al., 2018).

This issue relates to standardization, which often inevitably follows modularization efforts: Complying to standards for compatibility reasons becomes an obsolete commitment as soon as higher performance and efficiency are reached through R&D which "grow" into a new standard. An example are standardized power supplies for mobile phones, micro USB-B connectors, soon replaced by USB type-C for higher data transfer and power transmission (Schischke et al., 2016).

A third point of view in research is to handle modularity as more widely disseminated than usually perceived, i.e. when the demarcation of module is down to "every part". For example tablets are shown to be "already arranged in modules", as they consist of "clearly distinct parts" (Schischke et al., 2016, p. 2). The same can be stated for smartphones with their similar assembly structure. Inspiration or role models can be drawn from the laptop/tablet-PC design world, f.i. from XO Infinity, a tough modular multi-OS laptop concept for kids, or the iameco D4R (design for reuse) laptop. The art of modularity for smartphones boils down to 'squeezing' well-known modules into the small size a phone complies with (Schischke et al., 2016). In that wider sense modularity appears at different levels, according to (Schischke et al., 2016) these are: add-on-, material-, platform-, repair- and mix&match modularity. Many examined design cases comply with these. For add-on modularity the Modu Phone/Modu T (first modular mobile phone concept before the smartphone age) can examplify: The small, rectangular device came with "jackets" in form of camera, Qwerty keyboard, fitness band etc. *adding* functionalities. Other examples are: Moto Mods, Motorola smartphone add-ons of type camera, power pack, docking, projector, speakers and many more; the Moduware Modular Smartphone Case - an external smartpack or smartphone case for several, respectively 3 different modules; as well as MODR - a case for smartphone and tablet features and expansion options, that can host 2 reModules simultaneously for functionalities such as Micro SD reader, flash/-light, customizable NFC button, (solar) battery pack, projector, Bluetooth speakers, zoom lenses, wireless charging (Qi). Those add-on examples at the same time blend into platform modularity.

Design cases for platform modularity are the RePhone and the imasD: Click ARM Tablet (mainboard) with its Advanced Removable Modules technology, which allow for individually configured units out of various electronics modules (Schischke et al., 2016). The B-Squares Modular Electronic Devices, the Kite DIY modular phone, and integrative tablet/-smartphone technology platforms like the XPX Life 7 (a low-spec 7-inch modular tablet with proposed modular phone) and the SHIFT 12 tablop (building on Shiftphone modules), range in the same category. The Lifebook modular laptop (concept) that "combines all gadgets into one" as well as the SHIFTmu and the concepts Graalphone and Seedphone expand the modularity understanding towards including whole devices as modules in higher performance devices. Besides, modular forms of related ICT exist like the Blocks Modular Smartwatch, Samsung SIMband and Tma-2 modular Headphones, which complement the platform idea.

The provided (re)configurability is important for to build a "shared product platform", where the relevant modules and not overdesigned whole devices can be reused for an adapted purpose. This can be other applications after for example the first life as a mobile phone, such as microcomputers and home automation devices. The Puzzlecluster - a first computer cluster platform based on recycled modular technology (plus the envisioned PuzzleTab, PuzzleTV, PuzzleIoT, PuzzleRobots, as well as cellRobot) and the environmental conceptual computer igglu are examplary for this. In a product platform each part or module can play a new role in a smaller or bigger, less or more complex device, without risking to be "downcycled" like whole devices in so-called upcycling applications (f.i. contemporary smartphone as fish-tank surveillance) tend to be ("Upcycling," n.d.). The mostly through platform and repair modularity addressed value preservation is as mentioned still dependent on users and a purposeful use.

The value of a broken Shiftphone for instance is appreciated through a deposit-payment on return. When we take this as an example for the much-welcomed extended producer responsibility we may also think of take-back of and deposits on each module: The Fonkraft concept advertised already for a web shop for new and used modules that could also be manufactured by third party companies.

Towards Sustainable Technology and Interaction Design (STaID) with modularity for value creation

Furthermore, the value of a product is first realized during the use, not fully contained in itself (Sonego et al., 2018). When we depart from an economic perspective towards a “concept [of value] that also embraces environmental and social aspects” (Sonego et al., 2018, p. 203), we can comprehend the importance of the consumption phase as key for the creation of sustainable value.

Nevertheless, creating sustainable value and preserving value root deep in the lifecycle’s design phase with according consequences for the use-phase. It is concluded that the design of ICT that is value preserving - be it through modularity or other design principles - needs to be of a critical design practice kind. Critical design (Malpass, 2017) within an academic context - i.e. fundamental creativity-based research driven by envisioning new possibilities - is said to serve overcoming the contemporary complex problems and insufficiencies. It shall even be obliged to find out what is meaningful, desirable and therefor sustainable.

With the presented design case study the inquiry into both the desirable possibilities and the existing insufficiencies has started. Two main concerns for further research may be inter-usability and inter-operability as described in (Rowland, Goodman, Charlier, Light, & Lui, 2015) to be applied on the ICT in focus here. It shall lead to concrete answers how to overcome overlooked details in transfers, rebound effects, real-time responsive design, and in general how to promote values in technology creation, that go beyond the financial dimension. Modularity plays a significant role as one principle in the envisioned Sustainable Technology and Interaction Design (STaID!).

Figure 1. Modular design cases reviewed. © Phonebloks (*) and author’s drawings.

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Deconstructing the Clothing Design Process for a Circular Economy

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Keywords: Circular Economy; Clothing Design; Design Practice; Design Process.

Abstract: The transition from linear to circular fashion system(s) requires substantial changes at the level of legislation, infrastructure, technology, education, business and consumption. This exploratory study zooms into the business level, specifically into sustainable-minded clothing companies and their design practices. What happens in practice inside these companies and what are designers' current concerns when aiming for sustainability and circularity in the clothing industry? Semi-structured expert interviews were conducted with five clothing designers. Findings of the study show that designers are not much acquainted with the existing sustainable/circular design strategies, tools and guidelines. Strong focus is still on material selection and clothing longevity. Some discussions also link to the use phase of garments and especially reuse. It is obvious that designers need more applied knowledge to support their design practice if aiming for a circular economy.

Introduction

In recent years, the circular economy model has gained the attention of the global textile and clothing industry. Stakeholders within are increasingly showing interest to transform the linear processes which dominate the current fashion system. However, as stated in Pulse of the Fashion Industry 2019 Update: "Fashion companies are not implementing sustainable solutions fast enough to counter-balance negative environmental and social impacts of the rapidly growing fashion industry" (Lehmann et al., 2019: 1). The industry's transition to a circular alternative requires substantial actions and changes at multiple societal levels, such as legislation, technology, education, infra-structure, business, design and consumption (Global Fashion Agenda, 2018a; EMF, 2017). In the quest for this transition, our paper zooms into the business level, and specifically into the design practices within clothing businesses. The main purpose is to address the extent to which clothing designers could contribute to this transition.

Sustainable design approaches and strategies have been extensively studied and proposed for sustainable fashion (e.g. Fletcher, 2010; Niinimäki, 2011; Karell, 2014; Dissanayake & Sinha 2015; Han et al. 2017; Kozlowski et al., 2018). Founded on the principles of circular economy, more strategies, tools and guidelines are constantly being developed to assist designers towards textile circularity (e.g. Hasling & Ræbild, 2017; Niinimäki, 2018; Earley & Goldsworthy, 2018; Global Fashion Agenda, 2018b). Even though knowledge and interest towards sustainable practices and textile circularity is increasing among clothing businesses, the industry has largely continued business as usual.

Some reasons can be found in previous studies focused on sustainable clothing design practices (e.g. Palomo-Lovinski & Hahn, 2014; Lawless & Medvedev, 2016; Elander & Ljungkvist, 2016; Karell, 2018; Karell & Niinimäki, 2019). The studies show that integrating sustainability into the design process in business environments can be challenging for multiple reasons such as economic sustainability, company strategy and lack of sustainability knowledge. Especially in small companies, sustainable choices are often made to the detriment of profit margins (Lawless & Medvedev, 2016). This situation stems from the fact that sustainable materials (such as organic or recycled materials) are often more expensive than standard options (e.g. Elander & Ljungkvist, 2016). To balance these financial sacrifices, designers are obliged to prioritise their sustainable approaches (Lawless & Medvedev, 2016). Regarding that aspect, company strategies are

substantially important. They steer the financial targets, collection structures, and budgets, and hence the whole clothing design framework, often limiting sustainability-minded designers (e.g Lawless & Medvedev, 2016; Karell & Niinimäki, 2019). To the contrary, studies also indicate that clothing designers lack knowledge of sustainable and/or circular design strategies and of sustainability in general (Palomo-Lovinski & Hahn, 2014; Lawless & Medvedev, 2016; Elander & Ljungkvist, 2016; Karell, 2018).
To better integrate the knowledge of sustainable and circular approaches into the design practices, more detailed information is needed on how design processes in sustainable companies actually proceed. To address this need, the following questions guide the study: What occurs in practice inside sustainable-minded clothing companies and what are designers' main concerns related to sustainability and circularity?

Methods

Semi-structured expert interviews (Flick, 2009) were conducted in 2019 with five clothing designers who work for three established small or medium-sized [1] clothing companies. Only companies which have a clearly formulated sustainable vision or agenda were chosen for the study. The designers were recruited to the study from Northern Europe through email requests. The interviews were organised face-to-face or through Skype calls. Table 1 provides a summary of the designers' positions, their experiences within the clothing industry and short descriptions of the employer companies.

The expert interviews included two stages, where we applied some aspects of object interviews (Woodward, 2016): In stage one, we asked designers to describe their usual schedule and various tasks regarding the design process. To initiate this conversation, a set of cards was developed based on earlier research addressing the "standard" clothing design process (Han et al., 2017). In stage two, we showed three commercial product types to the designers: A t-shirt with a placement print, a pair of jeans and a padded winter jacket with all-over-print. This activity was planned to facilitate the conversation on the aesthetic and functional properties of the exemplary products in relation to sustainability and circularity. The selected product types represented different complexity levels in terms of material combinations and product structures. Hence, they were assumed to prompt specific concerns related to sustainable and/or circular design practices.

	Current position, work experience in the clothing industry	**Description of the employer company**
D1	Design manager/ Designer, 18 years	Clothing and life style brand for adults; focus on organic and recycled materials, clothing longevity and repairability
D2	Development manager/Designer, 20 years	Clothing and life style brand for kids and adults; focus on organic and recycled materials, and clothing longevity
D3	Sustainability advisor/Designer 5 years	
D4	Head designer, 16 years	Clothing brand for kids and adults; focus on organic materials, clothing longevity and user-centred design
D5	Assistant designer, 2 years	

Table 1. Summary of the interviewed designers and the companies they represent.

The interviews were audio recorded and transcribed. The data was analysed through thematic analysis (Flick, 2009), looking into identifying common and/or varying patterns of current practices and the most critical issues within sustainable clothing design processes.

Findings

Based on the interviews we identified the following areas that currently steer the sustainability related discussion and the design processes in sustainable-minded clothing companies:
1) sustainable mindset, 2) sustainable design knowledge and 3) sustainable design practice.

Sustainable Mindset

Since their establishment all the represented companies have set a certain sustainable vision and criteria for their design and business activities. These companies have constructed internal guidelines which designers need to follow when making design choices. The brands are built on ethically produced, long lasting, reusable and/or

[1] Small and medium-sized enterprises (SMEs) represent 90% of all businesses in European Union (European Commission, 2015).

repairable garments, mostly made of organic and/or recycled materials. All three companies aim for physical and aesthetic durability through good quality materials and timeless design. All the designers claimed they try to avoid trends when ideating new collections.

All companies have a single person or a team dedicated to sustainability issues. The companies also use or have used external sustainability expertise. Some companies, for example, have organised mandatory education on general sustainability issues for their personnel. Even if there is a nominated person or team for sustainability, the entire staff have to be committed. In addition, the companies take part in sustainability and circular economy related seminars, collaborate in recycling projects or have participated in roundtable discussions on the same topics.

Sustainable Design Knowledge

Despite the companies' sustainability efforts, the interviewed designers were not always aware of the existing sustainable design strategies. Although the companies' practices reflected sustainable design strategies such as 'design for longevity' and 'design for reuse', knowledge of these terminologies among the interviewees was limited.

The designers had not heard of sustainable and circular design tools and guidelines either. Here we refer to tools and guidelines such as 'The Higg Index' (Sustainable Apparel Coalition), 'The TED's TEN Cards' (Textiles Environment Design), 'Sustainable Design Cards' (Hasling & Ræbild, 2017), 'The Circular Design Guide' (Ellen MacArthur Foundation, 2018) and 'Circular Design Toolbox' (Global Fashion Agenda, 2018b). As one designer commented:

D3: These were totally new for me. Not at all familiar. I guess we have mostly used our intuition and pragmatic, kind of traditional, approach in our design process.

Next to companies' internal guidelines, designers' personal intuition and knowledge seems to play an important role when making design decisions. In this respect, some designers also expressed their concerns of missing specific and reliable information that would be needed in order to make more educated decisions. The designers try to think, for example, how they could enable the recyclability of their products through their own design practice. This task in practice, however, is much more complicated compared to product durability or reusability, as this quote demonstrates:

D3: If we want to make it so that it would be possible to recycle it in the future, we should consider all the details so that they can be separated easily.

All of the interviewed designers are aware of the emerging recycling technologies like chemical recycling. Yet, they are not aware of what kind of material blends could be eventually separated and recycled, and what kind of elements (dyes, finishes and additional materials) might hinder the various recycling processes. The following quote demonstrates this knowledge gap:

D4: I have to say that I don't even know what happens with all zippers or metal buttons, which we have in our products and what that means in the recycling process.

The designers also acknowledged that information of sustainability and circularity is emerging fast. In this respect, some are concerned whether the companies will actually have enough resources to adopt the latest knowledge:

D3: All this information on sustainability and circular economy proceeds so quickly […] that perhaps we haven't got the resources to follow that speed so that we could be as sustainable as the original idea has been.

Sustainable Design Practice

Materials

Considering the sustainable design practices, most frequently mentioned aspect among the designers was the material selection. This was discussed from multiple perspectives; environmental perspective, product durability, usability and functionality. From environmental perspective all companies use only recycled or organic materials in their production. Materials are generally certified and follow specific company criteria. High-quality and physical durability are the foundation for usable and functional designs.
However, the availability of ecological and recycled materials was the most problematic

aspect mentioned by the designers. All of them stressed that the business interest towards sustainability, let alone circularity, is too low. Only few likeminded companies can be found at trade fairs, which limits finding suitable fabrics and trims. Hence, new collections are largely based on materials from the earlier seasons as the offering of sustainable options is poor. The following quotes illustrate the ongoing difficulty of sustainable material sourcing:

D2: Finding suitable materials is the main challenge. It's a huge task to find such materials which truly function in our products and which best fulfil our criteria from the existing alternatives - all of which are actually bad.

D1: Sometimes it's very frustrating […] it's a challenge in your mind when you want to achieve something that is right in front of you but you can't use it because it's not ok by the standards that we have set.

As seen above, companies' internal demands for sustainability may even restrict designers. Due to the internal company criteria, design teams are not necessarily free to choose the materials. In one company there is sometimes even tension between designers and the sustainability team as it is not easy to find balance between products' aesthetic appeal and sustainable material choices. As one designer stated, however, a product must serve the brand and be desirable in the end.

Considering material sourcing all three companies have well established relationships with their current material suppliers. One company has made a strategic decision to rely purely on their suppliers' material offerings in order to guarantee stable quality. The other two companies, on the other hand, have decided to actively participate in the material development with their suppliers. Regarding material circularity, one designer described their activities as follows:

D1: The limitations that we have now is because we can't really find everything that we are looking for… Now we are trying to develop biodegradable buttons, which is not easy, but so that we could make 100% biodegradable jeans.

Even though biodegradability may not be the best solution in textiles (Niinimäki, 2018), it is a valid strategy in supporting circular economy. Meanwhile, the same company is also investigating how to recycle their own post-consumer products so as to find recycled alternatives to virgin material use.

Long Lasting Design & Repairability

Some discussions related to design practice also link to the use phase of garments and especially the aspect of reuse. In this respect, all companies try to avoid too trendy look to emphasise longer lasting design. Aesthetic durability is important when making product-related decisions, but also in terms of entire collections and their continuation. Even half of the collection can be based on timeless designs which do not change. The continuation allows customers to easily combine products from different collections. Long lasting design approach does not only imply longer product use time but can encourage reuse. As many designers mentioned, product reusability is already taken into account in their design process. Multiple sizing, transformability or loose pattern design are considered especially in children's wear:

D3: We have multiple sizing, meaning that one child can use the same product longer and then it can be given to a sibling or to somebody else. I think that the longevity is the most important aspect in sustainability.

A free repair service is also offered by one company to increase the product longevity. The repair service links to business model and do not necessarily affect the design work:

D1: It [repair service] doesn't affect how I design the product. But if I can see that certain product parts break down easily then we could make the pattern a bit different.

In another company, however, structural aspects are well considered already in the design process, as the following quotes illustrate:

D4: I think that repairability should be the most important aspect, especially in the outdoor wear, which should stay in use for 10 years.

D5: We take durability into account in product structures. We know where products wear out *the most. Hence, we know how to minimize the related risks.*

Interestingly, the role of second-hand sale was also mentioned in two interviews:

D3: We have been discussing about reuse with second-hand companies and we have been thinking collaboration with them. […] We are wondering if we have enough resources to collect back our own products. […] Could we develop some new business models instead of trying to sell new products as much as possible?

D4: We want to encourage our customers to buy less, make more considered purchases and use products as long as possible. We think that ecological cannot be only a material choice. Instead it has to be a durable product, which can be modified according to changes in life. It has to be multifunctional and long lasting. We also want to encourage our customers to see the resale value of the product, which [for them] is also economically wise.

These quotes are direct statements supporting slower consumption ethos and show sustainable values behind the companies' activities and deep commitment towards product longevity. Yet, even if companies aim for long lasting design, they don't have information of the use phase and lifetime of their products, i.e. what happens to the garments after the point of purchase. Currently, designers can only design the potential for a product to be, for example, long lasting or recyclable. Thus, more research on the actual garment lifetimes would be needed**.**

Conclusions

The purpose of this paper was to study how clothing designers could contribute to a circular economy. Based on our preliminary findings and earlier studies, clothing companies must have a strong commitment to sustainability before designers can act accordingly. This is in line, for example, with Sihvonen (2019) who found in her study that sustainability does not enter into design practice if the company is not strategically committed. Enthusiastic indivi-duals are important but not enough.

The knowledge of sustainable and circular design practices is growing, but it seems that the industry practices do not follow similar pace. Material choices seem to dictate the sustainability discussion in the companies interviewed for this study. The designers of these companies approach sustainability and circularity mainly through high-quality and timeless design, easily suitable for reuse. Yet, there is no profound understanding of how to increase the circularity of products. A knowledge gap is obvious and even if designers are motivated to include sustainability into their design practices, they need more applied knowledge to implement it.

If aiming to transition from linear to circular fashion system(s) it is of substantial importance to apply more holistic approach into the design practice. One way could be through the provision of repair and maintenance services when targeting longer lifetimes of products (Armstrong et al., 2015). This could further aid companies in constructing the understanding of users' needs and garment lifetimes while creating a dialogue between the company offering and the customer. This way it could be possible to make effective changes in the design process to better serve the end customer as well as the environment.

To conclude, it is not easy to be a pioneering company in the circular economy context. The constant search for better material alternatives takes a lot of time and needs commitment from the company. The pioneering work also requires a lot of fate and high motivation among design teams. It implies a continuous development, collaboration and negotiation, as the following quote demonstrates:

D1: [W]e are constantly talking to the suppliers about making them [materials] as much recycled and sustainable ways as possible… I think we make them as good as we can for now.

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The Community of Transformative Repair

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Keywords: Transformative Repair; Reuse; Generative Design; Sustainability; Rrhizome.

Abstract: *Transformative repair* is repair that transforms the appearance, function or significance of an object, categorising a broad and open-ended collection of techniques for the material conservation of objects beyond conventional repair. Detailing aspects of the research project *Transformative Repair & Perception Research*, this paper argues transformative repair can be framed as a type of generative design. Generative aspects result from the engagement of professional product designers, architects and craftspeople in reparative response to the mix of practical and contextual information presented by broken and obsolete products. Repair can be understood to be a generative system from a number of different perspectives: at the local level in which a repairer must process (repair) the output (damage) of a generative event (a break), or at a repair-scenario level, in which designers respond to contextual relations, such as personal significance, history of use, and cultural or commercial notions of value. Deleuze and Guattari's concept of the rhizome (1987) is used to interrogate these processes. Several case studies are illustrated, including the transformations of ceramics, textile and glass objects. The proposal that creative forms of repair and reuse can be conceptually understood as a *novelty* generating transformative craft that minimises material waste is discussed in relation to how qualitative and quantitative evaluative criteria for transformative repair may be developed.

Introduction

Transformative repair is a term for repair that transforms the appearance, function or significance of an object. The term categorises a broad and open-ended collection of techniques for the material conservation of transformed objects, including practices variably termed visible mending, upcycling, dynamic repair and adaptive reuse. This paper introduces the research project *Transformative Repair and Perception Research* (TRPR), a yearlong study of transformative repair and reuse practices in regional areas of Australia, loosely modelled on participatory design principles of engaging both end users (object owners or custodians) and experts (visual arts processionals, including artists, architects and designers). The methods of this research will be very briefly described in order to foreground the key argument of this paper that transformative repair practices can be considered a form of generative design. This consideration, when understood through a conceptual framework of the rhizome proposed by philosophers Giles Deleuze & Félix Guattari (1987), facilitates new understandings of the practice illustrated with a number of examples from our case studies (Figs 1–11). This leads towards a discussion of its key benefit for sustainability, namely the capacity of transformative repair to generate novelty while conserving material and embodied energy relative to conventional forms of repair, reuse or recycling. A future direction for research, the development of qualitative and quantitative evaluative criteria, is briefly discussed at the end of the paper.

Method

After ethics clearance, TRPR began with an Expression of Interest release seeking broken or obsolete objects at two locations, Noosa, southern Queensland, Australia, and Launceston, northern Tasmania, Australia.[1] Objects were selected based on their repair or remaking possibilities and quality of contextual information, such as personal significance or history of use. The objects were then matched

[1] The expression of interest (EOI) was facilitated by project partners Noosa Regional Gallery and Design Tasmania, and distributed through their social media platforms and local networks.

to professional visual art experts with complementary skillsets or demonstrated capacities to experiment with novel materials. Object owners and experts were both interviewed before and after the resulting repair processes. Repairers were able to access the object owners first interview, in which the broken object and its history or significance was variably described, and the transformed objects were returned to their owners during their second interview.

TRPR was developed from the prior research project *Object Therapy* (2016). A fuller description of similar methods can be found in Keulemans, Rubenis and Marks (2017), noting that key differences are the addition of in-depth interviewing for repairers and a focus on matching object owners to repairers in their own communities. The latter aspect, a focus on regionality, is intended to prefigure at more extended longitudinal study of how to activate repair and remaking practices in specific communities.

Key outcomes for both projects are non-traditional i.e. aesthetic objects. Both projects generated a surprising range of repair possibilities from both general and eclectic products, demonstrating a fertile area of artistic practice. Professionals applied their existing and sometimes newly acquired material transformation skills to unexpected challenges presented by the broken objects. For *Object Therapy*, these outcomes are documented by exhibition (Keulemans, Rubenis, Marks & Honey, 2016). For TRPR, the outcomes are documented in a series of 8 videos that narrativise the repair process from dual perspective of owner and repairer (Keulemans & Rubenis, 2019).[2]

Both Object Therapy and TRPR are framed as participatory design in which non-expert members of the public influence and contribute to the transformation of their broken possessions by expert studio practitioners. It was hypothesised during TRPR development that the wide range of outcomes resulting from this participatory process suggested a *generative* function was at play. Erika Cortés and Aura Cruz published a paper (2018) proposing that participatory design can be framed as generative design, motivating the work of this paper to argue that transformative repair as a dynamic and participatory process is also generative design.

Transformative repair as generative design; transformative repair as rhizome

Generative design is a term primarily used to describe a broad range of practices predominantly centred around computer-aided design practices that use algorithmic inputs to vary design outcomes in a way typically beyond the expectation or control of the designer (Galanter, 2016) (Fisher & Herr, 2002). Examples include evolutionary design – notably beginning with Richard Dawkin's computer biomorph experiments in the 1970s – and other optimisation practices used in product design and engineering, especially automotive, aeronautical and medical industries. However, theoretically, generative design does not require the use of computer tools and can pertain to others systems that includes an element of chance or variation modulating the production of novel outcomes in human collaboration (Galanter, 2016: 150–152) Human input typically includes the setting of the initial parameters or operational code based on a configurative design-led hypothesis, and the selection of outcomes based on aesthetic or functional criteria (which can also be fed back in to the system in the case of circular generative processes).

Keulemans (2012) has previously used the Deleuzian-Guattarian concept of the rhizome to better understand aesthetic outcomes of generative design processes and proposed selection and presentation strategies for generative designers.[3] The concept of the rhizome is also used by Cortés and Cruz due to its correspondence to the generative processes they observe in participatory forms of design that are modelled on Manzini's

[2] These videos can be viewed at https://australiandesigncentre.com/object-platform/films-transformative-repair/ and at transformativerepair.net

[3] In Keulemans' prior paper, it was argued that the 'fecundity' of generative design – its capacity to generate many and multiple variations from an initial starting point - has the potential to both captivate and overwhelm an audience, dependent on practices of selection and framing. Drawing from a range of generative practices across art and design, it was proposed that outcomes from within a generative family presented *en masse* and not selectively filtered for interest, had the greatest potential to aesthetically overwhelm. The significance of this insight for transformative repair is that may sensitise the repairer to similar aesthetic effects.

Design for Social Innovation (2015) and, in particular, those that use the generative research tools proposed by Sanders and Stappers (2012).

The principal analogy of the *rhizome* concept is the botanical rhizome (from the Ancient Greek: *rhízōma* "mass of roots") a runner- like network of underground rootstalks. A key feature of the concept is the principles of heterogeneous connection that draws attention to the comprehension of the multiple, and multiplicities, within the network: This is the interconnectedness of moving parts, or "terms in play" (Deleuze and Guattari 1987: 7–9, 34, 239). Deleuze & Guattari position the concept in contrast (but not opposition) to the arborescent tree model, a more hierarchical arrangement of components in a typically linear structure; root, trunk, branch, leaves. They consider the hierarchical structure of the arborescent model more correspondent to paradigmatic social-political structures, logics of production and logics of capitalism. Such logics are challenged by the dynamic, heterogeneous and non-hierarchical model of the rhizome.

An important consideration is that any knowledge emerging from a rhizomatic system cannot be representational because its moving parts are dynamic. Rather, knowledge functions as a tool productive of practical reasoning (Cortés & Cruz, 2018: 46). We note that there is an epistemological question to answer: how can the role of 'fixer' generate new ways of seeing and understanding the world of products, different to the more conventionally understood roles of 'designer' or 'user'? (Jackson, 2014: 229). We propose that the rhizomatic way of interrogating transformative repair as generative design has potential to help answer this question, especially in regard to how repairers develop an understanding of the world of products through navigating a rhizomatic mix of contextual information presented by products in their broken state.

Cortés & Cruz likewise lean on a rhizomatic framework to proposes there is benefit in understanding participatory forms of design as generative design, because the "rhizomatic organism grows indefinitely and are also destroyed in their oldest parts" in their adjustment to circumstances (Cortés & Cruz, 2018: 46, paraphrasing Deleuze & Guattari, 1987). They propose the benefit of this conceptual framing is to understand the dynamic nature of participation, in which experts and non-experts actively acquire new skills, tools or mindsets that open further possibilities for creation, empowerment and autonomy (Cortés & Cruz, 2018: 45–6). We note that Sanders & Stappers, and Cortes & Cruz's framing of generative tools and generative design are focused on participatory forms of 'creativity-generating' human activity and not entirely correspondent with the more widespread framing of generative design as 'form-generating' in its computational modes. As the generative art theorist Philip Galanter argues, the inclusivity of the definition means theory can focus on "systems, their roles, their relationship to creativity and authorship, system taxonomies and so on" (Galanter, 2016: 151). These are also areas of interest for transformative repair theory and additionally the differences in framing are productive: we propose that generative design has the scope to apply to transformative repair in both its creativity-generating production of repair techniques, tactics and mindsets within a community of practitioners *and* its form-generating production of transformed objects. The rhizomatic model, as deployed in Keulemans (2012) in relation to form-generation, and as deployed in Cortés and Cruz (2018) in relation to creativity-generation, can likewise interrogate transformative repair.

Firstly, in the transformative repair of an object, it is frequently the 'oldest parts', that which is broken or obsolete, that are renewed or replaced by remaking. Secondly, the rhizome concept conveys the dynamic engagement of transformative repairers to a practical and contextual scenario. They must flexibly adapt to a range of products and their varied typologies of damage or obsolescence, in order to practically transform them in response to a heterogenous mix of contextual information, such as but not limited to provenance, personal significance, history of use or other notions of value. It is the rhizomatic interactions of such practical and contextual parts, and how they mediate between the object owner and repairer, that give shape to the community of transformative repair.

We likewise consider that the goals that Cortes & Cruz propose for participatory design should be the same desired from the transformative repair process: creation, empowerment and autonomy – for consumers and repairers alike in how they manage the consequences of owning and interacting with objects that break or decay as a result of their emergence from waste-permissive linear economy paradigms.

This paper now uses this rhizomatic framing of transformative repair as generative design in order to better understand the outcomes of our case studies.

Case Studies

The need to destroy or replace the 'oldest parts' in the act of remaking is clear in the first example of architecture firm Bark Design (Noosa, Queensland) and their transformation of an old shawl, hand-embroidered by its owner Domi when she arrived in Australia as a migrant many years ago (Figures 1 & 2). Their concept to turn the shawl into a pendent lamp was in response to the owner's description of using the shawl as sun and privacy screen on her deck. The washing and cleaning of the shawl made its translucent qualities re-emerge for Bark Design's Lindy Atkins and Steve Guthrie. Their vision for the lamp required the removal of the oldest parts (the torn and sun-damaged areas) to selectively conserve the areas of most intense embroidery (Figure 3). We note this is the area of most sentimental interest and embodied labour-energy, something recognised by Atkins and Guthrie.

Figure 1. Domi' s shawl.

Figure 2. Domi' s shawl, transformed by Bark Design.

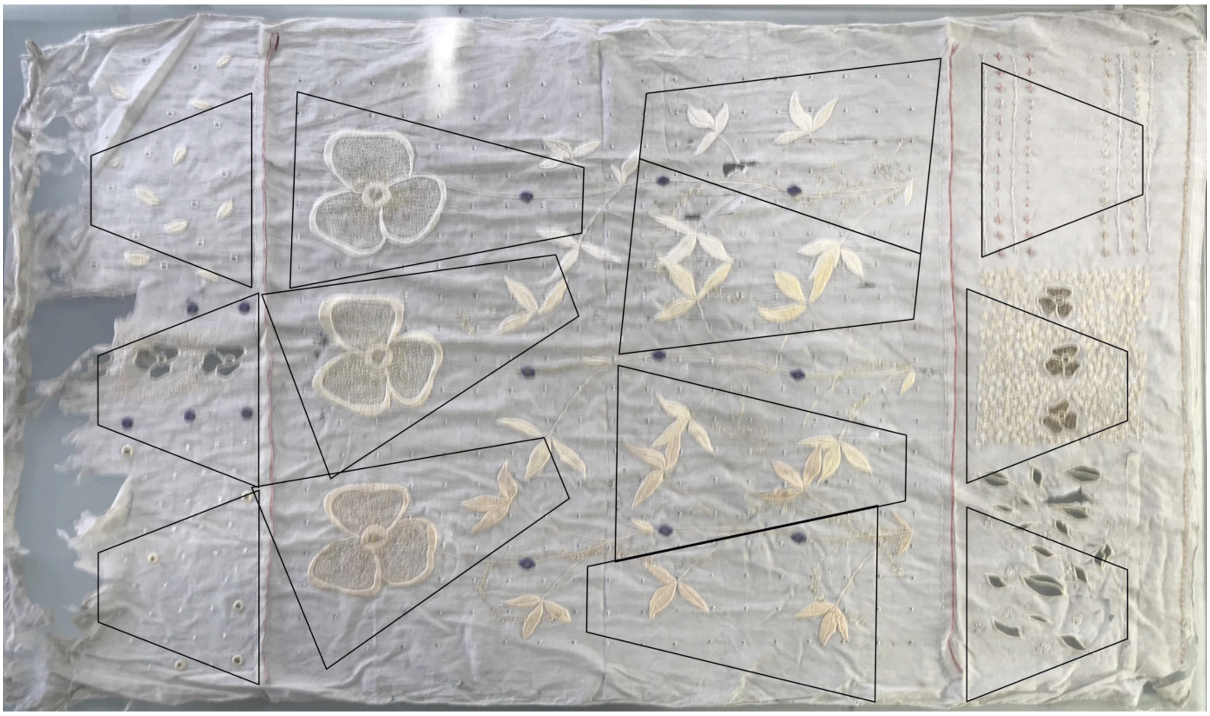

Figure 3. Cutting study for Domi' s shawl. Image supplied by Bark Design.

Converse to this practice of material selection, Peter Bowles of Glass Manifesto (Launceston, Tasmania) aspired to transform every part of material from the broken vase presented to him (Figures 4 & 5). Many repairers commented on the difficulty of the assignment and this was true for Bowles. When he first saw the vase, he noted it was “monumentally smashed”, and that its particular kind of crystal glass was soft and “tricky” to work. In ordinary circumstances he said he would not believe any repair would be possible. Nonetheless, Bowles accomplished a number of sophisticated glass crafting processes in his repair. This includes trimming broken edges and slicing off the bottom to extract the signature of the original manufacturer, Lalique, within a disc. This slicing exposed a transparency through the base of the vase when inverted, transforming it into a display glass for which to view a pair of glass earrings crafted from the broken vase’s trimmed edges (Figure 6). He then melted down the remaining trimmed edges and blew them into a second vial or vitrine shaped display glass. Reminiscent of a scientific museological display, this display glass captures and transforms the frosted ivy leaves in the original shards into cloudy bubbles that drift across the glass surfaces like a cluster of stars or nebulae (Figure 7). Both display glasses sit on wooden plinths, with the second vial-like display glass holding the disc with the signature.

In this case we see a generative aspect developing from Bowles’ desire, explicitly stated, to use as much of the material as possible. Bowles used a myriad of details from our interview with Mignon, the owner of the vase, to inform his aesthetic outcomes. For example, an off the cuff description of the vase falling from a Jarrah wood bookcase informed Bowles’ decision to make the base for the second display glass from the same wood. The life-journey Mignon had experienced, travelling from Perth in Western Australia to Launceston, likewise informed this decision to make the first display glass base from Huon Pine, a wood geographically particular to the Tasmanian island. It is worth considering that such contextual information was not hierarchical or structured in the way it presented to Bowles. Rather, Bowles parsed and responded to the information provided by Mignon in a way that follows the flows of a rhizome. Concerns that are typically top-down or hierarchical in affirmative design—conventions of functional use, commercialisation or suitability for manufacturing—are mostly ignored in favour of responding to an organic human narrative and a goal of meeting unstructured and loosely articulated aspirations. This is to coax an emergence of ‘desire-lines’ from the rhizome. Bowles found this challenging, but rewarding, albeit noting he would not be satisfied until he knew what Mignon thought of the repair.

Figure 4. Mignon’s broken Lalique vase.

Figure 5. Mignon' s vase transformed by Peter Bowles of Glass Manifesto.

Figure 6. Mignon' s vase transformed by Peter Bowles: the first display glass and earrings.

Figure 7. Mignon' s vase transformed by Peter Bowles: detail of the second display glass.

Conversely, ceramist Sophy Blake (Noosa, Queensland) thought the assignment to repair a broken cup was "far less of a challenge" than she initially thought it might be (Figures 8 to 11). When first shown the cup, her mind "raced with ideas", so for her the challenge was in "honing" down the range of possibilities. In her second interview, post-repair, she notes how inspired and connected she felt towards the story of the broken cup, as described its owner. The "honing down", a process of designing one way from a selection of many, is then determined by wanting to do service to that story. Nonetheless, the generative aspect asserts in the multiple crafted outcomes (Figure 10). These progressed well beyond a simple repair of the cup. Blake added many sculptural and decorative elements. For example, the sculpted hands that hold the cup were a response to the owner Denise' interview in which she described how she held the broken cup in her hands immediately after it broke, contemplating the value of the cup as a gift from her daughter. Blake added little ceramic flowers decorating the broken and missing handle, a response to the material conditions of the cup's damage (Figure 11). Crucial to Blake's decision making was a need to materialise Denise's narrative of the cup, that characterised the women in her family and established a thematic of esteem for familial care. In this, Blake achieves a correspondence to the desire-lines emergent from a rhizomatic scenario.

Figure 8. Denise’ s broken cup.

Figure 9. Denise’ s broken cup, transformed by Sophy Blake.

Figure 10. Denise’ s broken cup, transformed by Sophy Blake.

Figure 11. Denise’ s broken cup, transformed by Sophy Blake: detail of the broken handle repair.

Transformative Repair as generative design for sustainability

In this paper we hoped to illustrate some of the generative outcomes of repair observed through our case studies. Framing the repair of broken objects as an act of generative design brings into question the aesthetic/sustainability relation value in a world increasingly desperate for solutions to socio-environmental problems of overproduction and hyper-consumerism. Such problems are, at least in part, the consequences of a human desire for novelty. This can be seen for example in the persistent desire for novelty in new product streams and the expansion of consumption possibilities promoted and exploited by marketing. Generative design, as per affirmative or conventional design, also creates novelty. It has no inherent environmental imperative, and superficially its novelty generating capacities may work against the sustainable need for fewer, better products. But sustainability imperatives can be ‘programmed’ into generative design. This is possible because generative design accepts purpose-driven constraints based on configurative design-led hypotheses. For example, some forms of evolutionary design or optimisation-based forms of generative design aspire to lightness, conservation of material or other forms of efficiency that may have environmental benefit.

Framing transformative repair as generative design then begs the question of how environmental imperatives can be programmed in while retaining its novelty generating capacities. In transformative repair there is potential to conserve material and embodied energy – the material and energy used to manufacture, transport and maintain the product. This conservation is relative. It is practically and theoretically better than the typical alternative of disposal and re-purchase of a new product. It is theoretically and potentially better than industrial recycling, that may conserve material as feedstock for new products, but loses embodied energy and requires new energy for new manufacturing. The conservation potential of transformative repair is however also relative to the *more* efficient forms of *conventional* repair that may solely restore function and likely need less material or energy to complete. The downside to conventional repair is, however, that it does not generate novelty or necessarily remake the object to fit a new circumstance. Arguably, it does less to re-value the object in the perception of the user and potentially conventional repair may perpetuate a stigma that results from extending the life of an old or obsolete product.

In this sense, transformative repair strikes a balance that may be desired in particular circumstances. While it may not conserve as much material or embodied energy as conventional repair, such conservation has little value if it does not foster use or appreciation, or cultivate a desire for further repair. As discussed in a prior paper (Keulemans, 2018), transformative repair has this potential. It saves material too, but more consequentially, by responding to an array of dynamic contextual information (rhizomatic information) within design practices productive of desirable aesthetic outcomes, transformative repair has potential to create a flourishing of interest for new arts and crafts that also conserve material and energy. Therefore, transformative repair can be understood specifically and theoretically as a design-led transformative craft that generates novelty while minimising material waste. It appears suitable for certain circumstances; from our case studies that seems to be products of high contextual value without easy application of conventional repair, but there may be other viable product categories.

However, as a generative system, each outcome is typically varied and needs individual assessment. Further steps in the evaluation of creative repair practices is the development of qualitative and quantitative criteria. User impact, such as the perception of responses to a wide range of user-supplied contextual information, might comprise a qualitative aesthetic criterion, while life cycle analyses and longitudinal studies of use might comprise a quantitative criterion. How such a metric could them be extrapolated to larger user groups, scaling up for more effective mass forms transformative repair requires investigation. However, this knowledge might reasonably be extracted from a case study of existing ‘upcycled’ product ranges. Or it could emerge through the use of consumer research frameworks, such as user group consultation, when added to future studies of transformative repair.

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PLATE
Product Lifetimes And The Environment

Wardrobe Sizes and Clothing Lifespans

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Keywords: Clothing; Lifespan; Wardrobe; Garment; Sustainability.

Abstract: It is easy to assume that a large wardrobe is characterized by excessive clothing and high acquisition, with little use of each garment and thus a big environmental impact. However, it is also possible to think the opposite; that the large wardrobe is a result of clothes remaining in use for a long time, that disposal happens rarely, while acquisition can be normal or even low. Whatever the reason, in a large wardrobe it is more likely that clothes become old before the technical life expires. This is because many of the garments are seldom used. Small wardrobes are often presented as favourable for both people and the environment, and as part of an ecological-friendly lifestyle, but we know little about the interaction between wardrobe sizes, longevity and the environmental impact. In this paper, we investigate this relationship based on survey material from five countries; China, Germany, Japan, UK and the USA. We find that consumers with large wardrobes use their clothes longer, but consumers with small wardrobes use their clothes more often before they are disposed. We conclude that a good utilization of resources is possible with both large and small wardrobes, but in different ways. As we work towards more sustainable clothing consumption, we need to approach consumers differently, in order to give constructive advice to all.

Introduction

Wardrobes are complicated to get an overview of and study in detail (Fletcher & Klepp, 2017). They can consist of active and passive parts, various garment categories, clothing for different occasions such as everyday, sports and parties, and clothing for the seasons. We know that the size of wardrobes vary not only a lot, but tremendously. People who dress similarly take part in a daily chore of choosing what to wear based on a selection of clothes, which can be only one piece and to up to dozens in some garment categories. During the past 100 years, a distinctive feature of clothing consumption is the growing size of wardrobes (Klepp & Laitala, 2015). An average wardrobe in Norway during the 1860s consisted of about 44 garments, including socks and headwear but excluding shoes (Klepp & Laitala, 2015; Sundt, 1869/1975, p. 235), while farmers in Herjädalen in Sweden in the 1800s had 54 to 71 garments (Ulväng, 2012). Today it is complicated to count all the garments in our wardrobes, but we have estimated that Norwegians in 2017 owned an average of 85 kg clothes, corresponding to 379 garments, but a wardrobe with more than 500 items is not unusual (Klepp & Laitala, 2015). Two surveys in the UK have indicated that the British have between 115 and 127 clothing items in their wardrobe, excluding footwear and accessories (Gracey & Moon, 2012; Langley, Durkacz, & Tanase, 2013). According to international surveys conducted by Nielsen, the average male owned 122 articles of clothing in 2018, which has increased from 114 in 2012. The average woman owned 141 articles of clothing and this has increased by 10 items in the last 7 years (The Nielsen Company, 2012, 2019). The same data based on recent figures is the basis for our analysis.

Extending the life of existing textiles is a central strategy in the work towards sustainability (Cooper et al., 2013; Jørgensen et al., 2006; Laitala, Boks, & Klepp, 2015). Studies that quantify environmental impacts of extended product lifespans show that, extending product lifetime is desirable in all instances, except where there is a significantly more efficient new product available. Extending lifetimes of 10% of T-shirts on the market would reduce circa 100,000 tonnes of CO_2eq and 2000 tonnes of waste per annum in the UK alone (Defra, 2011).

A review of literature on the use phase of clothing showed that the average age across all garment categories was four years (Laitala, Klepp, & Henry, 2018). Langley et al. (2013)

showed further that there are some systematic variations, such as that people with low income or large wardrobes report longer clothing lifespans, and those with high interest in fashion and brands correlate with shorter lifespans.

The most common way to measure lifespan is age in years, understood as the time from a garment was acquired until it goes out of use. The number of times used can also be measured in different units, such as days, hours, or washing cycles. WRAPs clothing longevity protocol gives examples of garment categories and their active use in a more detailed form than just number of wears, and gives average wear days per year, per month, and even hours of wear for the total lifetime (Cooper et al., 2014).

Due to wear and tear, alternating between two jeans will lead to shorter lifespans measured in years, than alternating between ten jeans. This indicate that clothing lifespans can increase with a larger wardrobe, but is it really so? The relationship between clothing longevity and wardrobe sizes is complicated. The mentioned calculation is based on the jeans being disposed because of wear and tear. The disposal could also happen because the garment becomes too small, or out of fashion, but in that case, the jeans are not worn out during disposal. As such, we wish to investigate the relationship between clothing longevity, wardrobe sizes and the environmental impact, by asking *whether there is a connection between the size of wardrobe and clothing lifespans, and, do smaller wardrobes entail lower environmental impacts?* We will discuss these questions based on two different assumptions presented below.

Theory

Assumption 1: Small wardrobes reduce environmental impacts

Small wardrobes are often presented as favourable for both people and the environment, and as part of an ecological friendly lifestyle (Herziger, Berkessel, & Steinnes, Submitted). Several books and blogs define modern minimalism as glamorous, and describe how 24 or 33 garments are enough and preferable (Becker, 2016; Klepp & Laitala, 2015; Kondo, 2014; Wolfe, 2018). These wardrobes are sometimes referred to as 'the Capsule Wardrobe', where the aim is to have a few selected outfits suitable for any occasion without owning excessive items of clothing. This is usually achieved by buying what are considered 'key' or 'staple' items in coordinated colours and by disposing of the garments in passive use.However, small wardrobes is dependent on all clothes being in good condition and having extensive usage. In addition, such wardrobes predicate the owner's ability to purchase less items. It may seem likely that a transition to a Capsule Wardrobe will occur by rapidly disposing items, and not by acquiring fewer items over time. Thus, smaller wardrobes do not necessarily entail lower environmental impacts, besides taking up less space.

Assumption 2: Large wardrobes reduce environmental impacts

Assumption 2 is not as common as assumption 1, but there are still valid arguments for this correlation. A preferable usage of resources would involve utilizing all items to their final end. When a wardrobe is large because nothing is disposed of, the items can still increase, even though few items are bought new. Garments can be acquired through other practices, such as receiving gifts or hand-me-downs, or by purchasing second-hand clothing. When the garments eventually become too worn or old, they can be reused for other less important purposes and occasions, such as chores in the home. It is also possible to store garments that are too small or too big, and wait for a development in terms of body size or figure, occasion, or fashion. In older books giving advice for clothing, the recommendation is to own two shirts and two trousers to go with one suit jacket (Klepp, 2000; Roetzel, 1999), because enabling clothes to repose will increase their lifetime. Clothing longevity can be extended by owning items that disengage our best and most used items, especially when the norms for clothing demand something else than our favourite pair of jeans.

Method

This article is based on a consumer survey conducted online by AC Nielsen during November-December 2018. The focus is on five countries with large clothing markets: China, Germany, Japan, the UK and the USA. A bit over two hundred respondents from each country answered to a comprehensive web-based survey on their wardrobe contents. Questions included number of items owned in specified categories, and for a selection of these items, details such as clothing lifespan, active use time, wear occasions, materials, and laundering practices were registered.

The survey focused on working age adults (age 18 to 64 years). The sample was pre-stratified to represent the gender distribution and other demographics of the country in question. The respondent demographics for each country are given in Table 1. The data is weighted to the population. For enabling the analysis, one database was prepared per respondent (N=1111), and another per garment (N=53 461).

	CN	DE	JP	GB	US
Respon-dents	230	224	224	213	220
Garments	10595	11705	12022	9384	9755
Men	54%	51%	51%	47%	49%
Women	46%	49%	49%	53%	51%
Age 18-29	41%	19%	19%	22%	21%
30-49	49%	45%	50%	52%	44%
50-64	10%	36%	31%	26%	35%

Table 1. Respondents' background variables. Weighted data.

To prevent respondent wear-out, the number of clothing categories assessed in detail was limited to a list of "focus categories" that were[1]:

- Suits (2pc)
- Pant & Trousers
- Skirts and dresses (F)
- Jackets & Blazers
- Overcoats & Raincoats
- Jumpers, Sweaters & Cardigans
- T-shirts & Polos
- Singlets & Tanks (F)
- Socks
- Stockings (F)
- Thermal Underwear
- Sports T-shirts & Tops
- Sports Singlets & Tanks
- Scarfs, Shawls, Pashmina's & Stoles

This means that questions asked for specific clothing items were only stated for these types of clothing. Item-specific questions were also limited to a maximum of 10 items per category to combat respondent fatigue.

In the analysis, we have categorised small, average and large wardrobes by dividing respondents into three groups based on the number of garments they reported to own. The small wardrobes consist of 79 items or less, average size have 80-129 items, and large wardrobes have over 130 items. All the presented results on differences between wardrobe sizes are significant (p<0.05).

Limitations

The survey was not intended for the questions posed in this article. If they were, it would have been easier to look specifically at large and small wardrobes and then the difference between acquisition, disposal, and lifespan.

Results

When looking at the relationship between wardrobe size and garment age in years, small wardrobes consist of more new garments than larger wardrobes (Fig.1). The difference is from 3.9 to 6.2 years, with the medium-sized wardrobes in between. The difference is rather significant, as it amounts to 2.3 years, which, as an example, is more than half of the total lifespan for garments in small wardrobes.

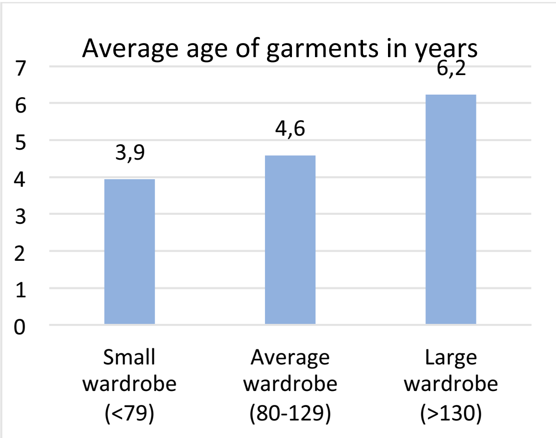

Figure 1. Average age as in number of years for how long garments are kept in wardrobes by wardrobe size. (N=46 857 garments).

A less used method to measure lifespans is to calculate the number of wears. In terms of method, this is also more complicated. Our data is based on estimations from consumers, while the preferable would be various types of recordings of wear. In the following, we combine the total number of wears estimated by user, including planned future wear.

[1] Those marked with F were asked only from female respondents.

The data indicate that also this method for measuring lifespans creates differences between large and small wardrobes, but in the opposite direction of the previous measuring. Garments in small wardrobes are worn more times, with the difference being 74 wears in large wardrobes and 83 wears in small wardrobes (Fig. 2). Garments in average sized wardrobes are used as much as those in large wardrobes.

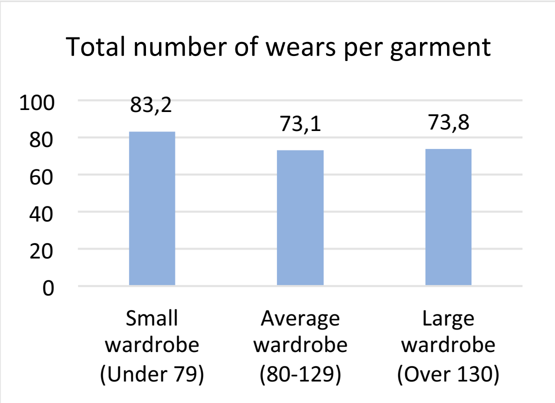

Figure 2. Total number of times garment is worn by current user based on questions «How many times have you worn this item?» and «How many times do you expect to wear this item in the future?» (N=38 948 garments).

This difference becomes even clearer in the number of times a garment is worn during one year. Garments in small wardrobes have the most frequent wear (Fig. 3).

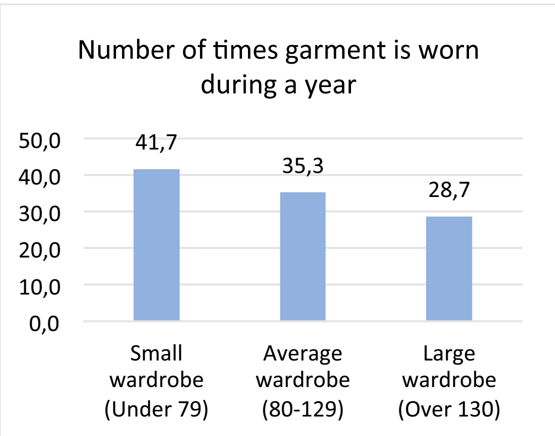

Figure 3. Number of times garments is worn during a year based on answers to questions « How often do you typically wear this item? » (N=37 709 garments).

The number of items bought new is an important factor for measuring the environmental impact. Purchasing new items contributes to production and transportation, and generates waste. We asked "In the last 12 months, approximately how many new items of clothing have you bought, including pairs of socks and underwear?". This is likely easier to estimate than the number of wears. These results also indicate big differences between small and large wardrobes (Fig. 4).

Figure 4. Number of new clothing items purchased last 12 months (N= 1042 respondents).

People who owned large wardrobes purchased more clothes, a total of 22.5 items per year, while those with small wardrobes purchased 13.9 items. Both of these numbers are high, as it estimates to more than one new garment per month.

Only one percent of those with small wardrobes had bought over 50 items during the past year, while 11 % of those with large wardrobes had done so.

Concerning clothing disposal, 47 % of garments in small wardrobes are likely to be disposed of due to wear and tear, while the same figure for large wardrobes is 42 %. Owners of large wardrobes were less likely to know why the specific garments went out of use (9%) compared to 4 % in small wardrobes, and they experienced that lack of space was a more likely reason for disposal (6 % in large wardrobes compared to 4 % in small wardrobes). About half of the garments are aimed to be delivered to reuse, either donated to charity, friends or sold, and this share was higher in large wardrobes (54% of garments) than in small wardrobes (50%).

Conclusions

The first question to our study sought to determine if there is a connection between the size of wardrobes and clothing lifetimes? Our results confirm that consumers with large wardrobes use their clothes longer, as anticipated by assumption 2. This means that owners of those wardrobes have several outfits to choose from for different occasions, and can be diverse in their dressing if they wish so. On the other hand, we find a distinct difference between the owner's estimation of total number of wears, present and future, and these results support assumption 1. Garments in small wardrobes are used more. These results indicate that it will be interesting to look closer at the owners of large and small wardrobes in relation to other aspects of clothing habits.

Our second question asked if small wardrobes entailed lower environmental impacts. If we limit the scope of this question and include only newly purchased clothing, then the answer would be yes. In terms of less purchases of new clothing, assumption 1 makes a valid claim that small wardrobes have lower impact. However, if we note that clothing lifespans is decisive to the total environmental impact, the answer will depend on how we measure lifespans. If we estimate lifespans in number of years, the answer will be that consumers with large wardrobes keep their clothes longer in active use, in line with assumption 2. On the other hand, if we estimate based on the number of times worn, assumption 1 is accurate. Consumers with small wardrobes use their clothes more frequently before they are disposed. Having an excessive amount of clothing in the wardrobe can be a bother for some and a joy to others. Both small and large wardrobes will likely have their own advantages for each person and in relation to the total environmental impact from clothing consumption. Our results show that both assumptions 1 and 2 are accurate, but depend on given circumstances. A preferable utilization of resources is possible with both large and small wardrobes, but in different ways. As we work towards more sustainable clothing consumption, we need to consider how to approach this differently for consumers with different habits. In order to give constructive advice to everyone, we need more knowledge about the connection between wardrobes, clothing consumption and environmental impacts.

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Estimation of Lifespan Distribution of Motorcycles in Vietnam

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Keywords: Lifespan Distribution; Population Balance Model; Vietnam; Motorcycle.

Abstract: Demand for various products has rapidly increased in developing countries due to rapid urbanization, increase in population, and change in lifestyle, which potentially causes a significant amount of waste shortly. It is expected that, because of the rapid increase in wastes, the current capacity of facilities would not sufficiently meet the requirement of proper treatment and recycling, potentially leading to vital environmental pollution. In particular, Motorcycles are used as major transportation means in Vietnam. The average possession of motorcycles per capita is high, approximately 36% as of 2016, and it is expected to continuously increase due to economic growth. Although there are several informal recycling sectors such as "craft village", hazardous substances are not adequately treated, causing air pollution and soil contamination in the surrounding environment. Therefore, it is of paramount importance to predict the number of wastes of motorcycles in Vietnam. This study assessed the lifespan distribution of motorcycles in Vietnam through questionnaire survey by using the Weibull distribution and predicted the number of motorcycle wastes and metals contained in obsolete motorcycles in Vietnam in 2019-2030. Considering the increase in the number of scrapped motorcycles and the demand for resources induced by motorcycles, the estimated value might assist policymakers in developing the strategy for efficient motorcycle recycling.

Introduction

Demand for various products has rapidly increased in developing countries due to rapid urbanization, increase in population, and change in lifestyle, which potentially causes a significant amount of waste shortly (Takahashi, et al., 2017). It is expected that, because of the rapid increase in wastes, the current capacity of facilities would not sufficiently meet the requirement of proper treatment and recycling, potentially leading to vital environmental pollution.

Among various sectors, the global increase in transportation means is significant. According to International Energy Agency (IEA) (International Energy Agency, 2012), the fuel use in road transportation in 2050 is expected to increase by two times compared to that in 2010. In particular, motorcycles are used as major transportation means in Vietnam. The average possession of motorcycles per capita is high, approximately 36% as of 2016 (General Statistic Office of Vietnam, 2016), and it is expected to continuously increase due to economic growth (Mitsubishi UFJ Morgan Stanley Securities Co., Ltd., 2014). Although there are several informal recycling sectors such as "craft village", hazardous substances are not adequately treated, causing air pollution and soil contamination in the surrounding environment (Hoang, et al., 2019). Therefore, it is of paramount importance to predict the number of wastes of motorcycles in Vietnam.

One of the approaches for predicting the amount of wastes is an estimation of the lifespan distribution. In this study, the lifespan is defined as a duration from shipping the product to discarding it by the final owner. The Weibull distribution has widely been applied to the estimation of lifespan distribution in various products in earlier studies to calculate the amount of waste on electronic home appliances and car (Tsasaki, Oguchi, Kameya, & Urano, 2001; Xueyi & Kang, 2017; Kim, Oguchi, Yoshida, & Terazono:, 2013; Yamasue, Nakajima, Okumura, & Ishihara, 2006). It is expressed by a shape parameter and the average lifespan. In order to improve the applicability of the estimation of the lifespan distribution to various products, a generalization of shape parameter in the Weibull distribution has been addressed in several studies (Oguchi, Kameya, Tasaki, Tamai, & Tanigawa, 2006; Oguchi & Fuse, 2012). These studies highlighted the following two hypotheses. First, the shape parameter can be possibly fixed for electronic home appliances in the same area except for unique items (Oguchi, Kameya, Tasaki, Tamai, & Tanigawa, 2006). Secondly, the shape parameters can be potentially fixed for many countries in the case of a car (Oguchi & Fuse, 2012). However, since there are cases where the shape parameter cannot be fixed in these two hypotheses, the identified shape parameters based on the hypothesis cannot merely be applied to various items and areas. Therefore, it is necessary to investigate both item and area separately at present, although it requires a lot of time and effort such as questionnaire survey to estimate the lifespan distribution. In particular, the number of wastes of motorcycles in Vietnam should be preferentially investigated, considering their severe influences on society and the environment.

Therefore, the purpose of this study is to estimate the lifespan distribution of motorcycles in Vietnam through questionnaire survey by using the Weibull distribution and to predict the number of motorcycle wastes.

Methodology

First, statistical data of the number of registered motorcycles from 1992 to 2016 (Nguyen, 2005; Nguyen, Duong, Nguyen, & Nguyen, 2015; United Nations, 2018) and the number of owned motorcycles per 100 households every two years from 2002 to 2016 was collected (General Statistic Office of Vietnam, 2016; General Statistic Office of Vietnam, 2012). Based on the collected statistical data, the average possession of motorcycles per capita in 2030 was predicted by using a logistic model. Logistic model is indicated in the following equation.

$$n_t = \frac{n_{max}}{1 + Aexp\{-B(t - t_0)\}} \quad (1)$$

Where, n_t is the average possession of motorcycles per capita, n_{max} is the maximum possession of motorcycles per capita, t_0 is the first year used as input for the logistic model.

Then, the number of motorcycles owned in the future was calculated by multiplying the average possession of motorcycles per capita with the estimate of the future population, presented in the following equation.

$$N_t = n_t \times H_t \quad (2)$$

Where, H_t is the population in Vietnam in the year *t*. The estimate of the future population in Vietnam is taken from the report of United Nations (United Nations, 2017).

Next, a web-based questionnaire survey was conducted from November to December 2018. A total of 187 valid questionnaires were collected.

The major contents of questionnaire include three main items; that is, the owned motorcycles at present (e.g., manufacturer, engine displacement, production year, mileage, year of acquisition, method for acquisition / discarding), the owned motorcycles in the past (e.g., year of discarding and reason of discarding), and the characteristic of respondents (e.g., gender, age, residential area, income and occupation).

In the questionnaire, the year of manufacture for each product was the main focus. The lifespan distribution of motorcycles was analysed by using Weibull distribution on the basis of the results of a questionnaire survey.

Weibull distribution is indicated in the following equation.

$$F_t(y) = 1 - \exp\left[-\left(\frac{y}{\bar{y}}\right)^{\beta} \cdot \left\{\Gamma\left(1 + \frac{1}{\beta}\right)\right\}^{\beta}\right] \quad (3)$$

$$= 1 - R(y) \quad (4)$$

Where, $F_t(y)$ is the accumulated obsolete rate of age *y* that reached the end of life in the year *t*, *y* is the age of motorcycles, $\bar{y}$ is the average lifespan of motorcycles, β is a shape parameter. Γ is a gamma function. $\mathrm{R(y)}$ is the survival rate of motorcycles in year *y*.

Then, the generation amount of obsolete motorcycles was estimated by using a population balance model. This model was widely used in the calculation of the generation amount of durable goods and described in the form of the relation between the number of possessions, shipments, and disposals, as presented in the following equation.

$$N_t - N_{t-1} = W_t - P_t \quad (5)$$

Where, N_t is the number of motorcycles owned in the year *t*, W_t is the number of motorcycles discarded in the year *t*, and P_t is the number of motorcycles shipped in the year *t*.

The number of motorcycles discarded in the year *t* is calculated in the following equation.

$$W_t = \sum\{P_{t-i} \times f_t(i)\} \quad (6)$$

$$f_t(i) = R_t(i-1) - R_t(i) \quad (7)$$

Where, $f_t(i)$ is the obsolete rate of age *i* that reached the end of life in the year *t*, $R_t(i)$ is the survival rate in year *i* after motorcycle is shipped.

Finally, based on the number of shipments estimated by the population balance model, the number of wastes in the following year could be predicted. By repeatedly calculating the number of wastes and the number of shipments for each year in this manner, the number of wastes in the future was estimated.

After estimating the number of wastes in Vietnam, the amount of metal contained in obsolete motorcycles was calculated. The composition of motorcycles was taken from literature survey (Berzi, Delogu, Pierini, & Romoli, 2016). Since the data presented in their work correspond to the motorcycle different from ones mainly used in Vietnam, for simplicity, the obtained data was converted to the weight of motorcycles mainly used in Vietnam, as presented in Table 1.

element	Rate [%]	Weight [kg]	Converted weight [kg]
Steel	80	146.42	70
Aluminum	116	29.28	14
Copper	2	3.66	1.75
Lead	2	3.66	1.75

Table 1. The data of composition of motorcycles (Berzi, Delogu, Pierini, & Romoli, 2016).

Results and Discussion

The average possession of motorcycles per capita in Vietnam in 2004-2030 is presented in Figure 1. The maximum possession of motorcycles per capita in Vietnam was approximately 44%. While the number of vehicles owned by statistical data in 2016 was approximately 34 million units, the number of motorcycles owned in 2018 and 2030 was estimated to be approximately 37 million and 46 million units, respectively.

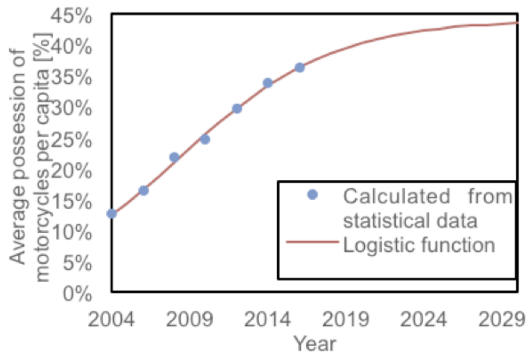

Figure 1. Average possession of motorcycles per capita in Vietnam in 2004-2030.

The average lifespan of motorcycles in Vietnam is presented in Figure 2. The average lifespan based on the questionnaire result was estimated as 16.9 years. The shape parameter in the Weibull distribution was 1.6.

It must be noted that there is the dispersion between regression curve and smoothed and standardized raw data. The determination coefficient is 0.40. This would be due to the lack of number of respondents. Further data collection is required to improve the reliability of model.

According to a survey in Hanoi in 2016 (Yamasue, Cravioto, Nguyen, Oguchi, & Daigo, 2017), the shape parameter in the Weibull distribution was 2.4 for TVs, 2.3 for refrigerators, 2.3 for air conditioners, 2.2 for washing machines. It would appear that the shape parameter for household electric appliances cannot be applied merely to motorcycles even in the same country.

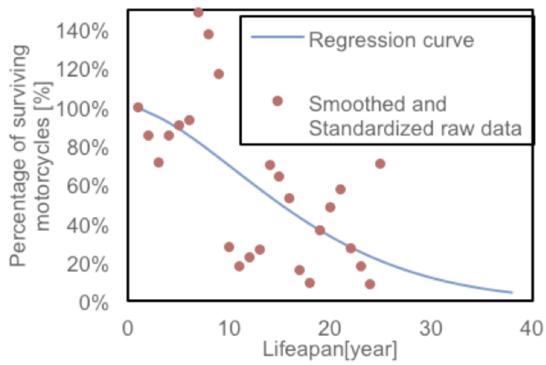

Figure 2. The average lifespan of motorcycles in Vietnam.

The estimation result of each number of motorcycles in Vietnam in 2010-2030 is presented in Figure 3.

The estimated number of shipments after 2018 was approximately 3 million each year. The number of motorcycle waste disposal in 2018 and 2030 estimated by the average lifespan and the number of shipments of each year was approximately 1.6 million and 2.4 million units, respectively.

The predicted values in 2010-2014 are not deviated from statistics, whereas the ones in 2015 and 2016 are highly matched with the statistics. In spite of the lack of statistics in 2017 and 2018, the value similarity in 2015 and 2016 would indicate the reliability of model estimation to some extent.

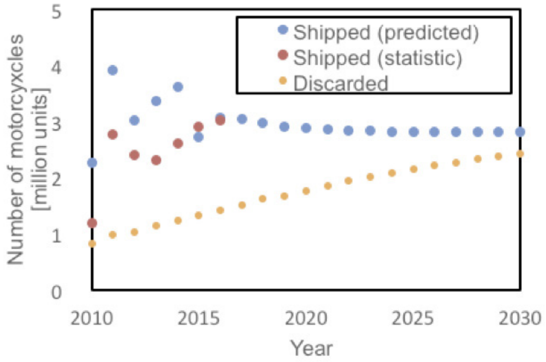

Figure 3. Estimation result of each number of motorcycles in Vietnam in 2010-2030.

Based on the predicted number of motorcycles waste disposal in Vietnam in 2019-2030, the amount of metals contained in obsolete motorcycles in 2019-2030 was estimated. The result is presented in Figure 4. The total metals contained in the motorcycle wastes are 146 thousand tons in 2019 and 211 thousand tons in 2030. The amount of steels, aluminum, copper and lead contained in obsolete motorcycles in 2030 was estimated as 169, 33, 4 and 4 thousand tons, respectively.

Steel, aluminum and copper are mainly recycled by using a backward technology in craft villages, Vietnam. These wastes are fed into furnaces, which are not equipped with any air treatment system (Tran, et al., 2018). Lead is recycled in melting furnaces regardless of function for waste gas (Ministry of Economy, Trade and Industry, 2017)This current recycling situation in Vietnam not only lead to the loss of metal during the recycling process but also cause environment damages through waste gas, dust and slag containing metals. It is highly expected that the increase in these waste metals in the future will trigger more serious environmental pollution. Thus, it is important to promote the proper treatments of obsolete motorcycles.

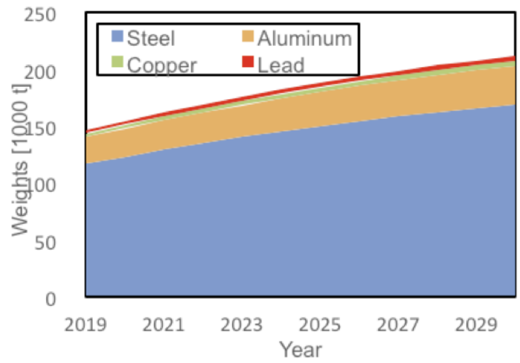

Figure 4. The amount of metals contained in obsolete motorcycles in 2019-2030.

Conclusions

This study estimated the number of motorcycles owned in 2018-2030 in Vietnam, the lifespan distribution of motorcycles in Vietnam, the number of motorcycles shipped in 2017-2030 in Vietnam, the number of motorcycles discarded in 2010-2030 in Vietnam, and the amount of metals that generated from obsolete motorcycles in 2019-2030 in Vietnam. The number of motorcycles owned in 2018 and 2030 was estimated to be approximately 37 million and 46 million units, respectively. The average lifespan was estimated as 16.9 years. The shape parameter in the Weibull distribution was 1.6. The estimated number of shipments after 2018 was approximately 3 million each year. The number of motorcycle waste disposal in 2018 and 2030 was estimated 1.6 million and 2.4 million units, respectively. The amount of metals that generated from obsolete motorcycles in 2019 and 2030 was estimated 146 thousand tons and 211 thousand tons, respectively.

Considering the increase in the number of scrapped motorcycles and the demand for resources induced by motorcycles, the estimated value might assist policymakers in developing the strategy for efficient motorcycle recycling. In addition, considering the electrification using rare elements such as lithium of motorcycles in the future, the recycling of motorcycles will be more vital.

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Product Lifetimes And The Environment

Global Differences in Consumer Practices Affect Clothing Lifespans

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Keywords: Clothing Consumption; Lifespan; Use Phase; Wardrobe Audit.

Abstract: Most studies of clothing and related habits are carried out within a country. However, apparel production and sales are a highly globalized industry, with many of the same large chains operating worldwide. It is thus quite possible that the use of the same mass-produced clothing differs between various geographical areas. Based on a practice theoretical approach, we have studied differences in consumption, use and disposal of clothes in different countries that may affect the lifespan of apparel. The paper is based on an international survey in five countries with large apparel markets: China, Germany, Japan, UK and the USA. 200 respondents from each country answered to a comprehensive web-based survey on their wardrobe content. We found differences in practices that could affect the lifespans of clothing in these five countries. At the same time, we find many similarities. For clothing acquisition, buying new items dominates in all the five markets, and washing machines contribute to the main chore of keeping clothes clean. Home production and second-hand clothes constitute a very small part of clothing consumption in all five countries. Many respondents showed low sewing skills, and repair activities were done irregularly. Thus, many of the challenges to increasing the lifespans of clothing are similar for all the five countries. At the same time, there are significant differences. These differences open up for the possibility to learn "best practice" by studying the countries and transferring knowledge between regions. When defining use phase in LCA and other sustainability tools, it must be taken into account that despite the fact that clothing is a global industry, consumption is part of local practice.

Introduction

Longer lasting products will generally lead to less material extraction, less pollution and less energy-use in all the phases of a product's life, including transport (Cooper, 2010), with the only exception being when there is a significantly more efficient new product available (Montalvo et al., 2016). At the same time, a tendency towards a short 'service life' and low intrinsic material value has been the effect of the current market-based system of mass consumption and low-cost production, exemplified by so called 'fast fashion' (Fletcher, 2008). Economic growth, whilst raising incomes, has led to an increase in the use of materials and energy, and related pollution and waste. Montalvo et al. (2016) estimated that longer lasting products could increase economic activities related to extended use through activities such as maintenance, repair, and rental services by 7.9 billion Euros per year to Europe's economy. An example within clothing shows potential reduction of circa 100,000 tonnes of CO^2eq and 2000 tonnes of waste per annum in the UK, if just 10% of t-shirts were used longer (Downes et al., 2011).

To include length of lifespans and other parts of the use phase of textiles into various forms of LCA analyses and comparison tools, knowledge about how clothes are used is needed (Laitala et al., 2018). There is also a need for knowledge about environmental impacts in the use phase (Wiedemann et al., Forthcoming) and how longevity contributes positively to environmental accounting.

Studies of clothing habits are usually done locally or within one country, but to integrate consumer based data on lifespans and use into LCA, we need knowledge about global variation. The knowledge we have about these conditions is usually based on comparisons of the results of different national studies (Laitala et al., 2017). Few have compared countries within the same study and with the same methods, although some examples can be found (e.g. Gwozdz et al., 2017; Pakula &

Stamminger, 2009, 2010; Presutto et al., 2007; Spencer et al., 2015; The Nielsen Company, 2012).

This lack of global comparisons applies to clothing research in general and not only related to lifespans. In particular, there is little knowledge about the southern hemisphere, developing countries, and the growing markets for clothing (Laitala, 2014b). Clothing lifespans have mainly been researched in a few European countries (Goworek et al., 2013; Gracey & Moon, 2012; Klepp & Laitala, 2016; Laitala, 2014a; Langley et al., 2013; Maldini et al., 2017; Maldini et al., 2019). This paper seeks to fill the knowledge-gap by examining some major countries in different parts of the world; China, Germany, Japan, UK, and the USA.

We will use a practice theoretical approach. Based on Reckwitz (2002), Shove et al. (2012), define practices as composed of three elements: 1) meanings, referring to what Reckwitz called mental activities and emotions, 2) competences; the elements of motivational knowledge, meaning multiple forms of understandings and practical knowledgeability; and 3) materials, encompassing objects, infrastructures, tools, hardware, and the body.

Due to limited space we can only draw some examples of aspects that can affect clothing longevity. Many of the survey questions are related to what consumers do, and therefore include all the three aspects of the theory. For example, repair of clothing presupposes access to equipment, know-how and an intention to repair. Similarly, laundering is related to cleanliness and hygiene ideas, access to water and equipment, and skills (Shove, 2003).

The research question we ask is; are there major differences between consumers' clothing practises in distinct parts of the world that can affect the lifespan of clothing? Consumption, as we understand it, consists of acquisition, use, and disposal of goods. All three stages are relevant to longevity.

Method

The paper is based on a wardrobe audit (Fletcher & Klepp, 2017) conducted online by AC Nielsen at the end of 2018. Over two hundred respondents from each country answered a comprehensive survey on their wardrobe content. For selected clothing items, details such as lifespan, active use time, wear occasions, materials, and laundering practices were registered.

The survey focused on adult respondents between 18 to 64 years old. The sample was pre-stratified to represent the gender distribution and other demographics of the country in question. The respondent demographics for each country are given in Table 1. The data is weighted to the population. For enabling the analysis, one database was prepared per respondent (N=1111), and another per garment (N=53 461). In China, the oldest age group is underrepresented. In addition, the sample is only from the ten largest cities and is not representative for the whole country. This enables comparison of a bit more similar consumer groups in terms of living standard.

	CN	DE	JP	GB	US
Respondents	230	224	224	213	220
Garments	10595	11705	12022	9384	9755
Men	54%	51%	51%	47%	49%
Women	46%	49%	49%	53%	51%
Age 18-29	41%	19%	19%	22%	21%
Age 30-49	49%	45%	50%	52%	44%
Age 50-64	10%	36%	31%	26%	35%

Table 1. Respondents' background variables.

To prevent respondent wear-out, the number of clothing categories assessed in detail was limited to categories of common clothing items such as suits, t-shirts, trousers, skirts and socks. Item-specific questions were limited to a maximum of 10 items per category.

Results and discussion

Acquisition

We asked respondents how they had acquired each of the registered clothing items. Seventy-four percent of garments were newly bought items by the respondents themselves (Fig. 1). The second most common acquisition method is gifting. The percentage of preowned clothing is low (9%), both when we look at items bought second-hand (5%) and those received as hand-me-downs (4%). Respondents from the USA and the UK are more likely to receive and buy items second-hand.

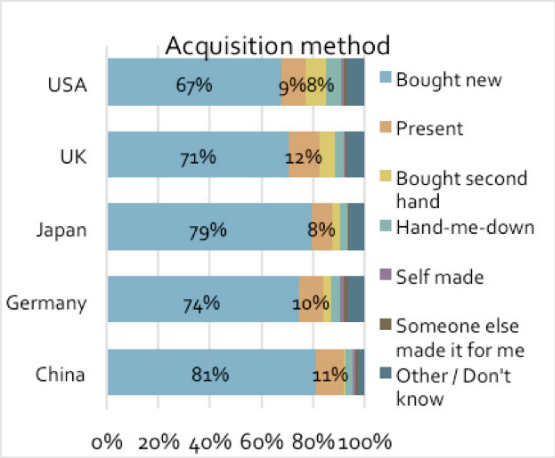

Figure 1. Which of the following best describes how this item was acquired? (Garment data)

Home production and repair

Even though only a few of the garments registered in the survey were homemade, questions on consumers' craft activities showed that some do acquire clothing by making it themselves. This is most common in Germany and the USA, where 15 % of respondents had knitted or crocheted during the past year (Table 2). These figures are still lower than in Norway, where 25 % of the population had knitted or crocheted during the past year (Laitala & Klepp, 2018). It was not that common to make something new out of old clothing or sew new clothing, but also this was most common in Germany and USA. The Japanese and the Brits are least active in making clothing.

	CN	DE	JP	GB	US
Sewn a button	57%	53%	52%	49%	48%
Fixed an unravelled seam	37%	17%	25%	18%	26%
Patched clothing	9%	32%	10%	17%	23%
Darned clothing	16%	22%	34%	14%	11%
Changed a zipper	29%	8%	2%	6%	14%
Fixed a trouser length	24%	17%	24%	20%	13%
Adjusted the size of clothing	18%	8%	6%	6%	10%
Made something new out of old clothing	4 %	8 %	5 %	2 %	10 %
Sewn new clothing	6 %	8 %	4 %	5 %	8 %
Knitted or crocheted	10 %	15 %	6 %	6 %	15 %
None of these	15 %	27 %	26 %	37 %	31 %

Table 2. Which of the following have you done in the last 12 months? (Person based data)

Of repair activities sewing on a button (51%) was most frequent, while changing a zipper was the least frequent activity (14%) (Table 2). Consumers in the UK are the least likely to have performed any clothing maintenance or production in the past year (37%), closely followed by the USA, while the Chinese are definitely most active as only 15% had *not* done any of these activities last year. The Chinese respondents were most likely to have fixed an unraveled seam (37%), while only 17 % of Germans replied that they had done the same. This is counter to patching, as 17 % of Germans had patched a garment compared to 9 % of the Chinese. Adjusting trouser lengths and darning clothing are most common in Japan and China (24%). This shows that there are national differences in which repair techniques are frequently used.

To repair and make clothes is also dependent on handicraft skills, and therefore we asked whether respondents knew how to sew by hand or use a sewing machine (Table 3). It is interesting that the Chinese report to have done most repairs in many categories, but are the most modest in reporting their sewing skills. This may be a cultural variation, grounded in the expectation of skills when asked if you can use a sewing machine or sew by hand.

	CN	DE	JP	GB	US
I can use a sewing machine	20 %	29 %	42 %	18 %	35 %
I can sew by hand	35 %	50 %	56 %	50 %	55 %
I can knit	15 %	22 %	15 %	14 %	15 %
I can crochet	9 %	25 %	15 %	6 %	17 %
None of these	50 %	37 %	27 %	39 %	30 %

Table 3. Here are some statements people have made about their skills in making / repairing / altering clothes. Which of the following best applies to you? (person based data).

Laundering

Laundering leads to high environmental impacts (Bain et al., 2009), and frequent laundering, use of old top-loading washing machines (agitator type), and use of tumble dryer can contribute to increased wear and tear of clothing (Hartline et al., 2016).

Table 4 shows which laundry appliances and methods are used in the respondents' households for washing and drying clothing. It shows that China has largest variations in washing machine types, and highest occurrence of hand washing. Top loading washing machines are most common in Japan and the US, while Europeans use mainly front-loaders. Tumble-drying is most common in the US. Line drying indoors is more common than outdoors in all countries besides Japan. Using shared appliances such as laundromats or machines in an apartment complex is most common in Japan and the US.

	CN	DE	JP	GB	US
Top loading wm	25 %	16 %	63 %	6 %	60 %
Front loading wm	29 %	62 %	11 %	64 %	17 %
Combination washer dryer	27 %	6 %	20 %	16 %	3 %
Twin tub wm	11 %	2 %	3 %	1 %	3 %
At home dry cleaning	8 %	1 %	2 %	2 %	2 %
Shared wm (laundromat)	6 %	8 %	10 %	8 %	13 %
Hand wash some laundry	96 %	55 %	65 %	52 %	54 %
Tumble dryer	8 %	24 %	5 %	21 %	54 %
Shared dryer (laundromat)	7 %	5 %	10 %	4 %	10 %
Line drying outdoors	51 %	20 %	38 %	27 %	10 %
Line drying indoors	53 %	37 %	34 %	38 %	19 %

Table 4. Please indicate which of these items you currently use. Do you hand wash any of your laundry? (WM=Washing machine) (Person based data)

Washing laundry by hand is a common practice in China, where 96% of respondents replied that they wash some of their laundry by hand. This is second most common in Japan (65%), while only a bit over half of Germans, Brits and Americans replied the same.

Disposal

The last stage of use is to dispose of the garment, and there are several reasons for disposal, as well as alternatives for where to dispose of the garments.

Clothing disposal reasons show that there are variations between countries, as the Chinese respondents were more likely to dispose clothing due to fashion or personal dislike (Table 5). Unsuitable fit was quite common in all countries except Japan, where only 7% of clothing were likely to be disposed based on this. Japan is one of the wealthier countries that is less affected by the obesity epidemic (Yeom et al., 2009), and it seems that fewer experience problems with changing body size than in the other countries.

	CN	DE	JP	GB	US
Not in fashion any more	21 %	10 %	6 %	9 %	9 %
Poor fit	12 %	17 %	7 %	14 %	16 %
Dislike the colour or style	20 %	10 %	4 %	6 %	7 %
Lack of space	6 %	3 %	2 %	3 %	5 %
Don't need it any more	11 %	5 %	13 %	8 %	8 %
The colour has faded	3 %	5 %	5 %	7 %	8 %
A hole in the fabric	9 %	18 %	15 %	18 %	18 %
Pilling	3 %	2 %	13 %	6 %	3 %
Loses its shape	12 %	16 %	21 %	13 %	11 %
Other wear and tear	2 %	5 %	6 %	4 %	4 %
Unknown	3 %	9 %	9 %	11 %	11 %

Table 5. What do you think is likely to be the main reason you would dispose of this particular item? (Garment based data)

Japanese are far less likely to donate their clothing and instead choose to trash it or sell it (Table 6). Donating clothing to reuse or recycling stands out as something typically Western, with the US and the European countries on top. If these habits were to spread to the East, it would have major consequences for the already oversupplied global second-hand clothing market.

	CN	DE	JP	GB	US
Donate to charity or recycling collection	39 %	42 %	8 %	44 %	44 %
Donate / give to family / friends	16 %	10 %	5 %	11 %	15 %
Put in the Rubbish Bin at home	26 %	22 %	56 %	22 %	17 %
Recycle at home (e.g. use as cleaning cloth)	11 %	8 %	7 %	7 %	8 %
Sell (e.g. garage sale, eBay)	2 %	7 %	10 %	3 %	2 %
Other / Don't know	6 %	12 %	15 %	14 %	14 %

Table 6. What would you expect to do in order to dispose of this clothes item or accessory when you no longer want it? (Garment based data).

Results from this survey show, similarly to many previous studies, that it is more common to give to reuse than to acquire and use second-hand clothing in developed countries, but there are big differences between east and west.

Conclusions

With respect to our research question, this study has demonstrated that there are differences in practices that can affect the lifespans of clothing in the five surveyed countries. However, we also find many similarities. In clothing acquisition, buying new items dominates in all the five markets, and washing machines do most of the work in keeping clothes clean. Handcrafted and second-hand clothes constitute a very small share of clothing consumption. There is absence of some sewing skills, and not all repair activities are done regularly. Thus, several challenges to increasing clothing lifespans apply in all the surveyed countries.

The differences between Japan and China are as big as between the three western countries. This means that research in different regions, not just per continent, is needed to increase our knowledge of clothing lifespans. This enables us to learn "best practice" by studying specific countries and transferring knowledge between regions. In working with LCA and other sustainability tools, consumption as part of local practice must be accounted for, even though clothing is a global industry. The same mass-produced clothes can be included in different clothing habits and used, repaired, washed and disposed differently. When the goal is to increase clothing lifespans, the efficiency of various measures differs between countries.

To steer these practices towards a more sustainable direction, we see that changes are needed in all the elements that constitute practices. These include materials such as the clothing, cleaning technologies, infrastructure, and meanings related to the importance of sustainability and fashion, and competences, for example in how to maintain clothing. In Japan and China, increased use of second-hand clothing could extend clothing lifespans locally. In the UK, a boost in practical knowledge of repair and handicrafts could contribute positively to keeping clothes longer in use. Poor fit is an important disposal reason, especially in Germany and the USA, and could be combated with strategies to avoid mistake purchases as well as improved size and fit labelling, and flexible design of clothing. The USA has a lot to gain in improving laundering practices such as reducing tumble drying, laundering frequency, and replacing top-loading with front loading washing machines. China differs in placing a higher importance to fashion, which has a potential to shorten clothing lifespans.

This paper provides an analysis of data collected with similar methods in five large consumer markets. Further analyses should relate these findings to local investigations, and to differences in economics, markets and regulations. In the work on environmental improvements, it is crucial to take the use phase seriously and increase the knowledge of geographical differences in today's clothing practices. China stands out and will therefore be an important country to investigate more closely, not least through cooperation with researchers with greater knowledge of the local conditions. Due to the large population of China, changes in the use phase of clothing there will have major global consequences.

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Focus on Reparability

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Keywords: Repair; Reparability; Business Models; Industry Pilot Applications; Practice-Based Elaborations.

Abstract: Technical equipment is subject to various forms of service life restrictions. Ideally, the material used for its production is then reintegrated into the material cycle. For the effective use of resources, these cycles must be closed at the highest possible level and slowed down as much as possible. Functional losses or restrictions of individual components must not lead to a permanent failure of the device. Therefore, repairs should be made easy and cost-effective.
In an extension of the Eco-Design Directive a number of requirements are already being formulated to facilitate repairs. However, complying with an obligatory directive does not create a competitive advantage for companies. This creates the danger that companies will only implement reparability as far as it is mandatory. For a device to be easy to repair, however, more requirements must be taken into account. These requirements make the development process more complex and the product design can no longer be optimized exclusively for assembly in production, but repair must also be taken into account. In order to achieve a design that is suitable for repair, it is therefore necessary to take into account more complex manufacturing processes, higher material costs and higher design costs.
A proactive advancement of reparability as a paradigm in product development can therefore only be expected if there is a prospect of additional income. Therefore, new business models that make an increase in reparability economically interesting for both producers and consumers are the best option.
Three business models are presented here for which BSH Hausgeräte GmbH already has practical experience. After a brief description of each model, the current status of these entrepreneurial experiences is presented.

What is the issue?

Technical equipment is generally subject to various forms of service life restrictions: Wear, material fatigue, material and production defects, operating errors, aging, etc. Ideally, the material used for production is then reintegrated into the material cycle. Even if a complete recovery of all raw materials used is currently not possible, the goal of sustainable product development remains to keep resource losses as low as possible.

This means not only closing the circuits at the highest possible level, but also slowing them down as much as possible. Functional losses or limitations of individual components must not lead to permanent failure of the entire product. In practice, such failures must either be prevented by predictive maintenance or, if they do occur, repairs must be carried out quickly, easily and cost-effectively (for a more detailed text on this topic see Longmuss & Dworak, 2019).

Failures during use

Initially, it seems desirable that a product should function without problems until customers no longer want to use it on their own, for example because it is technically obsolete. For this, however, each part and the overall construction must be designed to be so stable and fail-safe that they keep functioning without problems within this (very long!) period of time. Especially in view of increasing requirements and increased complexity of new products, for this a very high effort would have to be made in development and production, which does not seems justifiable economically, technically or from the point of view of resources. Therefore it must be possible to replace worn and defective parts - planned or unplanned - easily and quickly so that the product can continue to be used without problems. Construction and logistics for maintenance and repair must be designed in such a way that both the ecological balance and the cost/benefit calculation for the customer are positive over the entire period of use (which can also include the refurbishment and resale of a used product). This is

- Ecologically and economical advantageous: less material costs in production, replacement of components less costly than new purchase and recycling of the entire product at raw material level, and
- Socially helpful: A repair does not necessarily require the high specific competence of development and production. It can also be carried out locally by smaller specialist companies.

Factors influencing repair

In a revision process of the Eco-Design Directive, which is currently in progress, some requirements are already formulated for producers to facilitate a repair. From 2021 they will be mandatory for all manufacturers throughout Europe for a wide range of products such as washing machines, dishwashers and refrigerators (see e.g. COMMISSION DELEGATED REGULATION (EU) of 11.3.2019 ...). These requirements include i.a.:

- Availability of spare parts for seven, for various wearing parts ten years after the last unit of the model was placed on the market,
- These spare parts must be interchangeable with generally available tools,
- Delivery of spare parts within 15 working days after receipt of order,
- Access to repair and maintenance information for professional workshops, including instructions for installing relevant software.

However, compliance with a mandatory directive does not create a competitive advantage for companies, since all other companies at least formally comply with it as well. This creates the danger that companies will only implement repairability requirements to the extent that it is mandatory. In order for a device to be well repairable in practice, other basic features must also be taken into account, such as:

- It must be easily accessible, i.e. it must be quick, easy and safe to open (no electric shocks, toxic components, etc.).
- The components - especially susceptible parts - must be able to be dismantled to such an extent that each individual part represents only a small part of the value compared to the entire device, otherwise even the failure of a single part could render a repair uneconomical.
- Reducing the variety of parts - so far, for example, it has been possible for many different motors to be used within a single series.
- Errors must be detected as quickly as possible. Warning signs, error codes etc. can help.

Consequences for design and manufacture

These characteristics are to be broken down for the respective devices in detail and included in the requirement lists for new and further developments. Repairability as a paradigm thus makes the development and design process longer and more complex because more requirements have to be taken into account.
Moreover, the product design can no longer be optimized exclusively for assembly in production, but must take repair into account. Fastening sheet metal with rivets instead of screws, pressing in ball bearings instead of securing them with removable rings, using adhesive bonds that cannot be separated without damage, etc., may be faster and cheaper in mass production, but makes repair more difficult and costly, if not de facto impossible. For a repair-fair construction must be proceeded thus apart from the higher construction expenditure also from more complex manufacturing processes and higher material costs.

Possible business models

A proactive advancement and deepening of reparability as a central paradigm in product development can therefore only be expected if there is a prospect of additional revenues that justify this effort. Therefore, new business models that make an increase in reparability economically interesting for both producers and consumers are the best way to achieve this goal.
Revenues generated in this way do not necessarily have to come directly from product sales. They could also be achievable from additional services, multiple use and end-of-life material revenues. What these models have in common is that they extend the company's responsibility beyond the point of sale or the statutory warranty period. Conversely, reparability can be seen as the lever to make different business models commercially viable. Repairability is a prerequisite for offering an economical after-sales service, as well as for efficient and ecological management of manufacturer warranty obligations and, last but not least, for various

measures to extend the service life of a product, including second and third use.
BSH Hausgeräte GmbH already has practical experience and internal evaluations of the business models presented here. Their current status is presented after a short description of the model.

Model 1: Gain additional business and experience through refurbishment
The core of this model is that manufacturers take back used equipment - including defective and damaged equipment - free of charge when selling a new one, recondition it in their own repair shops if possible or have it reconditioned by subcontractors and sell it via their own or a separate sales network. On average, the returned equipment must be sufficiently well refurbished, but this can generally be assumed (Prakash et al. 2016). On the one hand, this saves manufacturers the fee they would otherwise have to pay for disposal. On the other hand, they can generate additional income with the refurbished used equipment. They can also learn about the durability, susceptibility and wear of components of their own devices – which may have been out of warranty for a long time – that will help future designs.
Whether this model covers costs depends on four factors:

- The amount of the saving disposal fee. This is now so high throughout the EU that it makes this business model fundamentally interesting.
- The cost of logistics for the (careful!) collection and intermediate storage of used equipment. This factor is strongly influenced by the distances over which used equipment has to be transported.
- The cost of repair and overhaul.
- The price that can be achieved for used equipment, which must also cover the costs of disposing non-repairable devices and at the same time be far enough below the price of a new equipment to be of interest to customers. Manufacturers in the premium segment with their higher-priced appliances (and their image) have an advantage here because the first three factors are largely independent of the brand, but low-cost suppliers can only achieve low prices even for good second-hand appliances.

Two pilot projects for reconditioning in Belgium and Spain have been running for several years and show that BSH can be reconditioned economically and successfully marketed. At various collection points for waste electrical and electronic equipment, devices of the BSH brands are pre-selected and sent to re-use centres. For this purpose, BSH developed a special concept for return logistics. The re-use centres have access to BSH spare parts under the same conditions as the BSH subcontracted customer service centres. They also have access to the drawings and repair instructions for all BSH devices. Together with the reuse organizations, BSH conducts repair training for its products and certifies the test equipment used for quality control. Approximately 20-30% of the overall collected equipment can be successfully refurbished and marketed directly through the reuse organisation's own stores.
In a large country like Germany, however, the distances to a single or a few processing centres would be so long that the model as a nationwide approach could hardly become profitable. Here, such a model would have to aim more at decentralised collection and processing in specialist companies, which would then no longer work directly for the manufacturer, but in cooperation with him. Such a concept would still have to be tested in practice.

Model 2: Additional business through service takeover
Manufacturers can also completely dispense with the sale of devices and offer washing as a service, similar to car manufacturers who now set up their own car-sharing companies in which their vehicles are rented. Two variants are currently being tested for washing machines:

1. Washing service as an individual service:
The customers receive a device, which however remains in the possession of the manufacturer. A monthly rental fee is payable for the use of the device. The responsibility for the smooth functioning as well as for a quick repair or replacement of defective devices remains with the manufacturer. Similar to other leasing models, the device can be offered to the customer for a favourable purchase after a predetermined period of use. This would be an incentive to treat the device well.
The model has been pilot marketed in the Netherlands under the "Blue Movement" label since the end of 2017. Consumers can rent Bosch washing machines and dryers there instead of buying them. From 9.99 euros a month and with

a minimum rental period of three months, customers can get the latest equipment with an "all-round worry-free guarantee". The feedback from consumers is consistently positive.
In August 2018, the Papillon Project was launched in Belgium, a collaboration between BSH Belgium and the social enterprise "Samenlevingsopbouw West-Vlaanderen". Here household appliances are rented to families living in poverty. The rental contracts run for a period of 10 years with a monthly rental fee of about 9 € per device. Thanks to subsidies from the Flemish Minister of the Environment, end customers pay only € 7 per month. In the rent is included: Delivery, installation, instruction, return of an old device, 10 years "full service", and pickup of the device at the end of the contract. Both projects also aim to gain initial experience with recycling management models in which the equipment remains the property of BSH. In addition, BSH would like to collect information on how equipment and processes need to be adapted within BSH to make them more suitable for such closed-loop recycling models.

2. Washing service as a community service:
Here, too, the device remains in the possession of the manufacturer, but is located in rooms that are accessible to a larger group of people, e.g. in special washrooms in residential complexes or student dormitories. The users share the device, as it is widespread e.g. in the USA. Modern service models using smartphones, such as booking the device for a certain time or automatic billing, can make such a model particularly interesting for younger customers. In Germany, a start-up company is currently developing a corresponding service offer under the name "WeWash" on behalf of BSH Hausgeräte GmbH.
One result is fast customer feedback on individual operating and maintenance functions, as the machines are used very frequently in a short period of time. This provides important insights for future product development. Every single use/booking of the machine is recorded and can be used by WeWash for predictive maintenance planning. Due to the exact adherence to the maintenance cycles, the machines are still in a very good technical condition even after long running times. If the machine is replaced in good time, it can be reconditioned for a second use with a relatively manageable amount of time and money. The number of cycles that a machine can be used, and thus the useful life, is significantly extended compared to the classic business model.

Model 3: Higher market prices through Service Label
A reliable customer service can be an important criterion for the purchase decision of the customer. A "service label" could justify a higher selling price with a high standard. However, it would not directly refer to durability, but to the speed and quality with which the customer responds to questions and problems - in the event of repairs, but also beyond. Important criteria can be:

- *Product information:* Fast availability of product information, operating instructions, assistance and spare parts.
- *Qualified service employees:* The employees must be well trained, down to the details of the equipment to be serviced and relevant sources of error, as well as in dealing with customers.
- If a service technician is required, a *quick and uncomplicated repair booking* – by telephone or online, around the clock, seven days a week – is important. In addition, customer visits should be prepared in such a way that repair cases can be remedied at the first use. Foresighted route planning, a dense network of technicians and an efficient spare parts supply all contribute to this.
- *Instructions for self-help:* Repairs by service personnel on site are, however, naturally expensive, because in any case there are costs for the journey. In the interest of the customer, on-site repairs should only be carried out if they are actually necessary. Instead, customers may be advised remotely so that they can help themselves.

A high quality of this "after-sales service label" would be another possible way to promote durable and service-friendly products within the framework of the Ecodesign Directive. However, it is difficult to make a robust certification by a neutral authority so comprehensive and meaningful that customers are prepared to pay higher prices for it. Alternatively, after-sales services could be evaluated via consumer portals and other information channels on the Internet. If these evaluations are trustworthy enough for new customers and are widely communicated by the company, then a good repair service could also be economically designed in this way.

In this context, BSH is working on the idea of a "Service Network Rating System" to sensitize end consumers and inform them about repair options. This is an opportunity for BSH to clearly differentiate itself from its competitors. Based on the current ecodesign legislation on repair information, BSH is currently developing a catalogue of criteria. In this way a manufacturer can differentiate itself upwards, based on the minimum requirements of ecodesign. The goal would be a scale analogous to the energy label, which is widely known and can be considered a success model.

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PLATE
Product Lifetimes And The Environment

Prospects for Increasing the Market Share of Longer Lasting Products in Consumer Durables Markets

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Keywords: Marketing Strategies; Product Life; Warranty; Washing Machines.

Abstract: Product longevity provides a route to sustainable consumption because the material flow in the environment is reduced when products last longer. Thus, there is a need to increase the proportion of such products in consumer goods markets. Warranties provide remedies when consumers buy goods which turn out to be defective. Warranties also play a significant role in promoting product sales and improving customer satisfaction with after-sales service quality. Therefore, this paper uses evidence from a review of warranties to explore the role of marketing strategies in decreasing the material flow in the economy. A warranty that, in essence, promotes use of a product for a longer duration is described in five parameters. Companies for investigation were identified using a systematic process and information about manufacturers' guarantees and warranties, together with other information that indicate product lifespans was collected using secondary research. The score of warranties on the parameters was considered as an indication of companies' commitment towards longer lasting products. Counter to expectations, the data indicated that the price points at which companies operate, brand perception, and warranty terms and conditions may not be linked, and offering a warranty may not always mean that the company stands by its products, supports repair to promote use for longer duration.

Introduction

In the past decade much research has focussed on identifying workable business models to help a transition to circular economy (Beltramello et al., 2013; Bocken et al., 2017; Boons et al., 2013; Schaltegger & Burritt, 2018). However, it remains unclear why sustainable business models are not more popular, especially considering that businesses have acknowledged climate change and their moral obligation to act upon it (WBCSD, 2010).

Product longevity provides a route to sustainable consumption (Salvia et al., 2016) because, by making products last longer, the material flow is reduced (Bakker et al., 2014). How long a product is used encompasses social and cultural factors (Cooper, 2010) in addition to its physical durability, which is more related to a product's functionality over time (Stahel, 2010). Warranties can support greater functionality (Bocken et al., 2014) and extended warranties can play a significant role in promoting product sales and improving customer satisfaction with after-sales service quality (He et al., 2018; Murthy & Djamaludin, 2002).

The purpose of this paper is to compare marketing strategies such as product warranties by companies producing large kitchen appliances, one of three product categories explored in a wider study, with different foci on product longevity. A manufacturer's guarantee is the initial guarantee that comes free with a product and (in the case of washing machines) is generally for 1 or 2 years. Warranties are product promises, although while a guarantee is a part of the sales contract, a warranty is not.

Other initiatives that support a product's longer use, such as availability of spare parts and warranties on repairs are also considered in the paper (Twigg-Flesner, 2010). Table 1 is a glossary of terminology of guaranties and warranties.

The paper uses evidence about warranties offered by companies (such as company websites, product manuals and publicly available warranty terms and conditions) to explore the role of marketing strategies in decreasing the material flow in the economy.

Methods

This section of the paper explains how companies were chosen. Data were collected using a systematic process, shown in Figure 1. In order to be able to compare warranties, a specific type of product, washing machines, was chosen, as their sale and trade is significant in the UK and high number of units are discarded every year. On average, about 3 million washing machines reach the end of their lives each year (James, Maddox, & Gisher, 2011).

Glossary	
Guarantee	An undertaking to the consumer given without an extra charge by a manufacturer that, if the goods do not meet the specifications set out in the guarantee statement or in any associated advertising: 1. the consumer will be reimbursed for the price paid for the goods 2. the goods will be repaired, replaced or handled in any way.
Warranty	Term used for promises other than those under guarantee, that is they are not a part of the contract of sales of the product. They are of different types.
Service contract	A contract in writing to perform, over a fixed period of time or for a specified duration, services relating to the maintenance or repair (or both) of a consumer product.
Implied warranty	Obligations on the manufacturer that are implied under law such as fitness for purpose and merchantable quality of the product at the time of sale until a specified duration.
Full warranty	Warranties that meet all of the following criteria: 1. In the case of a defect, malfunction, or failure to conform with written warranty, the company remedies the product within a reasonable time and without charge 2. The company does not impose any limitation on the duration of any implied warranty on the product 3. If the product or a component part contains a defect or malfunction after a reasonable number of attempts by the company to remedy defects or malfunctions in such product, it permits the consumer to elect either a refund for, or replacement without charge of, such product or part.
Limited warranty	A warranty that does not meet any of the criteria for full warranty is a limited warranty.
Manufacturers' guarantee	A warranty on new purchases provided by the manufacturer and promises that such material or workmanship is defect free or will meet a specified level of performance over a specified period of time; Also called standard warranty on new purchases.
Promotional warranty	Manufacturers' guarantee that has been extended for a longer duration, by the manufacturer.
Retailers warranty	This is an extended warranty provided by the retailers at a cost to the consumer.
Extended warranty	Warranty that is bought by the consumer after the manufacturers' guarantee or retailers' warranty has expired.

Table 1. Glossary of terms for guarantee and warranty. Sources: Consumer Rights Act 2015, Magnuson-Moss Warranty Federal Trade Commission Improvement Act 1975 and Sale of Goods Act 1979.

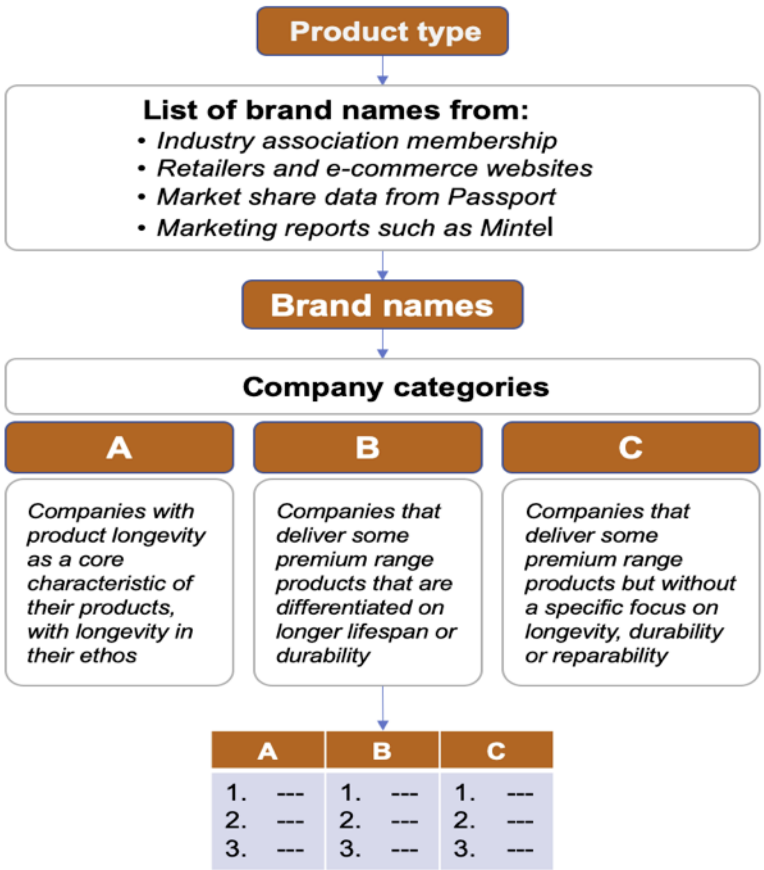


Figure 1. Process to identify companies.

Companies were listed from their industry associations and those that sell washing machines were identified. Information for minimum and maximum price points (retail prices) at which the specific products are sold were identified from retailer websites such as Argos.co.uk, Currys.co.uk and JohnLewis.com.

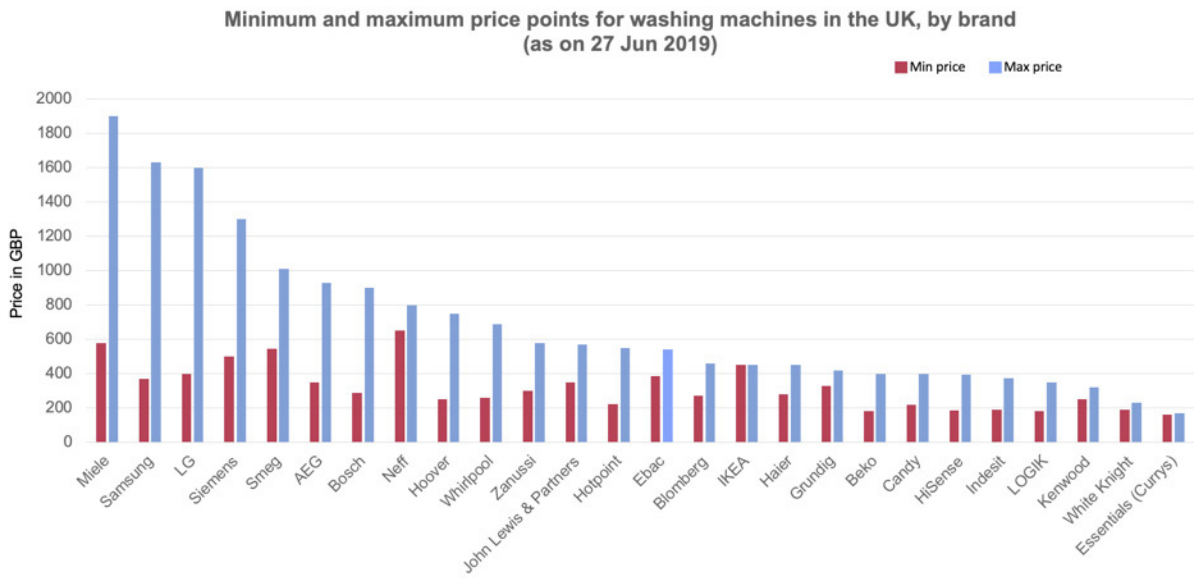
Each company was then studied and evaluated for its degree of focus on longevity. Three focus levels were identified and are referred to below as categories A, B and C.

A. Companies with product longevity as a core characteristic of their products, with longevity in their ethos
B. Companies that deliver some premium range products that are differentiated by longer lifespan or durability
C. Companies that deliver some premium range products but without a specific focus by longevity, durability or reparability.

The criteria to classify companies in categories A, B and C evolved during the process of studying the companies in detail, see Table 2.

Three companies were chosen for this study, one company in each category. Warranties offered by the three companies were read in detail using widely available information on company and retailer websites, to answer the following five questions:

1. Duration: Is the duration of the warranty equal to, or more than, the duration of implied warranties?
2. Transferability: Is the guarantee transferable with a change in ownership of the product?
3. Cost: Is the warranty inclusive of labour and parts, including the cost of returning and reinstalling the product?
4. Choice: Is the consumer given the option to choose either replacement or refund if repair is not possible or economical?



Graph 1. Plot for minimum and maximum price points.

5. Duty: Is the consumer eligible for the warranty service even if they have not fulfilled duties such as registering the product?

Other criteria to classify companies on the basis of their focus on longevity were:

6. Spare parts availability: What is the duration for which spare parts will be available?
7. Warranty on repair work: What is the duration of the warranty on repair?

These answers were collected using desk research and are summarised using a colour scheme in Table 3. If the answer to the question is yes, it is represented in green colour, if no then red and if the answer is not clear or is at the discretion of the company, then amber. The colour scheme is used for visual convenience to represent the data. A warranty that, in essence, promotes product longevity will have five green scores. The score was considered a proxy for companies' intention to making longer lasting products. Companies offer different warranties, and these are coded in Table 2, for ease of reference.

Company categories	A	B	C
Manufacturers' guarantees: 1. *Duration* 2. *Transferability* 3. *Cost* 4. *Choice* 5. *Duty*	Answer to these five questions is Yes	Answer to three of the five questions is Yes	Answer to less than three questions is Yes
Warranties: 1. *Duration* 2. *Transferability* 3. *Cost* 4. *Choice* 5. *Duty*	Answer to these five questions is Yes	Answer to three of the five questions is Yes	Answer to less than three questions is Yes
Spare parts availability	Lifetime	Limited period	No mention
Warranty on repair work	Lifetime	Limited period	No mention

Table 2. Criteria to classify companies.

Results

This section is organised as follows: It discusses the rows in Table 3 row-wise. First, the graph of the minimum and maximum price points for washing machines in the UK is discussed and the choice of companies is explained. Then, observations about the three companies are discussed under six sub-headings: Brand perception, price points, manufacturers' guarantee, warranties, warranty on repair work and availability of spare parts.

The minimum and maximum price points for washing machine brands in the UK are shown in Graph 1. The data is sorted by maximum price points, in descending order. Most brands operate in a narrow range of maximum price, with some brands having a comparatively higher maximum price. There appeared to be a relationship between the highest price charged and a perceived 'premium' status broadly in line with Mintel's descriptions of washing machine brands. According to Mintel (2017), Hotpoint, Zanussi and Indesit are 'middle market' brands, Beko is also a 'middle market' brand, bought for its 'cheap price', and Bosch is a 'premium' brand far from the 'mass market', which has a 'sophisticated image' and faces 'stiff competition from Samsung' which is regarded as the 'most trustworthy' brand.

Almost all companies offer a manufacturer's warranty of 2 years or less. Warranty details show that most companies do not provide the five essentials of warranties, described in the previous section, and hence their warranty provision may be described as limited, and consequently none of the companies were categorised as A.

Brand perception

The three companies scrutinised in this paper are Miele, Samsung and Hotpoint. Miele, categorised as B, was included because they claim that their washing machines are designed to work for 20 years, which is above the average lifespan of about 12.5 years (Alfieri, Cordella, Stamminger, & Bues, 2018). Miele has a reputation of 'high value' and is recognised for its 'high build quality' (Mintel, 2019). Samsung is in category B and perceived to have the 'strongest personality' of the major brands (Mintel, 2017) and continues to be the 'most-trusted' brand in 2019 (Mintel). Hotpoint was chosen from category C as it is a popular washing machine brand in the UK in terms of volume of sales: over 15% of sales in the UK in 2017 (Euromonitor, 2019); Mintel (2017) reports that consumers identify the brand as 'reliable, accessible and affordable' and is the 'most-trusted of the value brands' (Mintel, 2019). Thus, all three are established brands that are preferred by consumers for different reasons.

Price points

The minimum and maximum prices (retail prices) were noted on the same day from three online retailer websites, as noted above. The price range for Miele and Samsung is very similar, with an overlap in the range £600 to £1600. However, the manufacturer's guarantee and warranty schemes are different for the brands. Miele and Samsung are perceived as 'premium' brands (Mintel, 2017), while Hotpoint is a 'mid-market' brand and its price range does not overlap with Miele.

Manufacturers' guarantees

Consumers are not charged for a manufacturer's guarantee, which is in line with the definition of a guarantee (Table 1).

Duration: The European Union Directive on certain aspects of sales of consumer goods and associated guarantees (1999/44/EC) requires companies to provide for 2 years of an implied warranty on products. Legislation in the UK provides a legal guarantee, also called the legal prescription period, of 6 years to the consumer (and 5 years in Scotland) (Europa.eu, 2019). The duration of warranty offered by the manufacturer must not limit the duration of implied warranties and, if it is so, the seller must mention it conspicuously. The implied warranty of 2 years provided in the EU Directive was taken as the benchmark for the first question in this study. Companies that operate in the premium range, such as Miele and Samsung, normally provide a manufacturer's guarantee for 2 years, while Hotpoint, which operates in the 'mid-market', offers a 1 year manufacturer's guarantee, which is less than the minimum requirements by the EU Directive.

Brand	Miele		Samsung		Hotpoint		
Brand perception (Mintel 2019)	*'expensive and prestigious'*		*'most-trusted'*		*'most trusted of value brands'*		
Price points							
Min. price	579		369		220		
Max. price	1899		1629		549		
Manufacturer's guarantee							
Guarantee period (months)	24		24		12		
Price (GBP)	0		0		0		
Duration	Green		Green		Red		
Transferability	Amber		Amber		Amber		
Cost	Green		Green		Red		
Choice	Red		Red		Red		
Duty	Green		Red		Red		
Warranty							
Warranty details*	**M10**	**M5**	**S10**	**S5**	**H10**	**HCP**	
						a	**b**
Warranty period (months)	96	36	96	36	96	6	12
Price (GBP)	0	0	0	0	0	Differs with product	
Duration	Green	Green	Green	Green	Green	Red	Green
Transferability	Amber	Amber	Red	Red	Red	Red	Red
Cost	Green	Green	Red	Green	Red	Red	Red
Choice	Red	Red	Red	Red	Red	Red	Red
Duty	Green	Green	Red	Green	Red	Red	Red
Warranty on repair work							
Within manufacturer's guarantee period	12 months		No mention		No mention		
During warranty period	12 months		Remainder of the warranty period		No mention		
After warranty period	12 months		3 months		No mention		
Availability of spare parts							
Information	No mention		No mention		No mention		

Green=Yes | Red=No | Amber=Discretional
**M10: 10 Years promotional warranty*
M5: 5 Years promotional warranty
S10: 10 Years parts only warranty on Digital inverter Motor
S5: 5 Years promotional warranty
H10: 10 Years parts guarantee
HCP: Care plans | a: One-off repair | b: Repair and care

Table 3. Criteria to classify companies.

Transferability: We argue that warranties must be on the product and their status must be independent of the ownership of the product, provided the product has been registered and is used in accordance with its purpose. Manufacturers' guarantees are generally non-transferable for washing machines; however, they can be transferred at the discretion of the company. Guarantee provisions, therefore, do not automatically apply for a second buyer unless the company has agreed such an arrangement.

Cost: Cost here refers to labour, parts, and returning and reinstalling charges if the product needs either repair or replacement. The consumer must not be liable to pay for repair that is caused due to manufacturing or workmanship defects and bringing faulty products to conformity must be 'free of charge', including postage, labour and materials. As large appliances such as washing machines are hard to move the repairs are generally provided in situ, thus postage is not a concern. Within the manufacturer's guarantee period any repair related expenses are borne by the manufacturer.

Choice: Different remedies- either repair, replacement or refund- are possible if the product turns out to be faulty. Of these remedies, repair is normally considered to be the most environmentally sustainable (Cooper & Salvia, 2018). A Parliamentary Committee report (House of Lords, 1997) advocated repair over other remedies as it increases the demand for maintenance and quality control. The report also indicates companies' preference for repair over replacement or refund as it is comparatively less expensive for them. Companies may encourage repair because they believe that if left to choose from the three remedies, most consumers will opt for refund or replacement over repair and therefore their costs will be greater. The Consumer Rights Act 2015 has taken this into account. While it gives consumers the right to repair or replacement, it also provides sellers reasonable opportunity to negotiate. Companies retain discretion to choose between replacement or refund if repair is not possible.

Duty: Companies generally encourage consumers to register their products, but claims can otherwise be made under manufacturer's guarantee.

Warranties

Miele's warranties scored the highest of the three companies, with three green and one amber (Table 3). Samsung's 5 Years warranty is comparable to Miele's, while its 10 Years warranty scores similar to Hotpoint's, which is very low with one green.

Miele, Samsung and Hotpoint do not charge consumers for promotional warranties or parts only warranties but Hotpoint's care plans are paid and price differs with product type and age.

Duration: The maximum warranty period offered by manufacturers is 8 years. Samsung and Hotpoint provide a 'parts only' warranty on selected products, while Miele provides promotional warranties. The total warranty period, including manufacturers' guarantee, is a maximum of 10 years, which is less than the average lifespan of washing machines, 12.5 years (Alfieri et al., 2018). Hotpoint's manufacturer's guarantee is not as long as the minimum requirement in the EU Directive. Even with its additional one-off repair care plan, the product is covered for less than 2 years.

Transferability: As a product is likely to undergo a change in ownership in its later years, transferability under warranty is beneficial to customers and the environment. Samsung's promotional 5 Years extended warranty mentions that the manufacturer's guarantee is transferable whereas the extended warranty is not. Miele's warranties are transferable and renewable at the discretion of the company.

Cost: Hotpoint care-plans, charged to consumers, offer one repair 'followed by ongoing maintenance' and provide reward points on buying. These plans do not offer significant protection against breakdown (red boxes in Table 3). Hotpoint also offers a 1 year parts and labour guarantee but mentions that replacement of any removable or consumable parts is not covered. Its protection plan covers appliances that are out of guarantee but are under 5 years old. In this plan there are no charges for labour, parts or call out, but reinstallation charges have to be borne by the consumer.

For Miele products under warranty all costs are borne by the company including labour, parts, removal and reinstallation. Miele also provides repair for products that are not covered under service certificates (5 and 10 Years promotional warranty); however, unlike Hotpoint, Miele mentions the costs on its website. Both Hotpoint and Samsung offer 10 Years 'parts only' warranties, at no additional cost, for which consumers do not pay for parts but must bear the cost of labour, which is generally very high (Domestic & General Group, 2019).

Choice: As with a manufacturer's guarantee, no company provides the choice of refund or replacement to the consumer if repair is not feasible when the product is under an extended warranty, and keep the decision to their discretion.

Duty: Companies require that for consumers to claim services under warranty, the product must be registered, and the purchase receipt verified within a few days of purchase. This helps product tracking especially if recall is needed.

Warranty on repair work

Companies that focus on product longevity will design their repair services such that a consumer is inclined to repair the product. We argue that companies that provide warranties on repair work probably are more confident in their products and repair services than those that do not.

Miele provides 1 year guarantee on their repair services, which is not provided by Samsung. If a Samsung product is repaired within warranty, the warranty on the replaced part is as long as the warranty remaining on the product. If the product is out of warranty, Samsung provides a 3 months warranty on repair. Hotpoint does not provide a guarantee on repair services but as part of care plans, they provide 'an initial repair followed by ongoing maintenance'.

Miele lists repair charges on its website. These are to be paid for items that are not covered under a standard guarantee or warranty, or if repair is performed due to failure because of conditions mentioned under the list of exclusions of a warranty deed. Samsung and Hotpoint charge for labour, if the consumer chooses to repair using spare parts provided under warranty, but do not provide similar warranties as those by Miele on repair work.

Availability of spare parts

Availability of spare parts helps to make products last longer, as the maximum period of use of a product is determined by the shortest-lived component (Alfieri et al., 2018). Members of the Association of Manufacturers of Domestic Appliance (AMDEA) had a voluntary agreement to provide spare parts for up to 6 years from when a model was discontinued (UKwhitegoods, 2012). The latest guidelines state that manufacturers will try to retain functional spares for as long as 'there is a market' (AMDEA, 2014).

Miele, Samsung and Hotpoint do not mention their spare parts policies on their websites. However, Miele cover the cost of parts and labour in their warranties, which may indicate that Miele keeps spare parts for 10 years (maximum promotional warranty period), or on the positive side, for 20 years because they claim their products last for 20 years.

Summarising the results, guarantees and warranties do not seem to have much influence on product lifespans. Miele's warranty promotes longer use of the product as can be distinctly seen in Table 3 from the number of green scores. Samsung's 5 Years warranty has somewhat similar green scores to Miele. Samsung sells some of its washing machines at comparable price points but has a warranty scheme with different durations for its components. This variation in warranties for products sold at similar price points suggests that companies differ in confidence in their products. Hotpoint experiments with various warranty options, but these appear to be selling ploys as evidenced by the number of red scores in Table 3.

Conclusions

This paper provides a comparison of manufacturer's guarantee and warranty initiatives from three established washing machine brands. Warranties can promote the use of products for a longer duration and stimulate sales and customers satisfaction and may be considered when consumers purchase goods such as large kitchen appliances. Other initiatives by a business, such as providing warranties on repair work, help consumers to consider repair over replacement, as does affordable spare parts.

Warranty, brand perception and price points

Companies selling products at higher price points, such as Samsung and Miele, provide similar manufacturer's guarantee but 'mid-market' companies may not provide similar terms and conditions. Samsung is 'most trustworthy', 'expresses my personality' and is a 'fun' brand (Mintel 2019). It sells at higher price points, similar to Miele, however its longer warranties are similar to those of Hotpoint in terms of the five essentials considered in this paper.

Hotpoint operates at the value end of the market. It is perceived as 'affordable', 'user-friendly' and 'reliable' by consumers (Mintel 2019). Although it offers 1 year manufacturer's guarantee, from the data collected in this paper, it does not seem to provide adequate cover even if the consumer is paying for the warranty. The company seems to be popular for its cheap price. Considering it accounts for 15% of the total sales of washing machines in the UK, it seems to be performing reasonably in accordance with the expectations of consumers. Consumers are, probably, not considering warranties when buying products such as washing machines, even if they want them to last a long time. If consumers are not seeking robust warranties, what could motivate companies to extend the life of their products?

Marketing communications

Hotpoint promotes its protection plan by highlighting 'unlimited' repairs. To get messages through, marketers may encode their messages in a way that takes into account how the target audience usually decodes messages (Kotler et. al., 2013). Logically, consumers would not want machines to break down, therefore use of the word 'unlimited' seems inappropriate unless consumers believe that repairs are expensive. Samsung's and Hotpoint's 'parts only' warranties turn out to be much more expensive for minor repairs, as free parts can be claimed under warranty only if their service is used and the labour charges are generally very high (Domestic & General Group, 2019). The use of the word 'unlimited' is explained further: 'It doesn't matter how many times you need a repair, we'll be there to help'. Therefore, while Hotpoint is making minor repairs expensive, it is simultaneously advertising care plans with 'unlimited repairs' for a charge. This may be interpreted as an attempt to create an impression in the minds of the consumer that the plan will be helpful in case of malfunctioning and will cost less for repairs. Also, Hotpoint mentions that the protection plans are covered by Domestic & General, that provides warranty services to household appliances, and can be transferred to a new owner. This communication may be aimed at luring consumers into buying the plan.

Samsung and Hotpoint provide warranty terms and conditions in product manuals and do not provide a comprehensive document. Miele has a comprehensive document informing consumers about all its warranties on all products. The cost of delivery, disposal and recycling of old appliances are included in the cost of the product. Miele also allows for appliance registration up to 12 years from purchase, conforming with AMDEA's consumer safety initiative to improve the traceability of products (AMDEA, 2019).

Repair and product longevity

The findings of this study suggest that established brands such as Miele, Samsung and Hotpoint provide warranties but do not always make repair a simple experience for the consumer. Therefore, it can be interpreted that some of the warranties may not promote longer use of the product. Samsung's warranty information on its website (Samsung.com, 2019) states that: 'To make a claim under this warranty, end users must produce the original proof of purchase…', thus making it difficult for a second buyer to make claims. Miele and Hotpoint also have a clause of a written consent for transferring warranties if products are sold by the first buyer within the warranty period. This requirement may thus be interpreted as an impediment to second-hand markets.

Miele specifies that they will not bear the repair charges of any appliances operated beyond 10,000 hours. Considering their claim that washing machines are designed to last for 20 years, their calculations seem to be based on the expectation that a machine is used for 500 hours per year on average. By contrast, Hotpoint only offers warranties for products that are less than 5 years old, which is one quarter of the life expected from a Miele washing machine.

Companies that focus on product longevity appear more likely to design their repair services such that the consumer is inclined to repair the product. Miele and Samsung offer repair for products that are not covered under warranty for which they charge. Hotpoint does not provide repair for products not covered under warranty but advertises Domestic & General's plans for repair on its website which are also charged. In general, consumers may prefer to repair if they can find value in paying for it (Kotler et. al., 2013). Providing a warranty on repair may help to instil consumers' confidence in repair over replacement. In the case of products being repaired but not under warranty Miele provides a 1 year warranty on repair work and Samsung provides a 3 months warranty; Hotpoint does not mention duration of a warranty. As manufacturers provide warranties for a maximum of 8 years, products are typically covered for a maximum of 10 years. Thus if a product were to fail just after a warranty expired, even with Miele's 1 year warranty total lifespan of the product, the period covered would be 11 years, less that the average lifespan of 12.5 years. Therefore, despite manufacturers' offering various warranties, none of them cover the average lifespan of products.

The observations from this study indicate that there may not be a connection between the price points at which companies sell products, brand perception and intention for producing longer lasting products. The next stage in this research is to test these observations through interviews with key informants in companies' marketing and after-sales departments. Retailer guarantees have not been studied in this paper and these must also be included in further investigating the role of marketing strategies such as warranties in decreasing the material flow in the economy.

In this paper, warranty details are taken to indicate the intentions of companies regarding the lifespan of their products. Evidence from warranties suggests a higher price may not indicate that the product is fully supported by the company to last for as long as possible. This study needs to be extended to more companies to form more robust conclusions.

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The Story of Product Quality and its Present Day Meaning

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Keywords: Product Quality; Quality Management; Product Quality Definition; Quality Attributes.

Abstract: An increase in the uptake of longer lasting products will be more likely if consumers associate longevity with quality, but this relationship has rarely been addressed by academics. To increase understanding in this area, this study explores how companies interpret and implement the concept of product quality. A literature review is used to provide a conceptual analysis of product quality and its evolution in management thinking. To explain the current notion of the concept, the paper discusses initial findings from interviews with informants in companies producing durable consumer goods. An argument is proposed that ideas of product quality have expanded to include aspects such as branding and marketing, and consequently there may be a need to revisit the concept in the light of these new developments. Furthermore, the paper's purpose is to distinguish the concept of product quality from the quality of processes that build up a product's quality, and to review the dimensions of product quality. Discussion on quality has evolved from a focus on production processes and employee training to customer satisfaction and delivering value. The paper also captures the influential role of marketing in incorporating the quality of products offered by companies and proposes a definition of product quality that forms a stance through which the concept can be studied further.

Introduction

Product longevity is proposed as a solution to problems arising from planned obsolescence (Packard, 1960; Satyro et al., 2018) and the resultant 'throwaway society' (Hellmann & Luedicke, 2018). It therefore affects the activities of both production and consumption (Cooper, 2010). To transform consumer goods markets such that products are used for their full useful lives and a higher proportion of goods in markets are longer lasting, there is a need to revisit the fundamentals of product quality as it encompasses the concept of longevity (Cooper, 2012).

Many academics (Dahlgaard-Park, 2011; Dooley, 2000; Feigenbaum & Feigenbaum, 1999; Garvin, 1984a; Juran et al., 1999; Montgomery, 2009; Reeves & Bednar, 1994) have discussed the concept of quality or the evolution of the 'quality movement'. They have mostly focussed on production management techniques wherein the evolution of product quality is also integrated. By contrast there is a gap in literature on the concept of 'product quality' since the influential work of Garvin (1984a, 1984b, 1987). This paper initially summarises developments in the evolution of the 'quality movement' and the extent to which it focussed on 'product quality'.

There has been a fundamental change in how buyers take decisions (Feigenbaum & Feigenbaum, 1999). Consumers no longer see quality primarily in terms of individual functions, dimensions, characteristics or attributes of a product, but by perception of the total value of the product and of the organisation, its delivery and its maintenance network. Marketing and branding can influence consumers' attitudes, which affect their behaviour (De Bruyn & Lilien, 2008; Pickett-Baker & Ozaki, 2008). Since management is the key decision maker in bringing about any desirable transformation of markets, managers' understanding of the concept of 'product quality' is important. Businesses' constructs of product quality are therefore explored in this study.

Methods

This paper presents an exploratory study which aims to examine product quality and develop a comprehensive list of its dimensions. The study is a part of a PhD project that aims to explore the role of business strategies in increasing the uptake of longer lasting products.

A literature review was conducted, the results of which are discussed through a historical review of the concept. Findings from preliminary interviews with key informants in the clothing industry are discussed in building the case for revisiting the concept of product quality.

Results

Story of 'product quality'

During the early stages of the Industrial Revolution, in the late 1700s, the introduction of factories resulted in raised productivity, reduced costs and increased complexity of products. Taylor's 'scientific management' in late 1800s further raised productivity by increasing efficiency in manufacturing. After World War II companies in the US and beyond prioritised delivery times and productivity to meet the huge demand supply gap, and as a result quality suffered (Dooley, 2000). For example, the standard of electrical products in the US Navy in the 1950s was such that only around a third of products worked properly (Garvin, 1987). Reducing failure rates thus became a priority in the US (Juran et al., 1999).

Production-related failure costs were considered quality costs that needed to be reduced to as low as possible (Juran et al., 1999). This 'cost of quality' approach was justified on two premises: what is measured correctly is managed correctly, and twenty per cent of problems are responsible for eighty per cent of costs (the 'Pareto principle'). Reducing quality costs implied incorporating prevention initiatives, such as pre- and post-production inspection by using sampling and sorting, and over time more sophisticated statistical tools were developed.

Independent quality control teams were responsible for quality in products, broadly to determine the conformance of the product to the standard or specific requirements. The 'zero defect' concept promoted by Crosby (1984) was an extreme form of traditional quality control wherein the ultimate goal was to achieve a total absence of failures. Since the tools used by trained quality engineers were highly technical, they could not engage the interest of upper management in other business functions and they became detached from the process of managing for quality (Juran, 1991; Wareham & Stratton, 1991).

Two major trends in product quality can be identified, one that was followed in the US (evolutionary) and other in Japan(revolutionary). In the US the focus was on quality control by engineers. The development of quality concepts in the UK was similar to that in the US, although in the late 1970s the UK's approach characteristically emphasised standards and certification (Juran et al., 1999).

In Japan, planning was seen as critical for product quality, and companies adopted a stronger quality control theory that required the involvement of senior management, while responsibility for product quality lay with the engineers. In Germany too, quality was regarded as added value for customers and a competitive tool, rather than conformity with standards.

Customers' perspectives of quality hinged on reliability and performance, influenced by growing sales of Japanese- and German-made automobiles in US markets. Superior product quality was identified as a 'competitive weapon' to increase market share (Doyle, 1989; Garvin, 1984a; Jacobson & Aaker, 1987; Hellofs & Jacobson, 1999; Jacobson & Aaker, 1987; Shetty, 1987) and its importance was further strengthened through national and international quality awards.

In the late 1980s Total Quality Management (TQM), based on the philosophies of Deming (1981) and Juran (1986), focussed on quality improvement rather than quality control and insisted on the involvement of senior management (Dahlgaard-Park, 2011). The British Standard on quality systems, BS 5750, published in 1979, was adopted by many businesses and became the foundation for the ISO 9000 standards published in 1987. Leadership focus on quality improvement meant challenging board room processes, and the focus shifted from process quality and product quality to quality-related training and motivation of employees.

Quality awards, TQM, ISO certification and most quality tools had improved internal processes but were not always linked to customer satisfaction and continuous quality improvement (Han & Chen, 2007; Kanji, 1998). However, companies that adopted TQM and ISO 9000 reportedly achieved business excellence and profitability (Buttle, 1997; Kanji, 1998). One explanation was that companies' use of statistical methods and sophisticated processes may have assured consumers of their commitment to making quality products and, because products were more reliable, customers became loyal to those companies (Dooley, 2000; Juran et al., 1999).

By the 1990s some managers began to conclude that there is a limit to which profits can be increased by focusing on quality through internal processes. Marketing benefits, such as gaining new customers, keeping existing customers, increasing market share, increasing growth in sales and improving customer satisfaction, had not been fully appreciated and treated as secondary to the aims of ISO 9000 certification (Buttle, 1997). Companies, in their pursuit of avenues for sustained competitive advantage, began to ask consumers what else they desired in products (Woodruff, 1997). Butz & Goodstein (1996) suggested creating customer value as a strategic tool for greater customer satisfaction, and the relationship between quality, price and value was increasingly explored (Zeithaml, 1988; Parasuraman, 1997; Sweeney et al., 1999; Rao, 2005).

The present day meaning

When product quality is defined in terms of customer satisfaction the contribution of marketing and related functions becomes self-evident (Juran et al., 1999). In the late 1950s marketing research started to focus on a definition of quality based on customer satisfaction (Reeves & Bednar, 1994), but there continued to be lack of advice from researchers on how to improve quality in order to attain customer satisfaction.

Ever since the 1960s businesses have based marketing strategy upon the 4Ps: price, product, place and promotion (Kotler et al., 2013). Marketing includes the processes for creating, communicating and delivering offerings that have value for customers (AMA, 2019). Price, in particular, cannot be separated from product quality, as a high price conveys a prestigious image and companies are expected to offer a high quality product in return (Indounas, 2006). Studies also show that, beyond a certain point, price increases associated with high quality may not convince the customer, which may limit demand (Rao, 2005). A product's quality, when weighed against what the consumer parts with in exchange for the product, which could be either monetary pay-off or emotional trade-off is its value (Zeithaml, 1988). Therefore, value has greater subjectivity and encapsulates more variables than product quality. To fulfil customer expectations the concept of value may be more useful than product quality. Instead of product-driven, cost-based pricing, managers endeavour to apply value-based pricing, which takes into account the value customers attach to a product (Dudu & Agwu, 2014; Indounas, 2006).

The role of advertising and branding has expanded from information dissemination about a product to value creation. Marketing communications were designed to inform consumers about a product's origin and quality in order to reduce risk and uncertainty (Juran et al., 1999; Montgomery, 2009), but over time, branding and advertising can create value by promoting characteristics such as brand awareness and brand image (Moore & Reid, 2008) which can influence buying decisions (Brucks et al., 2000; Grewal et al., 1998; Meenaghan, 1995).

Feedback from marketing and branding not only assists companies' design and product decisions but may play an influential role in new product development in the company. This was revealed in two interviews that are discussed below.

Initial interviews with key informants

This paper analysis responses from two industry interviewees:
Respondent A: An academic and business advisor who was previously a designer for high-street clothing brands.
Respondent B: A production manager, working with a 'design-led' luxury fashion brand for clothing for 25 years.

The respondents considered quality in materials: they commented on inspection of material strength, such as the weave of the fabric, colour fastener performance, laundering and stitching tests. All products were graded after testing.

Business functions may understand quality slightly differently because they are looking at different aspects of the product. Asked about variations in the understanding of product quality across business functions, and which teams exert a significant influence in defining product quality, both respondents stated that their brands were buying-led and therefore the role of sales and marketing teams is especially significant in determining the sort of products that the company would launch.

In response to who decides price points, respondent B said: *"That's decided by our sales teams, who go out looking at competitors… and they also talk to people who buy our product… and that's fed back to the design teams… So, our design team, they go to all fabric fairs and choose the materials… mainly chosen for their aesthetic… and also our quality control will take lengths of sampling fabric… for testing… without quality control we cannot go into production."*

Elaborating on the roles of marketing and retail merchandising, respondent B said they work closely with design teams. Production teams "*don't know actually what they (marketing and retail merchandising) are telling people... we (production) are just trying to produce a nice product that satisfies design and satisfies quality control*". Respondent A resonated with this.

Pricing is a complex strategic decision and is critical among the 4Ps of the marketing mix, being directly associated with revenue and profits. Sales or merchandising managers decide the boundaries, in terms of price points, within which design, quality control and production teams work. Respondent A said analysis from sales and marketing teams "*often reflects what the range would look like anyway and how it should be changed to fit that end user.*"

Branding and advertising are effective in influencing buying decisions (Grewal et al., 1998; Meenaghan, 1995) and may also be crucial in determining quality parameters of future offerings of a company. Respondent A said: "*I work with external companies who are now restructuring themselves so that the brand now becomes the most important aspect of all.*" They confirmed that parameters of product quality are presently being "*led by the brand and the marketing teams.*"

Respondent B was convinced that they may gain a competitive edge if they entered into new product segments such as performance clothing (cf. fashion clothing) because the company has a strong brand image. A strong brand image provides a head start if a company ventures into new products as consumers prefer a trusted brand name. This indicates that companies find it favourable to build brand image and that branding may play a significant role in promoting new products. Brands venturing into new markets, even when they may not have the relevant product expertise, may benefit from customer faith in their brand, regardless of the quality of the product.

In the final section, below, the concept of product quality is explored further and dimensions of product quality are listed.

Dimensions of product quality

Scholars have developed a generalisable typology of quality dimensions for durable products (Brucks et al., 2000; Garvin, 1984b, 1987; Rao et al., 2013; Rao & Monroe, 1989; Zeithaml, 1988). The list of dimensions presented below summarises factors that affect a product's quality. It builds on earlier work and includes new dimensions in the present context. These factors are grouped into four categories which aim to simplify the usability of the concept of product quality and increase its understanding.

1. Product-related dimensions
   This category includes the dimensions of product quality that are related to the physical composition and are a primary responsibility of the design and manufacturing functions. If any of these dimensions change, the resultant product will be different from its present form.
   a. *Performance*
      The product's primary operating characteristics.
   b. *Reliability*
      The probability of a product malfunctioning or failing within a specific time period.
   c. *Features*
      Technical, operating characteristics affected by objective individual needs of consumers.
   d. *Reparability*
      The potential of a product to be repaired.
   e. *Durability*
      The amount of use that a product provides before it physically deteriorates.

2. Company-related dimensions
   This category includes dimensions determined by the managers of various business departments in a company. As companies choose the markets in which they operate, these dimensions of product quality may vary for the same product. Under this list are a set of management decisions that impact upon a product's quality.
   a. *Conformance*
      The degree to which a product's design and operating characteristics match pre-established standards. In manufacturing, quality is conformance to requirements established by production and design managers. There are testing requirements, the passing criteria of which is variable.
   b. *Marketing*
      The activities, set of institutions, and processes for creating, communicating, delivering, and exchanging offerings that have value for customers (AMA, 2019). Feedback from these can shape the future offerings of a company. Marketing and related functions can influence pricing, branding, advertising and packaging. Market research and feedback from sales and aftersales can influence interpretation of market needs and wants.

3. Consumer related dimensions
   When quality is difficult to evaluate consumers use higher level abstractions of intrinsic and extrinsic properties (Zeithaml, 1988). Companies' understanding of these can help them to design products and communication.
   a. *Aesthetics*
      How a product looks, feels, sounds, tastes or smells to consumers.
   b. *Quality perception*
      Consumers may evaluate products by their branding and advertising as much as by objective characteristics.

4. Legal environment-related dimensions
   Voluntary codes of conduct and laws under which companies operate have a bearing on product quality.
   a. *Policies and directives*
      Adopted by companies and governments to facilitate or conduct certain guidance principles or actions, such as product standards.
   b. *Laws*
      Legislation such as competition law and consumer protection law may influenced the quality of products.

Conclusions

To transform consumer goods markets towards sustainability there is a need to revisit the concept of product quality, as it encompasses product longevity. This exploratory paper is an extension of the earlier work on quality and recognises the increasing importance of marketing and related functions in defining product quality.

In the light of these developments there is a need to revisit the concept. This evolution must not be considered an indication that earlier definitions of quality are redundant. For example, closer conformance to standards has yielded benefits (Crosby, 1984) and must therefore be continued in production, operations and engineering functions.

Further, empirical data is required to test the argument proposed in this paper that ideas of product quality have expanded to include aspects like branding and marketing. More managers from the clothing sector will be interviewed, as well as managers in two other product sectors, white goods and bicycles.

In this paper the dimensions of product quality have been arranged and grouped to simplify the usability of the concept. This represents one of many rational ways in which they can be organised.

The paper has provided a conceptual analysis of the term 'product quality'. This is important to differentiate between product quality and the quality of the processes that underpin a product's quality. Understanding the dimensions of product quality alone is not sufficient when trying to comprehend the full picture. Thus, the following updated definition of product quality is proposed:

'The quality of a product is specific to its use and the intentions of the organisations involved in various capacities in bringing it to the market.'

This definition is simple, perhaps even trivial. However, it forms a stance from which the concept can be studied further. While earlier definitions of quality suggest that it is a relative concept, this definition sets the stage for quality to be treated as specific to the use and intentions of the organisation. It provides the basis on which the importance of product quality, in delivering sustainability by promoting product longevity, can be explored further.

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Taking Products Out of Waste Law: A (New) Legal Framework for the Circular Economy

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Keywords: EU Law; Waste Law; Products; Circular Economy.

Abstract: At the heart of EU waste law lies the prevention principle. Preventive measures in environmental law aim to avoid and reduce the risk of environmental harm that can target both pollution sources and point of impact. The point of departure of waste law is that waste is a source of pollution, the unwanted outcome of the production and consumption processes, an environmental externality. The risk results from the actions of the holder of a substance or object from the moment where that substance or object is no longer wanted and (carelessly) disposed of. Preventing waste is hence about ensuring that a discarded object is disposed in the least environmentally harmful manner. It is also about much more than that. It is about everything that takes place before a product or material becomes waste, it is about extended product lifetime, repair and re-use, sharing and renting. The role of waste law might have consisted in avoiding landfilling, ensuring that collection and recovery schemes are in place, and that information flows between producers, consumers and waste managers. The rest, the prevention of products from becoming waste in the first place, could arguably have been pursued in another (more fitting) context. EU legislators, and the CJEU, saw things differently. A wide definition of waste captured in effect the major issues of prevention. As a result, waste recovery is facing today great regulatory challenges, such as stringent conditions about when waste ceases to be waste (i.e. 'end-of-waste') and abiding by the strict rules about chemical production (stemming from the REACH regulation).

This paper aims at critically examining the existing EU legal framework on waste, in particular on issues of objectives and scope and laying the foundations for a new legal paradigm in accordance with the goals of the Circular Economy. It is argued that the definition of waste needs to be narrowed to leave room for the 'circular' model to flourish. It follows that a (new) legal framework - focusing on products - shall be established in the vacuum left by a shrunken waste law.

Introduction

The European Union (EU) is committed to transitioning from a linear to a circular economy (CE) "where the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste minimised" (EU Commission, 2015). EU waste law is a major part of the EU's efforts to develop a sustainable and resource-efficient economy. It encourages recourse to the most environmentally sound processes to treat waste and divert it from landfills. The waste hierarchy establishes a priority order from prevention, preparation for reuse, recycling and energy recovery and finally disposal. The Waste Framework Directive (WFD) sets out ambitious targets for the preparing for re-use and the recycling of waste materials such as paper, metal, plastic and glass from households (Article 11(2)(a)). Moreover, in the CE, waste is a resource that has the potential to replace primary raw materials from traditional extractive resources. Despite continuous improvements in waste management, the Commission found that the EU is currently losing a significant amount of secondary raw resources (EU Commission, 2014). It estimated that out of the 2.5 billion tons of waste generated in the EU in 2013, 1.6 billion tons were not reused or recycled. The EU also found that approximately 600 million tons could be reused or recycled in the future, still leaving a large portion to waste recovery (in particular energy recovery) and disposal (landfilling). Thus, even if waste management must further increase and improve, the best way to mitigate pollution from waste is to prevent it from occurring altogether. Waste prevention includes measures to decrease consumption, design more durable and reparable products, use lesser resources in production, extend the lifetime of products through maintenance and repair, and promote reuse.

Although the synergy of objectives between waste and CE policies may appear quite ideal, the first does not seem ideally fitted to promote the second. The Commission states that “the way we collect and manage our waste can lead either to high rates of recycling and to valuable materials finding their way back into the economy, or to […] potentially harmful environmental impacts and significant economic losses” (EU Commission, 2015). However, what the CE really seeks is to significantly reduce waste; the very broad scope of waste law means that whenever something is discarded, it becomes waste.

At both EU and national level, an increasing number of legal initiatives are being adopted that aim not only to regulate product design for durability and reparability, but also to inform consumers, ensure access to repair and repair tools, and providing tax incentives. These initiatives are showing that new thinking is possible, and this needs to be pursued further. Products need to start taking the front stage.

Waste: a problem of definition

The point of departure of waste law is that waste is a *source* of pollution. The *risk* of harm is not inherent to waste, but results from the fact that the holder of a substance or object it no longer wants might carelessly dispose of it (Cheyne, 2002, 62; Tromans, 2001, 135). The action that characterises the disposal represents a threat to the environment (Cheyne, 2002). Thus, the definition of waste developed as an *action-based* concept given the inherent risk of pollution arising from waste disposal and regardless of the toxicity of the original materials (Scotford, 2007; Cheyne, 2002). Initially, EU law defined waste as a substance or object that is ‘disposed of’ by the holder (Directive 75/442, Article 1(a)). However, the meaning of the term ‘dispose’ appeared ambiguous as to whether it aimed to cover not just normal disposal activities (tipping and incineration), but also recovery operations (Tromans, 2001, 141). An amendment to the Directive in 1991 changed the definition to include “any substance or object which the holder discards or intends or is required to discard” (WFD, Article 3(a)). The replacement of the verb ‘dispose’ by ‘discard’ confirmed the early interpretation of the definition by the CJEU (Joined cases C-206/88 and C-207/88 *Vessoso and Zanetti*, para 8 ff.). Discarding, i.e. getting rid of something no longer useful or desirable (Oxford Dictionaries), is meant to embody a comprehensive notion of waste that includes both recovery and disposal (EU Commission, 2012).

It is clear that the broad interpretation of the term ‘waste’ by the EU legislators and the CJEU (Joined cases C-304/94, C-330/94, C-342/94 and C-224/95 *Euro Tombesi*; Joined cases C-418/97 and C-419/97 *ARCO*; Case C-252/05 *Thames Water*; Case C-188/07 *Commune de Mesquer*, 39; Case C-1/03 *Van de Walle*; Case C-457/02 *Niselli*) aimed to prevent the threat of waste pollution by ensuring that virtually all ‘substances and objects’ would eventually fall within the scope of waste law and thus have to abide by its rules. However, as a result, the definition also encompasses materials that, although they may have no further use for the holder, constitute valuable resources for another user or production process. This all-encompassing definition of waste essentially defies the very core idea of the CE – that is, to do away with waste. The CE aims to extend useful lifetime through maintenance and repair, and ensuring the reuse of products and their recovery, while recycling is a less desirable option from an environmental point of view.

On waste or products?

Waste prevention is not, strictly speaking, merely an issue about waste. This is particularly apparent in the examples provided by the WFD of preventive measures that Member States shall establish as part of the development of their waste prevention programmes (WFD, Article 29). Annex IV refers to product eco-design, eco-labels and economic incentives for the efficient use of resources and for cleaner purchases. Clearly, none of these examples has anything to do with waste management or shall fall on Member States alone. In fact, the EU ended up legislating on some of those issues, among others adopting ecodesign and labelling requirements for energy-related products, and introducing some elements of sustainability in public procurement rules (Directive 2014/24/EU; EU Commission, 2008). These legal schemes now form an integral part of the EU’s action plan for the CE.

Product maintenance, repair and reuse are key aspects of waste prevention that remain largely underdeveloped in EU legislation. Their potential for reducing environmental impact and resource use should make them a priority. The

Ellen MacArthur Foundation refers to the 'power of the inner circles': "The closer the system gets to direct reuse, i.e., the perpetuation of its original purpose, the larger the cost savings should be in terms of material, labour, energy, capital and the associated externalities, such as greenhouse gas emissions, water, or toxic substances" (2013, 33). Several barriers hinder repair, including legal and non-legal barriers to accessing repair, cost and complexity of repair, and consumer attitudes not favouring repair (Svensson et al., 2018; Riisgaard et al., 2016; Wieser, Tröger, 2018). Removing legal barriers from e.g. IP or competition laws is certainly fundamental, but establishing an environment in which repair becomes mainstream is also essential for realising the CE (Svensson et al., 2018).

The issue of reuse is one that is particularly telling of the tensions between waste law's aim to avoid pollution from unregulated waste management and the CE's objective to keep resources within the economy. The WFD defines *reuse* as a means of waste prevention. It is the process of using products again 'that are not waste' "for the same purpose for which they were conceived" (Article 3(13); EU Commission, 2012). This process is not directly included in the waste hierarchy, contrary to the preparation for reuse, which is the second priority. *Preparing for reuse* is referred to in Article 3(16) WFD as a waste management process whereby a product is checked, cleaned, repaired or recovered (that is, reconditioned and remanufactured, not recycled) so that it can be used again for the same purpose. The distinction between direct reuse and reuse following repair appears to depend on whether the product was discarded in the first place. Some municipalities or charitable organizations put up 'reuse containers' as alternatives to recycling bins, in particular for clothes. For the most part, however, consumers who want to get rid of their items have little choice other than to 'discard' them. Hence, for lack of better alternative, a majority of potentially reusable products will fall within the scope of waste law.

This is far from a trivial issue because, under the current system, the qualification of 'waste' has strong legal but also practical and psychological implications. When a product becomes waste, there is a specific set of legal rules that applies to it.

Chemical legislation does not apply to waste, but hazardous waste must be managed under strict conditions (WFD, Article 17). However, there is a current dichotomy between waste and chemical rules that may lead to hazardous substances being 'lost' when a product becomes waste, and information about toxicity not being adequately passed along to new manufacturers (Bernard, 2017).

EU waste law has progressively grown into an extensive legal framework governing industrial, commercial and household waste. At the heart of this framework today is the WFD, which defines key concepts, establishes core principles, and allocates responsibilities that apply across the board to the entire legal field. A number of sectoral directives regulate specific streams of waste (such as packaging, and electrical and electronic equipment (EEE)) or specific forms of waste management (including landfilling and transboundary shipments).

Waste versus non-waste: a new hierarchy

Current waste management practices are strongly influenced by the 'waste hierarchy', which is set out in the WFD (see figure 1). It consists in a priority order for waste management options based on assumed environmental impacts (Van Ewijk and Stegeman). The hierarchy establishes disposal (landfilling) as the least preferred option, followed by waste recovery notably for the production of energy, heat or fuels, and by recycling. The next priority is preparation for reuse (or product recovery), which promotes practices that allow products to fulfil their functions again after their first useful lifetime (J Hultman, H Corvellec, 2414).

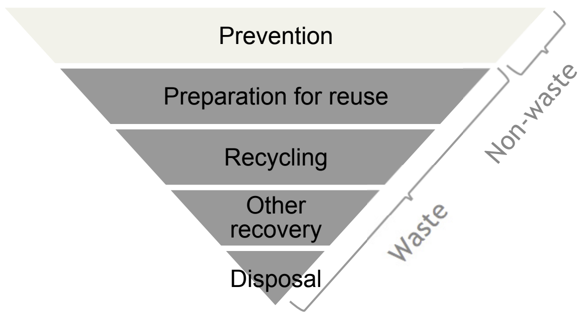

Figure 1. Waste management hierarchy (WFD 2008/98).

At the top of the hierarchy is prevention. Waste *prevention* encompasses measures aimed at avoiding waste that is by reducing either the amount of waste being produced (quantitative reduction) or the content of harmful substances they contain (qualitative reduction) (Article 3(12) WFD and DG Env Guidance document (2012), 28). This includes design measures to extend the product's lifetime, maintenance and repair practices as well as second-hand retail.

The waste hierarchy is criticized for being insufficiently detailed (Gharfalkar et al.) and promoting diversion from landfill, but being unable to reduce natural resources consumption (van Ewijk and Stegemann). Moreover, the inclusion of 'prevention' in the hierarchy raises the question as to whether it is indeed a waste hierarchy. Gharfalkar et al. propose to rename it a 'hierarchy of resource use'. This denomination appears more in line with CE's objective of 'waste as a resource' and is thus adopted in this article.

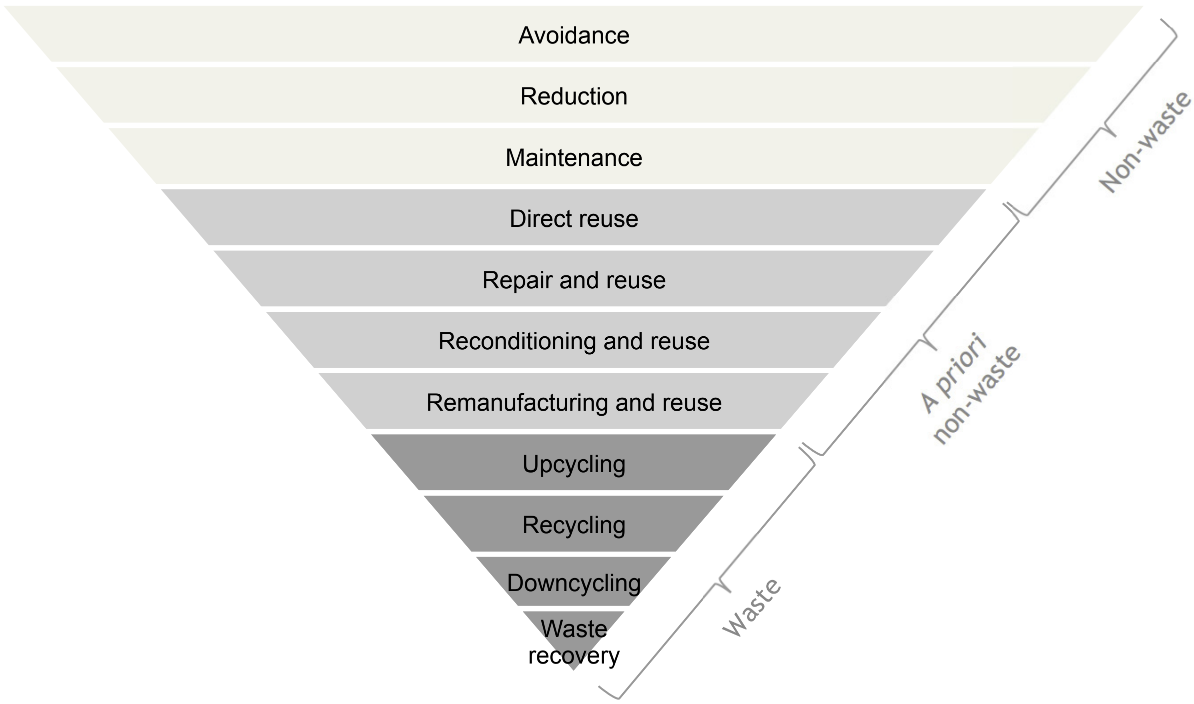

Figure 2. Proposed alternative hierarchy and new distinction between waste and not waste.

Current terminology and definitions as per WFD 2008/98 and waste hierarchy		**New terminology and definitions as per the proposed 'hierarchy of resource use'**	
Non-waste	**Prevention:** "measures taken before a substance, material or product has become waste, that reduce: (a) the quantity of waste, including through the re-use of products or the extension of the life span of products; (b) the adverse impacts of the generated waste on the environment and human health; or (c) the content of harmful substances in materials and products"	**Non-waste**	**Avoidance**: quantitative reduction in amount produced and consumed
			Reduction: qualitative reduction of the environmental impact of products (less materials, less harmful substances, more in-built durability and reparability)
			Maintenance: extending the product's useful lifetime by first user (including repair)
		***A priori* non-waste**	**Reuse:** broad term that includes direct reuse and other forms of reuse described below
	Reuse: "any operation by which products or components that are not waste are used again for the same purpose for which they were conceived"		**Direct reuse**: the use of a product by another user without repair process

Waste	**Recovery**: “any operation the principal result of which is waste serving a useful purpose by replacing other materials which would otherwise have been used to fulfil a particular function, or waste being prepared to fulfil that function, in the plant or in the wider economy”		**Product recovery**: recovery processes that allow reusing products for the same purpose for which they were conceived
	Preparation for reuse: “checking, cleaning or repairing recovery operations, by which products or components of products that have become waste are prepared so that they can be re-used without any other pre-processing”		**Repair for reuse**: creating slightly inferior products for second-hand markets
			Reconditioning for reuse: same as repair but involving a more extensive recovery process
			Remanufacturing for reuse: extensive recovery to return the product to original specifications
	Recycling: “any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes”	Waste	**Reprocessing** (or **material recovery**):
			- **Upcycling**: reprocessing of waste materials into products, materials or substances of *higher* purpose and/or value than the original:
			- **Recycling**: reprocessing of waste materials into products, materials or substances of *same* purpose and/or value than the original;
			- **Downcycling**: reprocessing of waste materials into products, materials or substances of *lower* purpose and/or value than the original
	Other recovery: e.g. energy recovery		**Waste recovery**
	Disposal: “any operation which is not recovery even where the operation has as a secondary consequence the reclamation of substances or energy”		**Disposal:** removed as a priority of the hierarchy

Table 2. Current versus proposed new terminology and definitions for the hierarchy.

A (new) legal framework for ‘non-waste’ products

The 2008 recast of the WFD introduced the concept of ‘by-product’ and turned into law jurisprudential developments and Commission guidelines from 2007. A by-product is defined as the residue of a production process that aim at producing another, primary product. Exclusion of such products from the waste definition depends on them meeting strict conditions about the lawfulness and certainty of further use without further processing, and about the product being an integral part of the production process.

The idea of developing a legal framework addressing the environmental impacts from products is not new (Dalhammar, 2007; Maitre-Ekern, 2015). A 1999 report from the Swedish EPA proposed to introduce such framework directive based on the Product Safety Directive as well as several daughter directives to lay out details product-specific requirements (SNV rapport). In 2004, the EEB put forward a similar proposal for a directive on the environmental soundness of products. The Commission did not follow that approach and preferred focusing on the adoption of a new directive on the ecodesign of energy-using products (2005/32/EC) that later evolved to cover all energy related products (2009/125/EC). The scheme, which aims at removing the worse performing products on the market, has also evolved in terms of its objective: at first, it focused on the energy efficiency of products, but it is developing to address other issues, such as resource efficiency, durability and reparability (Dalhammar, 2014b).

It is the author's view that the success and increasingly broad scope of the Ecodesign Directive should not hide the fact that it does not have the stature of a framework directive. Waste prevention goes beyond design. The European legislators justified the adoption of the Ecodesign Directive based on the affirmation that "the pollution caused during a product's life cycle is determined at [the design] stage". This vision is too limited. Reducing the environmental impacts of products is a matter not just of the product itself, but also of the structural forces that affect it (competition, prices, demand).

Conclusions

Policies on waste and the CE appear to go hand in hand. Waste law can contribute both towards boosting environmental sound waste management and avoiding contamination, and towards reducing our dependency on raw natural resources. However, waste law has developed at a different time and in a different context than the CE. The aim of the legislator and the CJEU was to avoid pollution from landfilling and other improper treatment that was a significant threat in the 1970s. This led to a broad definition of waste that encompasses anything that is being discarded. On the other hand, the CE aims to divert as many materials as possible from becoming waste to avoid the environmental impacts and loss of value that result from waste management. The CE intends to change the very functioning of the economy and particularly to establish new business models. New innovative regulatory schemes have developed under its auspices, such as the Ecodesign Directive, which imposes design requirements directly to the producers.
Preventing and reducing waste products requires in particular extending their lifetime through maintenance, repair, and reuse. The broad scope of waste often defeats this purpose.

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Planned Obsolescence in Smartphones? Insights from Benchmark Testing

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Keywords: Planned Obsolescence; Functional Obsolescence; Perceived Obsolescence; Smartphone; Benchmark Data; iPhone.

Abstract: This paper addresses the planned obsolescence in iPhones discussion through the analysis of two relevant datasets. The first of these is the benchmark test results of over 3.5 million devices from Sept 2016 to April 2019. The second is compiled of the entries and views of an on-line blog which covers news items and rumours related to Apple products. The analysis suggests that, outside of the batterygate episode for certain models, there is no evidence of deliberate reduction in performance of devices. The analysis also suggests that users may be subject to psychological mechanisms which cause them to question the performance of their devices at times when new products are made available.

Introduction

In recent years, growing interest in the circular economy, novel business models, collaborative consumption and the right to repair amongst other things have highlighted the key role that product lifespans play in shaping the environmental impacts of consumption. Indeed, several Industrial Ecologists have shown that product durability and turnover have meaningful implications for energy and resource efficiency, critical raw materials, waste generation, and climate change (Hertwich, 2019).

Planned obsolescence typically refers to the practice of designing and producing durable goods which would be considered outdated within a shorter time period than technically possible, clearing the stage for new product acquisition (Guiltinan 2009; Walker et al. 2013). Planned obsolescence encompasses many strategies including physical and technological means that may promote premature product replacement as well as psychological means by which, as its prominent advocate Brooks Stevens put it, "...*the desire to own something a little newer, a little better, a little sooner than is necessary*" is installed in the consumer (Adamson 2003, p. 123). Cooper (2004) suggested dividing all drivers into two main categories of absolute obsolescence (physical durability related to wear and tear) and relative obsolescence (technological, psychological and economic). Burns (2010), distinguishes between four modes of obsolescence (aesthetic, social, technological and economic) while Chapman (2005) highlights the relevance of emotional durability to product lifespans

With regard to electronics, while much of the public discourse, regulation, and academic research has centered on functional aspects of product obsolescence, psychological factors and specifically perceived obsolescence have not received the same attention.

In this work, through analysis of benchmarking results for iPhones and the activity of an on-line discussion forum, we explore both functional obsolescence & perceived (i.e. psychological) obsolescence by analyzing the objective performance of the devices over time, the frequency with which such objective tests are run by users and what may be triggering people to run such tests.

Benchmarking

Benchmarking is the act of running a set of computer programs, or other operations, in order to assess the performance of an electronic device using objective metrics. A user of a device, in this case an iPhone, would download and run an app which provides them with a composite score based on the range of operations performed that allows them to compare the performance of their device to other models of phones and also to track the performance of their device over time. These results are also returned to the benchmark provider where they are often displayed on-line.

Using publicly displayed results from the Geekbench website a dataset of 3,541,554 iPhone test results from September 2016 to May 2019 was compiled. A description of the data assembled is shown in Table 1.

Model	Frequency	% of Total
iPhone 11	31,201	0.88
iPhone 4s	8,813	0.25
iPhone 5	28,829	0.81
iPhone 5c	9,174	0.26
iPhone 5s	147,262	4.16
iPhone 6	336,927	9.51
iPhone 6 +	144,444	4.08
iPhone 6s	558,119	15.76
iPhone 6s +	249,742	7.05
iPhone 7	448,641	12.67
iPhone 7 +	431,560	12.19
iPhone 8	126,761	3.58
iPhone 8 +	217,401	6.14
iPhone se	226,776	6.40
iPhone x	446,440	12.61
iPhone xs	43,332	1.22
iPhone xs Max	86,132	2.43
Total	**3,541,554**	

Table 1. Dataset of Benchmarking Scores.

Functional Obsolescence

In exploring functional obsolescence, it is necessary to observe the extent to which the performance of devices changes over time and with operating system updates.

Figure 1 displays the mean score per week over the period of interest with various points of interest inserted into the timeline. It can be seen that in fact, average functional performance doesn't really change over time. The only deviation from this very "flat" performance over time is with certain models including the iPhone 6, iPhone 6s and iPhone SE due to the events surrounding "batterygate". This describes the period after the release of iOS 10.2.1 in January 2017 where certain devices with degraded battery health were deliberately throttled to prevent unexpected shutdown and was largely agreed to have successfully resolved this issue. The throttling of phones with degraded batteries became widely known in December 2017 and in January 2018 Apple subsequently offered $29 battery replacements to affected users. The iOS 11.3 update at the end of March 2018 eventually provided transparency on battery health and peak performance capability and recommends is a battery needs to be replaced. By June 2018 the average performance had returned to the original state. A detailed overview of iPhone 6 scores by iOS version is shown in Figure 2 which further illustrates how the performance changed over the course of this episode.

In spite of "batterygate", in the whole we don't see evidence from this data that the performance of software on iPhones is being used as part of a strategy of planned obsolescence. However, what is clear is that iPhones in general perform very consistently over relatively long lifetimes. For example, the iPhone 5 was first released in September 2012 with operating system support ending in September 2017 but has not shown any decline in software performance to date (almost 7 years). This is much longer than the reasonable service life of the battery which gives support to the argument that batteries as a consumable should be easier for users to replace.

Psychological Obsolescence

A multitude of factors influence consumers' perception of a product, its obsolescence, and subsequently the choice of whether and when to replace it. The availability (or even announcement) of a newer or improved model of their existing device is one of these factors. In this section of the paper we introduce some of the psychological mechanisms that have been proposed to exist when consumers are considering an upgrade and how they help to create the perception of obsolescence. Based on this we then examine the benchmarking dataset to see if there is any evidence that these psychological phenomena may be driving perceived obsolescence in iPhone users.

Consumers have been demonstrated to exhibit waste aversion and are driven by frugality and a distaste for unused utility (Bolton, 2011;

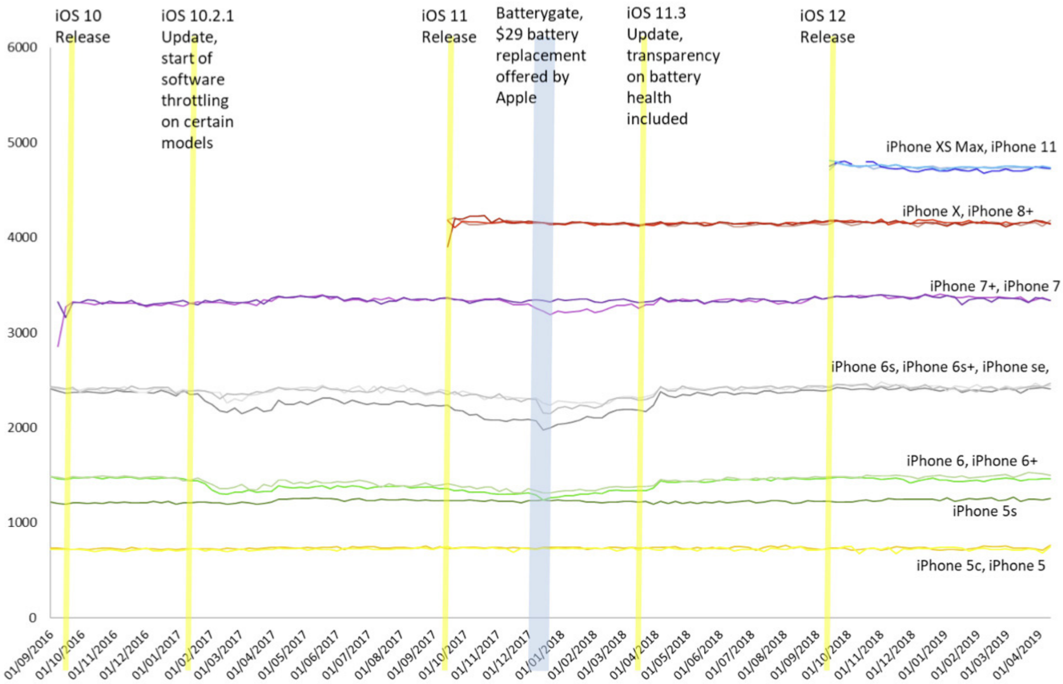

Figure 1. iPhone Benchmarking Scores Over Time.

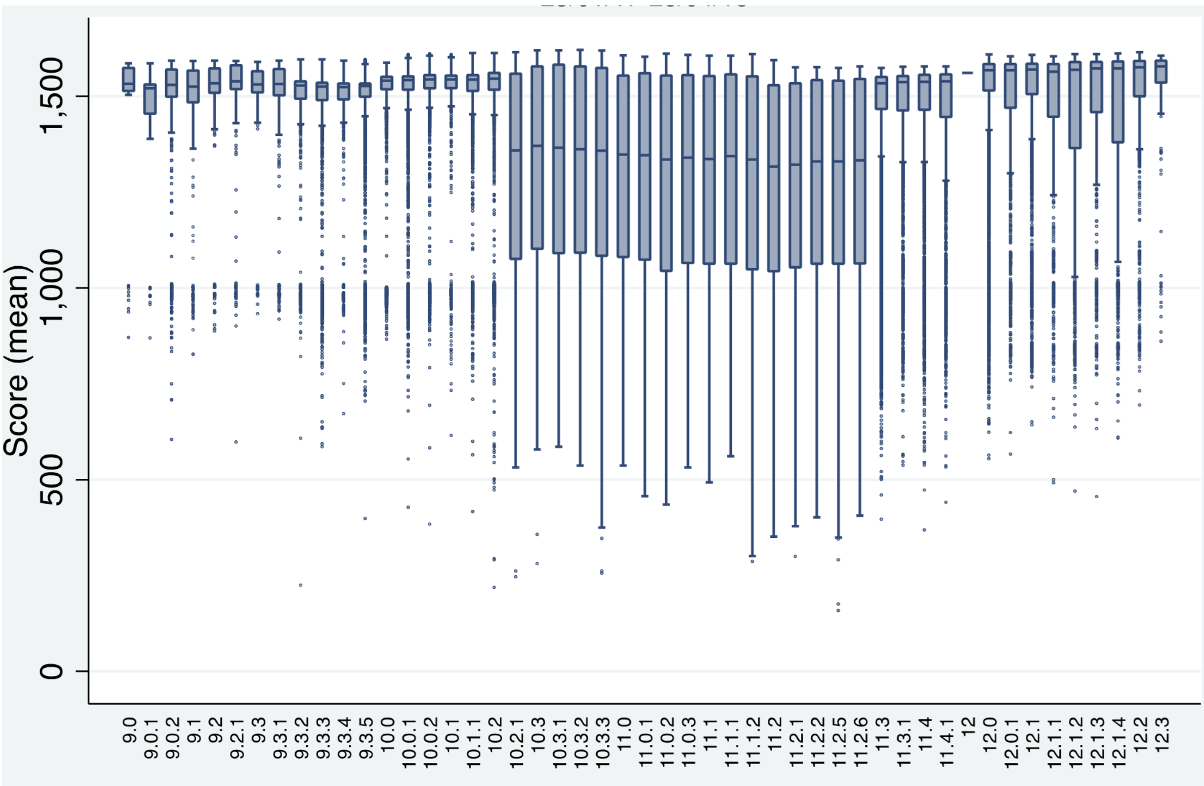

Figure 2. iPhone 6 Score Distribution by iOS version.

Casey 2019). When faced with an upgrade decision consumers consider the purchase price of the new alternative and the mental cost of retiring the old product before s/he has gotten his/her money's worth out of it (Okada, 2001). During ownership of a product, a consumer mentally depreciates the initial purchase price, thus creating a mental book value for the product. The write off of this mental book value is felt as the mental cost of a replacement purchase (Okada, 2001). Therefore, in order to support an upgrade, this mental book value would need to be as low as possible in order to overcome waste aversion and minimize the mental cost. Checking the performance of their device using a benchmark tool could be interpreted as a symptom of checking this mental book value. Likewise, the "upgrade effect" has been proposed which suggests that consumers exhibit careless tendencies with their possessions to help them justify the purchase of upgrades and has been evidenced by consumers being less likely to look for their lost phones when a new model is available in the market (Bellezza, 2017). This work also describes how upgrades generate a need for justification in consumers. We expect that this need for justification would be manifested through increases in consumers checking the functional performance of their existing phones at times at which major new product launches are made and upgrades become an option, or even the announcement of forthcoming products. A chart showing the distribution of tests for all models is shown in Figure 3 with some notable events inserted.

One observation that can be made readily on inspection of this chart is that it is characterized by a number of very obvious peaks in test frequency which, upon investigation, appear to be closely aligned with events such as major product launches, operating system releases and announcements and of course the battery gate period. The peak in tests in April 2017 should be disregarded as it was caused by the announcement of a major upgrade of the benchmark. This has been cross checked with other benchmarking apps which have shown no change in test frequency at that time.

Our work has focused on testing this dataset to explore whether it is possible to discern if actual or perceived changes in the performance of the device are the drivers of the peaks in test frequency. To get an objective measure of what messaging consumers are receiving about iPhones and also a relative measure of the extent to which consumers are engaging with these messages we have conducted a web scrape of the MacRumours website to assemble a dataset which includes the article title, the number of comments and the number of views. MacRumors.com is a website that aggregates Mac and Apple related news, rumors, and reports and is considered one of the most comprehensive sources of dialogue on all things Apple related on the internet. These articles were then included or excluded based on their perceived relevance to triggering the upgrade effect in consumers. Specifically, articles were examined to see if they addressed any of the following issues

- Is the article related to the release of a new model of iPhone?
- Is the article related to the release of a new version of iOS?
- Is the article about the performance of an existing model of iPhone?
- Is the article about performance issues of iOS

Finally, the comments on these articles were summed and plotted against the numbers of tests conducted as shown in Figure 4. Both of these traces were tested for local maxima to identify peaks as shown in Figure 5.

It can be generalized from observing this chart that spikes in benchmark testing often follow closely after heightened coverage of new devices, operating systems or performance issues.

Conclusions

While we find no clear relationship between low objective functional performance (i.e. low test scores) and the number of test preformed, our data reveals significant spikes in the numbers of benchmarking tests run by consumers closely following external events such as new product announcements and media coverage of iPhone performance. These results suggest that consumers are more likely to question the performance of their devices due to perceived obsolescence rather than actual deterioration in functional performance. These results are consistent with other findings illustrating the importance of psychological drivers for product replacement. Traditional market mechanisms directly linking business profits to sales volumes encourage corporations to make use of advertising and marketing channels to reinforce the desirability of consumer product replacement in saturated markets.

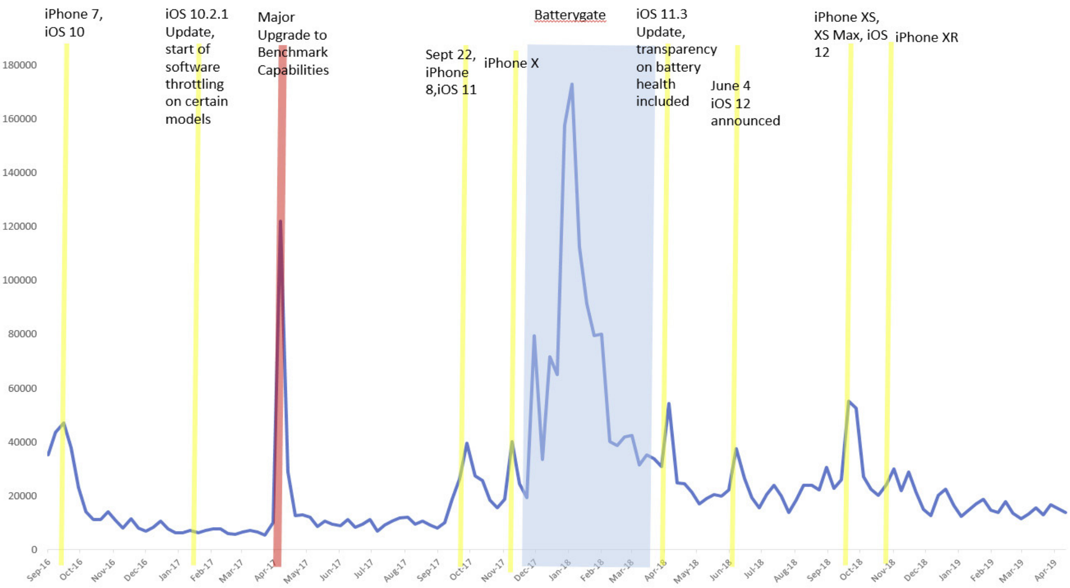

Figure 3. iPhone Test Frequency Over Time.

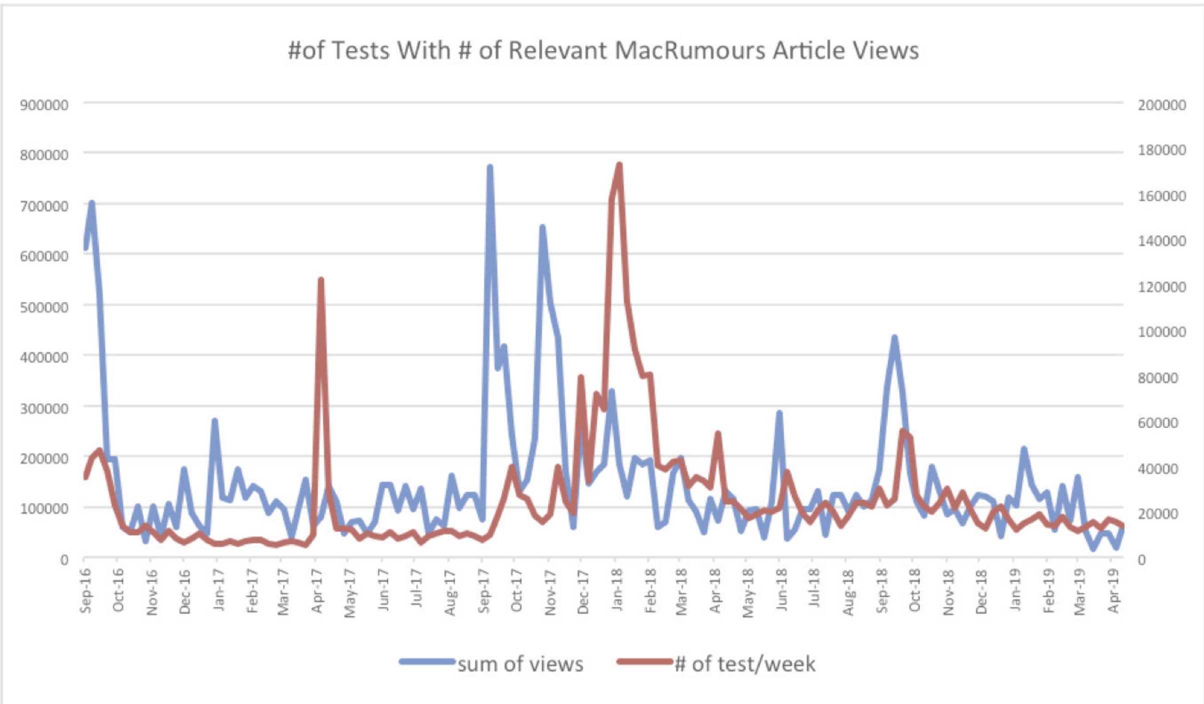

Figure 4. iPhone Test Frequency & Article Views.

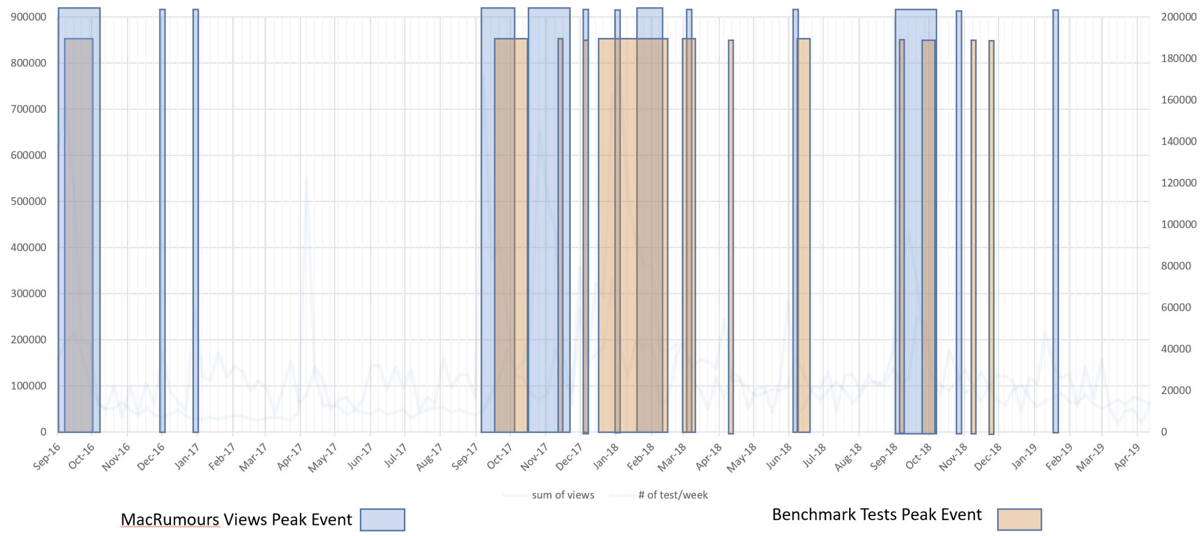

Figure 5. Time Series of Peak Events in Article Views and Benchmark Testing.

Indeed, consumer choices and habits play a critical role in the product replacement cycle and consumption patterns (Lorek and Vergragt 2015). Though design no doubt plays a role in how long products remain in use, we must keep in mind that ultimately, product life time and when a product is replaced is not a predetermined design creation, but rather the result of consumers' decisions (Brouillat 2014; Gordon 2009; Stahel 2010; van Nes and Cramer 2005) Future work will continue to examine these datasets around specific events and for specific models. Despite frustration with what many view as 'planned obsolescence', our work indicated that at least for now, focus on the psychological (rather than technical) drivers for product replacement might yield greater benefits.

Acknowledgments

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What is my Share? Using Market Data to Assess the Environmental Impacts of Secondary Consumption

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Keywords: Reuse; LCA; Market Data; Depreciation; Lifespans.

Abstract: Growing interest in alternative consumption models (e.g., circular economy, sharing economy) bring forth the need for new methods to better quantify the environmental impacts of reuse and specifically, secondary consumers. In this paper, we suggest using market data and economic depreciation to assess the full lifespan of products and allocate the environmental impacts of consumption across multiple users that reuse or share the same product. We demonstrate our approach using the case of smartphones and cars.

Introduction

Concern over environmental degradation has motivated research into and development of environmental accounting methodologies used to quantify the full life cycle impacts of durable goods (products). Today, companies across the business spectrum use tools such as Life cycle assessment (LCA) and foot-printing to measure and optimize the environmental performance of their products. At the same time, growing interest in circular economy models where multiple agents (users) reuse the same products either in parallel (e.g. Zipcar) or one after the other (e.g., via resale on eBay) creates the need to better track the environmental impacts of each user.

While traditionally, the full life cycle impacts of a product were associated with its producer, in recent years, environmental accounting methods have been slowly converging towards consumption (rather than production) based approaches. Consumption based approaches are based on the premise that demand for new products is the key driver for production. As such, they hold the agents who benefit from the products (e.g. countries, companies, households, consumers) responsible for the environmental impacts associated with their purchases regardless of where such impacts might accrue (Wiedmann et al. 2013; Ivanova et al., 2016; Kanemoto et al. 2016). Consumption based allocations have been instrumental in demonstrating the significant impacts of household consumption as well as the fact that developed countries have essentially outsourced pollution and environmental degradation, yet benefit from the utility delivered from product produced elsewhere.

Critically however, consumption based allocations typically overlook the role that secondary consumers play in driving primary production. This is problematic given that trade volumes in secondary markets (e.g., second hand markets, sharing economy) often surpass those of primary ones. Moreover, in the rare cases where secondary consumption is considered, it is commonly assumed to generate net environmental benefits. Research however, suggest that secondary consumption can also increase (and not only decrease) demand for primary production (i.e. production of new products). Some studies suggest that second hand markets stimulate new production, for example by allowing consumers to sell their older products and use the earnings towards the purchase of new units (Chu and Liao 2010; Waldman 2003; Cooper and Gutowski 2017). In addition, the presence of secondary markets might encourage manufacturers to introduce new products at greater frequency, or to increase prices for new units to capture the surplus of secondary markets as well (Yin et al. 2010).

Furthermore, secondary consumption as well as systemic differences in product design, quality, and branding affect the overall lifespan of products. As a result, even within the same product category, the utility products deliver at each stage of their use phase and their overall lifespan is not uniform. For example, some car models retain their value better and outlast other, similar car models. Additionally, lifespans are not constant and can change over time (REF). Current environmental accounting methods however, seldom take into account within category differences in product lifespans nor do they consider how secondary consumption and reuse, in all its mired forms, can change the environmental performance of products. In sum, to truly link the impacts of production to the agents driving its demand, environmental accounting methods should incorporate secondary consumers as well.

Methods

In this work we explore the following: (1) How to extend consumption base footprint principals when there is more than one user?; (2) How to divide the environmental impacts of new products that were used for very short time by the first user and were them sold to another user;

To this end, we propose a new method to allocate products' environmental impacts across all the users products might have over the course of their full lifespan according to their market depreciation (i.e., value loss). While depreciation is not a direct measure of the way secondary users impact demand, in a free market context, it reflects the amount of utility (i.e. benefit) to be gained from previously owned products. As such we argue that depreciation is well aligned with the basic premise that those benefiting from consumption should be held accountable for its impacts.
Specifically, we suggest using LCA in conjunction with market data on product depreciation to equitably allocate environmental impacts among multiple agents in both primary and secondary markets. Our method suggests that fixed environmental impacts (i.e. those related to materials, production, transport and EoL) be associated with pre-resale and post-resale 'lives' based on economic value retention. For example, if a consumer choses to sell her car after the first year of use, the share of fixed environmental impacts associated with the 1st life period (i.e. pre-resale) will be proportional to the overall share of value lost during that year.
For each product, we demonstrate the equations we used to calculate three parameters: the market depreciation, the climate change impact for the pre-resale stage, and the climate change impact in post resale stage. We also discuss methods to obtain depreciation data then demonstrate how to use LCA data for that purpose.

Modelling Approach: Cell phones

Depreciation model in this case was based on analysis of almost 500,000 listings from eBay from 2015-2016. We have estimated the depreciation curves based on econometric analysis we have done. We then used published life cycle GHG data from Apple Inc. downloaded from their website to calculate the pre and post sales emissions distribution. For full description of this evaluation, please refer to Makov et. al, 2018. The equations are listed below:

Market Depreciation

$$\%\text{VALUE LOSS}_m = 100\% \times (1 - (\text{eBay resale price}_m / \text{U.S. retail launch price}_m)$$

Pre-resale CC impact

$$\%\text{VALUE LOSS}_m \times \text{fixed CC impacts}_m + \text{AGE}_m \times \text{monthly CC impacts}_m$$

Post-resale CC impact

$$(1 - \%\text{VALUE LOSS}_m) \times \text{fixed CC impacts}_m + (\text{maxage}_m - \text{AGE}_m) \times \text{monthly CC impacts}_m$$

Modelling Approach: Passenger Vehicles

Depreciation model in this case was based on available market data. We chose three similar vehicles and for each of them the original retail price at launch (i.e. MSRP) and historical prices were obtained from the official website for the National Automobile Dealers Association (NADA website).
For all models, historical prices represent clean retail prices in California on January 1st of each year between 2001-2018. We chose California since it is the largest car market in the US. The equation is as follows:

$$MARKET\ DEPRECIATION\ it = 100\% \times \left(1 - \frac{resale\ price}{US\ retail\ launch\ price}\right)$$

We then calculated GHG emissions based on LCA we performed for each model according to its specifications. All emissions related to maintenance and fuel consumption (direct and embodied) are considered use phase impacts. All emissions related to the other life stages are considered fixed.

Specifically, impacts associated with pre-sale were derived my multiplying the share of value lost by overall fixed impacts, while impacts associated with post-sale were derived by multiplying the share of value maintained by overall fixed costs. Since average miles driven per year tends to decline with vehicle age, overall mileage travelled by Jan 1st of each year was calculated based on mean miles travelled by passenger vehicle in the US. We then used distance traveled by multiplying emission per km by the sum of km traveled before sale to calculate the use phase impacts.

Results

Cell phones

Our results first show (based on figure 1) that the life time of Samsung and Apple phones can reach five and six years in practice, suggesting that the two-three years use phase estimate used in many LCAs is likely not accurate enough. Second, in the cell phone case, where 80% of the product life cycle emissions are at the production phase, we show that substantial portion of the production related GHG emissions should be allocated to secondary consumers (i.e. post-resale transaction; see Figure 2). In contrast, methods that allocate all production related impacts to the first users, and consider only direct use phase impacts for secondary consumers (e.g. electricity) lead to lower emissions attributed to secondary consumption.

Passenger Vehicles

In the vehicles case, we find that on average in the US people sell new cars after 6.6 years and they reach their end of life stage after 11.6 years (figure 3). Since in vehicles 80-85% of the product life cycle emissions are at the use phase (when burning fuel), our results suggest that allocating the fixed costs of vehicle production to secondary consumers is less critical as production is only a small portion of the total GHG emissions (Figure 4).

Conclusions

In contrast to allocating impacts based on use time alone, our method accounts for the fact that in some cases the functional utility products can provide declines over time. In addition, we propose that use phase impacts be modeled in accordance with product age and location appropriate use patterns. For example, it is well documented that vehicles' annual travel distances decline over time. Thus, we argue that the use phase for the 1st life period be modeled based on average distance traveled during a vehicle's first year of life. Our findings suggest that depreciation based allocation is particularly relevant for products with large production phase impacts, and illustrates the importance of accounting for secondary users' specific use patterns (such as location and use length) in LCA modelling. In addition, our analysis provides insight into the actual lifespan of product with multiple users (for example 5-6 years for cell phones compared with 18-24 months cited in literature). Such analysis provide evidence based use phase data that can help to improve use phase assumptions when conducting or updating LCA data.
If circular and sharing economy will continue to be increasing trend and policy targets, the need to calculate consumption base footprint will grow and therefore our suggested method could be useful and practical. Finally, paralleling economic and environmental methods might help to push managers and policy makers to adopt eco-efficiency measures in a more intuitive way.

Figures and Tables

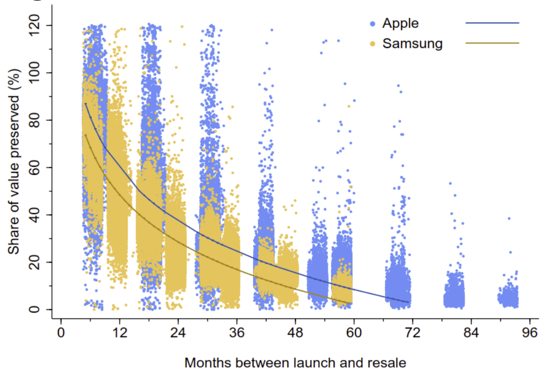

Figure 1. Phones: Smartphone depreciation curves (Adapted from Makov et. al, 2019).

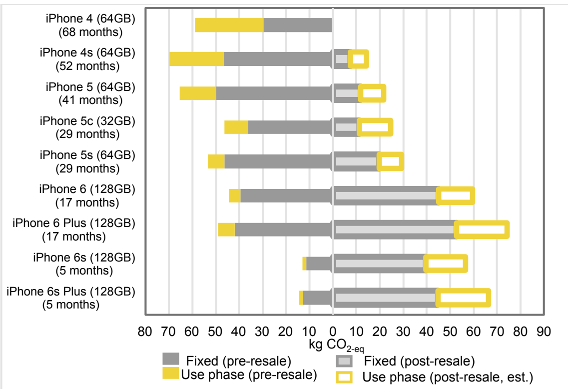

Figure 2. iPhones – Pre-resale and post-resale related emissions.

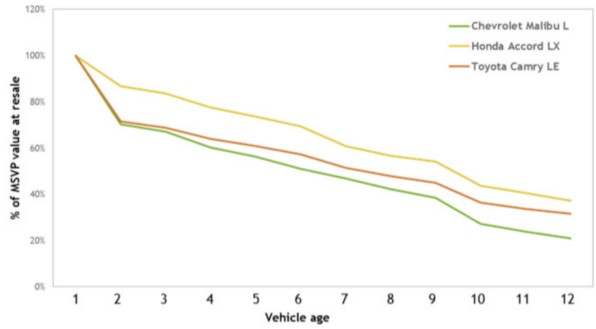

Figure 3. Cars: depreciation curves.

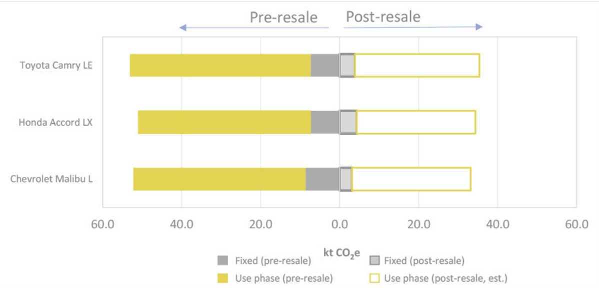

Figure 4. Passenger vehicles – Pre-resale and post-resale related emissions (production + fuel).

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Multifunctional Neglect Leads to the Purchase of Redundant Devices

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Keywords: Multi-functional Devices; Lifespan; Consumer Psychology; Obsolescence.

Abstract: Several researchers have suggested that the adoption of multifunctional devices will have wide-spread environmental benefits through dematerialization and a reduction in material and energy use. Here, however, we show that predictions regarding declining consumption may fail to account for a powerful countervailing force: namely, people's tendency to discount the utility of various features when they are performed by a single, multifunctional device versus by separate devices. We argue that because multifunctional devices bundle many functions together on a single device, each individual function may be given less weight than if those same functions were performed by separate devices. In a series of five studies, we demonstrate that such "multifunctional neglect" can bias consumers' perceptions, may lead to the purchase of redundant devices that are energy and material intensive.

Introduction

An increasing number of products are multifunctional. For example, many of the 2 billion smartphones currently in use (Poushter 2016) possess the functionality of a phone, a web browser, a camera, a GPS, a computer etc. Some have suggested that the adoption of multifunctional devices will lead to dematerialization; where once consumers needed many separate products, they can now rely on a single device to perform all tasks (Marian 2012; Tasaki et al. 2012 and Ryen et al. 2015). Recent survey data, however, suggests that instead of relying on one multifunctional device, consumers now rely on a community of multifunctional devices, using them interchangeably to preform similar tasks (Ryen et al. 2015 and Ryen et al. 2014). A consumer can start watching a drama series on her laptop, switch to her tablet, and eventually finish up an episode on her smartphone. Such consumption patterns stand in stark contrast to consumers' documented aversion towards waste and unused utility (Sun and Trudel 2016; Arkes 1996 and Bolton and Alba 2012). Furthermore, even though multifunctional devices such as smartphones are by no means cheap, most smartphones are replaced more frequently that T-shirts, despite being in good working condition (Wieser and Tröger 2017 and Geyer and Blass 2010).

The macro-level implications of such behaviors are potentially great as the purchase of multiple devices with redundant functions increases overall throughput of materials and energy and could exacerbate serious environmental and human health issues (Grant et al. 2013; Chen et al. 2011 and Zhang et al. 2012). For example, the climate change impacts associated with a single iPhone Xs amount to 70kgCO2eq (Apple Inc 2016), and each device makes use of over 50 different elements of the periodic table. These elements include hazardous metals (e.g. lead, mercury), rare earths associated with supply and environmental constraints (Sprecher et al. 2017 and Sprecher et al. 2015), and conflict minerals whose mining has been linked to civic unrest (Usanov et al. 2013; Moran et al. 2015 and OECD 2010). Thus, contrary to the popular belief that multifunctional products promote dematerialization, they may in fact have the opposite effect through increased replacement frequency and biased substitution evaluations.
In this research, we examine whether these consumption patterns are enabled (in part) by people's tendency to discount the utility of various functions when they are performed by a single, multifunctional device versus by separate devices. For example, imagine that a new model of a smartphone is released. Many of the functions are nearly the same as the previous model (GPS, storage, etc.), but the

camera has been significantly improved. A consumer may readily replace the entire smartphone, essentially only to gain the improved functionality of the camera, thereby duplicating nearly all of the functions of her older model smartphone.
Moreover, replaced multifunctional devices are often discarded, but not recycled or resold, so the utility of the duplicated functions is often lost. And, consumers may be likely to purchase further specialized devices that are redundant with existing functions—for example, a consumer may purchase a dedicated mp3 player for the gym, rather than use the older, discarded smartphone. The question we ask here is, hypothetically, would the same consumer be as likely to upgrade if those same functions were performed by separate devices (i.e., a separate camera, phone, GPS, etc.)?

Experiment 1

In Experiment 1, a total of 240 adult participants were recruited via Amazon's Mechanical Turk in exchange for $0.50 compensation. Participants who failed to answer a manipulation check and a comprehension check presented at the end of the experiment (see SI), or those who participated more than once (based on repeating IP addresses) were excluded from the study (n=52). The remaining 188 participants (54.8% male; Mage= 36.1; SD=12.3), were randomly assigned to one of two between-subjects conditions.
Specifically, all participants were asked to imagine that they had a home office, equipped with various devices. Half of the participants then read that their home office was equipped with a separate fax, printer and copy machine (separate devices), while the other half of the participants read that their office had a 3-in-1 printer, photocopier and fax machine (multifunctional device).
Critically, the original price paid for the three devices or the 3-in-1 device was the same ($275). All participants then read that the fax machine, which they used occasionally, had stopped working (though the printer and photocopier worked fine), and were asked to state the lowest sum of money they would be willing to accept (WTA) to sell the equipment (Carmon and Ariely 2000). No upper limit was imposed.

Results and discussion

The results indicated that the amount of money demanded for the multifunctional device (M=116.8, SD=51.7) was significantly lower than the amount demanded for the separate devices (M= 138.6, SD=55.6), t(186)=-2.77, p= .006, d=0.4, indicating that the same remaining functions were discounted more when they were contained in a multifunctional device versus among separate devices.
It is possible, however, that participants in Experiment 1 assumed that the fax was broken due to physical misuse, and that in the case of the multifunctional device, such an incident could also damage other functions. Therefore, in our next study we examined whether multifunctional neglect can also bias utility perceptions of intact devices by examining consumers' Willingness to Pay (WTP) for an upgrade.

Experiment 2

Participants in Experiment 2 were recruited following a similar procedure as our previous study. Participants who failed to answer a manipulation check and a comprehension check presented at the end of the experiment, or those who participated more than once (based on repeating IP addresses) were excluded from the study (n=52). The remaining 188 participants (54.8% male; Mage= 36.1; SD=12.3), were randomly assigned to one of two between-subjects conditions. Half of the participants were asked to imagine that they owned an Apple iPod that included a MP3 player, a 6.0 Megapixel camera, and GPS system (multifunctional device), while the other half were asked to imagine they owned a functionally equivalent set of standalone products (i.e., a MP3 player, a 6.0 MP camera and a touchscreen GPS device). Participants in both conditions were then presented with an upgraded iPod (that included GPS, a better camera resolution and more music storage) and were asked how much they would be willing to pay for it (open question no upper limit imposed).

Results and discussion

From a normative perspective, the more that the upgrade is differentiated from the product(s) that they currently own, the more that participants should be willing to pay for the upgrade (Okada 2006). It follows then that consumers' willingness to pay for the upgrade should be equal across the two conditions, or perhaps even greater in the separate devices condition, since the consumer is also gaining

enhanced portability by reducing the total number of devices.
Instead, however, the results indicated that WTP for the upgrade was significantly lower in the separate devices condition (M=$180.5, SD= 95.9) than in the multifunction condition (M=$215.5, SD= 92.8), t(167.5)=2.45 p=.016, d=0.37 (see Figure 1), even though participants in the separate devices condition were also gaining increased portability by upgrading to a single device. Said differently, the separate devices were valued more than the multifunctional device and therefore, participants perceived less “distance” between their current devices and the upgrade. These results demonstrate that functionality is more heavily discounted when it is part of a multifunctional device compared to an equivalent set of standalone products.

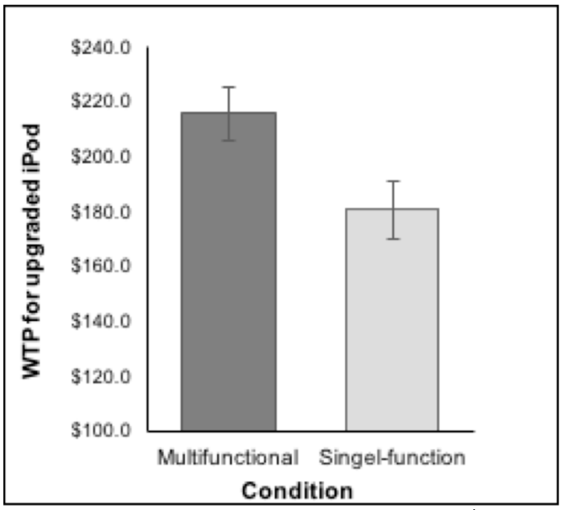

Figure 1. Experiment 2 results. WTP (in $US) by condition (Multifunctional vs. Single-function), for the purchase of an iPod with higher functional capabilities than currently owned. Bars represent standard error.

Experiment 3

Experiment 3 sought to replicate the effect with simple, non-electronic products. Participants in this experiment (N=193; 56.0% male; Mage= 35.2; SD=-12.3) were recruited following the same procedure as the previous study. All participants were asked to imagine they were preparing for a camping trip. Half of the participants were asked to imagine they owned a knife, spoon and fork (separate devices), while the other half imagined they owned a “dining” Swiss Army Knife, which contained a knife, spoon and fork (multifunction condition). In both conditions, participants read that as they were packing, they discovered that the fork was broken and they were asked to indicate how likely they would be to purchase a new “dining” Swiss Army Knife for $17.50 (1=not at all likely, 9=extremely likely).

Results and discussion

As in Experiment 2, participants in the multifunctional condition were significantly more likely to say that they would buy a new Swiss Army Knife (M= 5.28, SD=1.65) compared to participants in the separate devices condition (M=4.58; SD=1.94), t(176.1)=2.69 p=.008, d=0.39.
The results of Experiments 1-3 suggest that the utility afforded by various functions are valued less when they are supplied by a multifunctional device versus separate devices. One critique of Experiments 2-3 is that we did not give participants the opportunity to replace only the broken feature. It may be, however, that replacing only the broken feature more salient in the separate devices condition, which in turn, made participants value the multifunctional replacement less. A second alternative explanation may be that participants were simply using a matching heuristic, desiring to upgrade to a multifunctional device more when they currently owned a multifunctional device than when they owned separate devices.

Experiment 4

To examine these alternatives, in Experiment 4, 288 eligible participants (56.6% male; M_{age}=34.8; SD=11.7) were recruited following the same procedure as previous experiments. Participants were randomly assigned to one of three between subject conditions: Participants in the multifunction condition read that they owned a smartphone (including a built-in cellphone, GPS and a 10 MP camera), but that the camera was broken. Participants in the separate devices condition read that they owned a “travel kit” that originally included a separate cellphone, 10MP camera, and a GPS, but that the camera was broken. Finally, to test the matching heuristic, participants in the control condition read that they owned a smartphone (including a built-in cellphone, GPS and a 10 MP camera); i.e., the camera was still functional. In all conditions, participants were then asked to imagine that they were going on a vacation and were considering upgrading their camera. Specifically, they were asked to choose between a new smartphone (which contained a 12 MP camera, phone and GPS) that sold for $549, or a standalone 18 MP camera that sold for $349.

Results and discussion

In the separate devices condition, 60.7% of participants chose to replace only the camera. However, in the multifunctional device condition, only 45.9% chose to replace only the camera (the slight majority chose the new smartphone), *Pearson Chi-Square* (1) =10.7, *p*= .001). This result rules out the possibility that participants are equally likely across the two contexts to replace only the broken feature if given the option; although it is still consistent with a matching heuristic. However, in the control condition, only 38.6% of participants in the control condition chose the smartphone, which rules out the possibility that participants with multifunctional products simply prefer to purchase other multifunctional products (see figure 2).

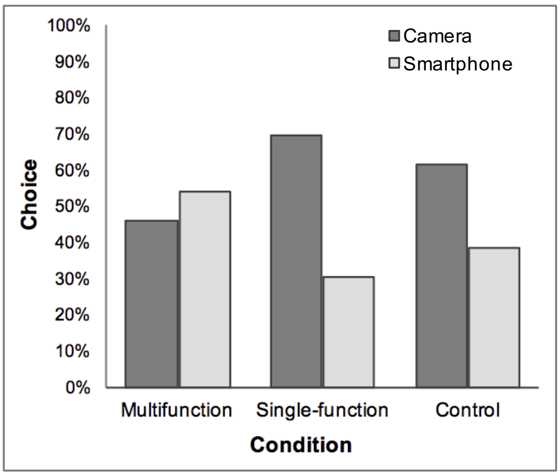

Figure 2. Experiment 4 results. Share of participants choosing each item (Camera vs. Smartphone) by condition (Multifunctional vs. Single-function and Control).

Discussion

Multifunctionality is often touted as the epitome of dematerialization—where once consumers needed many separate products, they can now rely on a single device to perform all tasks. Recent survey data, however, instead suggests that consumers now rely on a community of multifunctional devices rather than use one multifunctional device to deliver a particular function (Ryen et al. 2015 and Ryen et al. 2014). These consumption patterns may be aided by the multifunctional neglect documented here. Lower waste aversion might make it less painful for consumers to purchase several devices with redundant functional capabilities and use them interchangeably syncing data and content.

In addition, multifunctional neglect may discourage consumers from considering older multifunctional devices as reasonable substitutes for new, single-function products. For example, new parents may purchase a separate dedicated baby monitor rather than use potentially substitutable functions that are provided by a discarded smartphone that they already own. Ignoring the potential to repurpose multifunctional devices might be costly for both consumers and the environment. From an environmental perspective, reuse and repurposing are often preferable to remanufacturing or recycling since they do not require additional investment of materials and energy (Gutowski et al. 2011 and Zink et al. 2014). Since it is common for consumers to keep older devices home in hibernation, designing products that highlight consumer's ability to repurpose their retired multifunctional devices could potentially help overcome multifunctional neglect and reduce overall consumption. For example, apps that enable consumers to easily transform a smartphone into a nanny cam could potentially make consumers see the value still remaining in their possessions and capitalize on it.

Furthermore, as we show here, multifunctional neglect can lead to the discount of functional capabilities of multifunctional products. This in turn might discourage consumers from repairing their existing multifunctional devices and encourage them to buy new ones instead. While advocacy and legislation for the right to repair is gaining force (The Repair Association 2017; Koebler 2017 and Bloomberg 2017) consumers' biased evaluations might cause them to mistakenly think that their devices are not even worth repairing. Similarly, multifunctional neglect may discourage consumers from reselling their devices in secondary markets, or hand them in for rebates since they may assume that the transaction costs are higher than the potential gains. Thus, while smartphones today hold more computational power than the super computers used by NASA to send a man to the moon (Kaku 2012), more often than not, once partially damaged or retired, these powerful and complex devices are perceived as worthless. Since multifunctional devices group several functions together they are statistically more prone to malfunction. Therefore, multifunctional devices may be more prone to replacement than their single-function counterparts.

Here we document the existence of multifunctional neglect using a series of behavioral experiments. Though this methodology allows us explore multifunctional neglect in isolation, it may fall short of describing the complex settings in which real life decisions take place. More work, however, is needed to assess the extent of this phenomenon and its potential implications for sustainability. In addition to increased replacement rates, consumers misguided assumptions regarding the value of their old devices may also pose a major barrier for circular economy models that emphasize the recapture of materials and parts for reuse. As one example, one ton of cellphones today contains more gold than a ton of soil from a gold mine; failure to recirculate used multifunctional devices may severely limit the ability to recapture the precious materials they contain and reduce demand for virgin materials (Wilson et al. 2017). In particular, future work should examine whether specific multifunctional products (e.g., smartphones) are more susceptible to multifunctional neglect than other and if and how it can be overcome through improved product design or economic incentives.

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From Speed to Volume: Reframing Clothing Production and Consumption for an Environmentally Sound Apparel Sector

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Keywords: Speed; Volumes; Clothing Consumption; Wardrobe Studies.

Abstract: The article highlights the limitations of speed as a framework for discussing and tackling the environmental challenges of growing clothing volumes or quantities. This argument builds on a series of wardrobe studies mapping the number of clothing items owned, purchased, and disposed of by 25 people during six months, and the reasons behind purchase and disposal. The results indicate that clothing consumption is rarely driven by replacement and that opportunity plays a main role. These characteristics of clothing consumption explain why it takes more than producing long-lasting garments to reduce clothing demand. Rather than delaying the disposal of garments, a more straight-forward focus on reducing production is needed, that is the contribution of a volume-centric approach.

Introduction: a growing clothing mountain

Accounts of the environmental burden of the apparel sector have surpassed technical and scholarly literature and trickled into popular media. Public attention to this issue may be explained by the fact that (this being the "second most polluting industry" or not) the rapid changes in the sector since the 1980s are visible to all. The production of garments is now based on countries with low wages and shipped all over the world (Schor, 2005), prices have fallen relative to other consumer goods (EEA, 2014) and the launching of new collections has speeded up (Tokatli, 2008). As a consequence, demand has grown (EEA, 2014), as have the volumes of textiles disposed of. The international second-hand trade is overflooded and used textiles are struggling to find an environmentally-sound destination (Ljungkvist, Watson, & Elander, 2018). Rising volumes of virgin materials are needed to fuel this industry (FAO/ICAC, 2013), as are the resources necessary for the production and finishing of products, distribution and retail, and post-consumer textiles processing (e.g. Roos, Sandin, Zamani, & Peters, 2015). In short, the sector has a problem of volumes, with some estimations reporting growth in the worldwide volume sold between 2000 and 2015 by 100% (Euromonitor in Ellen McArthur Foundation, 2017), while global population grew by around 20%.

Nevertheless, most actions taken by industry and governments for reducing the environmental impact of the sector are still focused on impact per product and disregard the issue of clothing quantity. In the United Kingdom, for instance, the Waste and Resources Action Programme (WRAP) convened an industry-wide commitment supported by governments to reduce the environmental burden of the whole clothing supply chain. An intermediate balance of the commitment's results published in 2017 highlights savings in carbon emissions (10.6%), use of water (13.5%), and waste (0.8%) per ton of clothing sold since 2012. But given growth in the total tonnage sold in the same period by 19%, the absolute impact of the sector increased (WRAP, 2017). These results illustrate the urgency of developing actions for reducing clothing production volume, alongside others focused on impact per product or ton.

Slowing down

One exception to the lack of attention on clothing volume in the field has been the work of sustainable fashion academics and practitioners on speed (e.g. Aakko, 2013; Clark, 2008; Cooper et al., 2013; Fletcher, 2012; Laitala and Klepp, 2015; Langley et al., 2013; McLaren et al., 2015). By addressing clothing longevity and durability, and the value of slow fashion as opposed to fast fashion products, such scholarship implicitly engages with volume. It considers growing quantities in the context of production and consumption acceleration. However, this article highlights the limitations of speed as a framework for discussing clothing volume. While acknowledging the value of speed related approaches, the study calls for a straightforward focus on quantities to advance effective actions.

In the literature, “fast” is often used to imply “more”, and “slow” or “durable” to refer to “less” (e.g. Cooper et al., 2013; Greenpeace, 2017; WRAP, 2012). However, rather than being synonyms, these notions describe different qualities of production and consumption. The conceptual overlap of volume and speed leads to regarding product lifetimes as if they had environmental impact, when it is clothing production that poses environmental challenges (see e.g. Roos et al., 2015). For example, the influential 2012 WRAP report states that “extending the average life of clothes by just three months of active use per item would lead to a 5-10% reduction in each of the carbon, water and waste footprints”; but delaying disposal per-se does not result in environmental gains. This percentage is calculated by assuming delay in the production of new clothes, as if new garments were produced in order to replace disposed ones. However, this study claims that clothing purchases are rarely based on replacement; therefore, speed and volumes are not interchangeable.

Previous research on consumer influence on product life spans has already pointed out that purchases are made “without reference to any evaluation of existing possessions. Consequently, even when it might appear that product life spans are being optimized, environmental impacts may be increasing” (Evans & Cooper, 2010, p. 344). This study argues that this is often the case in clothing. Building on a series of wardrobe studies, the article highlights the value of a volume-centric approach for discussing and tackling the environmental impact of the sector.

Wardrobe studies

In 2017, we carried out 40 wardrobe audits in the Netherlands in order to answer other related research questions (Maldini, Stappers, Gimeno-Martinez, & Daanen, 2019). A secondary finding of that study was that clothing consumption is rarely based on replacement and wardrobes can grow and decrease over time. Therefore, the environmental advantages of delaying disposals are questionable. This article revisits those wardrobe audits with a focus on 25 respondents that traced the items coming in and out of their wardrobe during the six months following our visit. The analysis is based on quantitative and qualitative data that has not been previously published.

Respondents

The wardrobes considered in this study belong to 25 subjects living in different provinces of the Netherlands. The group is varied in terms of age (22 to 71 years old), household composition (living alone, in couples, with children, or in shared households), house size (38 to 400 m2), and income (from <€20,000 to >€80,000 annual gross income per household). Most of respondents live in cities, but some live in villages and towns. Lastly, the group includes 20 females and five males. This over-representation of women is a result of the profile of respondents sending back the completed forms after the study.

Method

During the wardrobe audits, respondents counted the number of garments owned in the presence of the researcher and according to previously defined garment types. The concept of “wardrobe” was considered broadly, including all garments owned by respondents regardless of the place where they were stored. Socks and underwear were excluded for privacy and practical reasons, but accessories such as shoes, hats, scarves and gloves were included. The counting process started at the hall of the home, continuing at the closet, the laundry area, and extra storage spaces such as the attic or spaces underneath the bed (see Fig. 1).

Starting at the date of the visit, respondents kept track of their wardrobe inflow and outflow during six months, handing the information to the researcher after completion (see Table 1). All relevant items (so no socks or underwear) coming in and out of the wardrobe were documented in a provided form, including items made, bought, received as presents, given away, thrown away, etc. The form included details such as date, garment type, and reasons for acquisition or disposal.

Responses were processed anonymously with no compensation offered to the subjects.

Next, the reasons for acquisition and disposal stated by respondents were classified in categories to enable further analysis (see Table 2). The categories were defined by grouping similar answers, although some responses were unclear, unstated or too general/particular to enable classification. In any case, this categorization should not be considered as a comprehensive taxonomy of the reasons driving wardrobe flow, but simply as a means to discuss the points introduced above.

Figure 1. Some of the items in the wardrobe of respondent 19.

Results

Table 1 gives an overview of the number of items owned by respondents during the audits, and their wardrobe inflow and outflow during six months. Only one of the 25 wardrobes (respondent 16) had equal number of items coming in and out. All other wardrobes grew or decreased during that period.

Replacement was not a significant driver for inflow (see Table 2). Only 12 of the 312 clothing items coming in the wardrobes was purchased or made with the purpose of replacing a disposed item. This was the case for respondents whose "old sneakers had holes", "old sweater needed replacement" or "favorite Levi shirt is too small now".

Respondent number	Initial wardrobe volume (items)	Wardrobe inflow (items)	Wardrobe outflow (items)	Difference (items)
1	268	21	32	-11
2	453	12	6	6
3	208	13	29	-16
4	200	6	0	6
5	429	21	48	-27
6	228	11	2	9
7	346	16	3	13
8	70	11	14	-3
9	164	28	32	-4
10	343	11	23	-12
11	353	7	10	-3
12	324	2	36	-34
13	124	12	5	7
14	100	15	14	1
15	259	14	5	9
16	126	23	23	0
17	235	16	11	5
18	167	9	0	9
19	272	11	15	-4
20	132	8	1	7
21	257	11	9	2
22	254	7	13	-6
23	87	7	2	5
24	263	13	3	10
25	390	7	46	-39

Table 1. Respondents' initial wardrobe volume and inflow/ outflow during a 6-month period (in number of items).

Participants bought, received, and made clothing for other reasons. Opportunity was the main driver for wardrobe inflow. In 89 of the 312 items, decisions to acquire a new item were based on reasons such as "sale more than 50%!!", "I found it while I bought the skirt", or "free". Sixty items were purchased on the basis of previously considered needs and wants. For example, items "needed for summer", "wanted to wear over tank tops, or "needed for walking the dog".

Other items got in respondents' wardrobes because of their aesthetic ("It is yellow!", "I loved it and it went really well with my new coat", "I like the clean lines and the way it compliments my shot hair") or functional qualities ("warm") or were intended for special occasions ("event coming up, wanted to look impressive and new").

INFLOW	
Reasons	**Items**
Opportunity	89
Need/Want	60
Aesthetic	50
Special occasion	24
Functional	12
Replacement	12
Unclassified	89
Total	312
OUTFLOW	
Reasons	**Items**
Worn out/broken/old	91
Style change	66
Body change	61
Initially unsuitable	39
Have better alternatives	12
Unclassified	113
Total	382

Table 2. Total wardrobe inflow and outflow classified by the reasons stated by respondents.

Reasons for given away, donated, and thrown away items included garments broken or worn-out ("too old to wear") or initially unsuitable ("didn't like it in the first place, "too big, it was a gift"). In other cases, outflow decisions were based on style ("old fashioned, I am not going to use it anymore", "not fun anymore") or body changes ("didn't fit anymore"). Lastly, some items were discarded based on the presence of better alternatives ("have better ones", "have so many").

In sum, the results of the study point out to a variety of drivers for wardrobe inflow (clothes received, made, and purchased) and outflow (clothes disposed of). Some of these reasons are connected to other items in the wardrobe (classified as replacement, need/want, have better alternatives). The majority of the inflow decisions, however, are unrelated to the items already owned (opportunity, aesthetic, functional, special occasion). They respond to other motivations such as pleasure in the act of purchasing or anticipated use.

These results underline the limited connection between wardrobe inflow and outflow and - more importantly - between speed and volume. If wardrobe inflow was exclusively driven by outflow, extending the lifetime of garments could have straightforward effects on clothing demand, but the data discussed above shows that this is not the case.

Discussion

As we have argued in an earlier study (Maldini & Stappers, 2019), strategies aiming at reducing clothing production volumes on the basis of garments' emotional and material durability tend to see the wardrobe as a collection with permanent volume, driven by need. As a need-driven collection, the wardrobe would be subject to "pull" forces solely, and new garments would be purchased to replace unsatisfactory pieces.

However, the data points out that clothing consumption follows other logics. Respondents incorporated and disposed of garments for a variety of reasons; new items were bought without consideration of those already owned, and owned items left the wardrobe because more attractive ones were coming in. The 12 garments disposed of because participants "had better alternatives" show that "push" forces drive clothing consumption as much as "pull" forces.

Moreover, the incorporation of new garments for opportunity-related reasons confirms that inflow and outflow are not always associated. The power of an owned (materially or emotionally durable) item in preventing a new purchase driven by "sale more than 50%!!" or "it is yellow!" is evidently limited. Lastly, the strong effect of "opportunity" and impulsive purchasing on overall wardrobe inflow may explain why 39 of the 382 items disposed of were considered "initially unsuitable" after purchase.
These characteristics of clothing consumption clarify why it takes more than producing long-lasting garments to reduce clothing demand.

Rather than delaying the disposal of garments, a more straight-forward focus on reducing production is needed, that is the contribution of a volume-centric approach.

Conclusion: from speed to volume

This study has argued that placing production volumes at the core of the sustainable fashion agenda would help tackling the exponential growth of the sector's impact. Acknowledging the conceptual difference between volume and speed is important because they call for different actions to address them. Actions aimed at prolonging product lifetimes may justify the production of new (materially and emotionally durable) products. From a volumes perspective, however, the aim is to diminish the quantity of new products altogether, leading to reductions in the absolute environmental impact of the sector.

Aiming at a reduction in production volumes has important political and economic implications that have not been discussed here, fundamental changes in this respect are surely needed to overcome the ecological crisis. A volume-centred framework can be linked to a variety of perspectives critical to mainstream politics and economics, while at the same time ensuring positive and concrete environmental change.

Lastly, while tackling production volumes is particularly imperative in the apparel sector, the discussion above applies also to other product categories. In building on product volumes or quantities, the field of fashion can bring relevant and novel perspectives to the bigger table of sustainable production and consumption. Sustainable fashion has borrowed much from scholarship focused on other products such as household appliances. The work on emotionally durable design and attachment in clothing is an example of that. But such scholarship does not usually acknowledge practices such as collecting, accumulating or impulsive purchasing. In building a volume-centric framework, sustainable fashion research can help to expand perspectives in thinking about products and the environment within the broader field. This study is a contribution to that end.

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Hide and Seek – a Systemic Approach to Sustainability in Product Development

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Keywords: Design for Longevity; Ecodesign Process; Barriers and Enablers; Interviews; Systemic Approach.

Abstract: The size and extend of a product's environmental impact along its life-cycle is mainly determined in the design phase. So far, studies on product design processes show that Design for Longevity criteria such as reparability, maintainability, and upgradeability are only considered secondarily or in exceptional cases. The crucial questions is why available eco-design processes as well as respective tools, methods are not used widely in the industry. To answer this question we conducted a literature review and semi-structured interviews with several product development experts about product development processes, particularly asking about criteria influencing design decision, and the relevance of measures to prolong the lifetime of products. The qualitative data revealed a number of categories for barriers and enablers for the integration of longevity into the product development. Based on that we developed a systemic approach to the conditions facilitating the integration of longevity into the product development process. At system-level, longevity is integrated into the product development process if the relevant strategic and operational knowledge and know-how is available, if "environmental" values are integrated in the company's strategies, processes decisions, culture, and mind-sets, if the production equipment, the infrastructure, materials, and components are available, if a close collaboration across departments and within a partner-network on equal footing can take place, and of course if the political framework supports long living products. Seeing the many "ifs" it becomes clear that it's not only about changing single processes but changing a company's internal practices and culture as well as the external drivers.

Introduction

Environmental impacts are caused in all stages of the product's life-cycle. From overburden during mining, energy and chemical use plus waste production during refining and processing the materials to components and products, emissions during the transport and use phase to landfilling at end of life. Those environmental profiles differ from product to product, but one can say that regardless of the nature, size and time of occurrence of environmental impacts for a product, they are mainly determined in the early design phase (McAloone & Bey, 2009). However, this is usually not considered by product designers. Design practices are mostly oriented towards other criteria such as competitive performance and functionality, costs, and material properties. A consideration of ecodesign criteria such as longevity, reparability, maintainability, upgradeability, and recyclability only happens in exceptional cases (Graulich et al., 2017) This is problematic from an environmental point of view, since these properties cannot be retrofitted once the product is designed. Therefore, ecological sustainability of products starts with the design. Thus, eco-design is a "systematic approach which takes into account environmental aspects in the design and development process with the aim to reduce adverse environmental impacts" (IEC, 2009).

The last 30 years were characterized by a huge increase of eco-design processes, tools and methods that are meant to facilitate the designs and production of eco-friendly products (Ceschin & Gaziulusoy, 2016). Due to their multitude and their complexity the correct selection and use of those requires high prior understanding. One reason why their application is far from being mainstream (Pigosso, McAloone, & Rozenfeld, 2015). What are the reasons that available know-how did and does not find its way into the common design practice? The following paper is tackling this questions.

Research Approach

A master thesis supervised by one of the authors investigated to which extend eco-design criteria are part of the decision process during product development (Maurer, 2018). Seven experts in the field of product development mainly working in the electronics industry were interviewed. The experts were recruited from the authors' and supervisors' professional and private network. It included experts of one large, one medium sized company, two startups and one micro-enterprise as well as one design consultant and one service provider for hardware development. (Maurer, 2018) frames the interviews with a "general" product innovation process, eco-design methods and tools (eco-design methodology), eco-design principles and eco-design strategies. Furthermore, he already collected barriers and advantages of eco-design from literature.

The interviews were transcribed, coded and categorized using a qualitative data analysis software. The interview transcripts were analysed with a focus on the process of product design and innovation management in the electronics sector and those process characteristics that were relevant for eco-design decisions (*process orientation*). Major questions were: What are relevant barriers, enablers, meanings and contexts that shape design decisions – particularly in the development of new products – and what is the role of eco-design criteria?

In a second step the research team embedded the process and the relevant practices identified by (Maurer, 2018) into contexts and settings that turned out to be relevant for them (*systemic perspective*). The question here was: What are contextual conditions that shape practices in providing possibilities for eco-design relevant decisions and actions?

The content of both *process* and *system* analysis were enriched and complemented with results of (Graulich et al., 2017) who conducted a desktop research and interviewed industry representatives from 19 different companies in order to identify triggers, success factors and barriers for eco-design. Besides, insights of expert interviews conducted during the European INTERREG Project EcoDesign Circle (www.ecodesigncircle.eu) were added (Marwede, Paukstadt, Hofmann, Clemm, & Jokinen, 2019).

As a result we propose a systemic framework that describes qualities of an organisational surrounding that support eco-design. This approach helps to understand which conditions can foster the integration of eco-design into the product development.

Limitation of this qualitative research approach is that results cannot be seen as representative for a whole sector or industry or company size and the results present rather the personal opinion and experience of the interviewee than the actual practice in the overall company. However, the in-depths interviews with overall 26 individuals backed-up with literature can give a good understanding of barriers and favourable conditions for eco-design.

Barriers for the integration eco-design into the companies practices

The following subsections represent the major categories of barriers found in (Graulich et al., 2017; Marwede et al., 2019; Maurer, 2018):

- **Knowledge, know-how and competences** of individuals in the company on all levels include the lack of awareness of the benefits, the lack of theoretical knowledge e.g. how to assess environmental impacts of products and the added value through eco-design. Also strategic competences of practitioners are missing how to combine eco-design and business models. Furthermore, the multitude and complexity of eco-design methods hamper the easy selection and use of those. But also data and specifications about alternative sustainable materials might not be available or easy accessible. Even if eco-design knowledge is available, this is not successfully integrated into internal processes and not brought into practice.
- **Organisational and structural barriers** relate mainly to the lack of cooperation and information exchange across departments e.g. the environmental management sector and the product development department do not cooperate. Also strong hierarchies, a high degree of bureaucracy and budgets assigned to single departments hamper eco-design.

  "*As bigger it gets the more difficult it gets because there are so many departments so many hierarchical levels and so and so that makes it challenging to work in that kind of multidisciplinary way of really taking care together and solving the*

problem what you are facing on in the project program" (Anonymous, 2017a)
Furthermore, eco-design requirements are not defined at all or are integrated too late into the product development process when all technical requirements are already defined.

- **Infrastructural and technical barriers (materiality):** The company might not have the required infrastructure, technical equipment or other necessary resources for the realization. Being stuck in **path dependencies** hampers the transition to eco-design, e.g. given production equipment, recent investments taken, or dependency on certain suppliers or components. Furthermore, the **"materiality"** determines the processes and products, e.g. alternative materials, manufacturing processes, infrastructure or equipment are not available – either not at all or not in a sufficient quantity or quality. Furthermore, eco-design criteria might conflict (trade-off) with price, functionality, safety and aesthetic criteria (e.g. dismantlability versus robustness, aesthetics and technical characteristics of recycled or renewable materials versus required specifications reached by current materials).
- **Strategic and managerial barriers:** the management is not aware, lack commitment and do not incentivise eco-design. This means that it does not make resources available to support the process, i.e. avoids investing into eco-design. Furthermore, it does not set long-term strategic goals and does not translate those into operational measures. Besides, a missing innovation culture within the company is hampering eco-design. Furthermore, sales and marketing decides over product innovation cycles in order to push sales which does not leave room and time for more radical innovations.
- **Economic barriers:** the lack of knowledge and competences means that you have to invest in building up this competences or buying external consulting services. Furthermore, the planning efforts increase, i.e. you have to change internal processes, reorganize internal structures and integrate additional steps and methods into the design process which leads to additional costs (personnel, time).
"We can't just impose sustainability on an existing product platform. It would require major changes in the entire platform production and supply chain." (Anonymous, 2017a)
Companies do not know how to get that initial investment back. "*There is a lack of knowledge about how design, particularly eco-design, can benefit companies and how it could be used to their advantage*." (Noor-Ilander, 2016) Moreover, it is tricky to convince partners along the value and supply chain to change their mind sets, processes and behaviour. Furthermore, companies fear lower turn-over in case they increase longevity and reparability of the product, i.e. current linear business models do not support eco-designed products. On top of that, lower economies of scale and a potential increase in production costs through reshoring production to high-income countries may increase overall costs. Also "green" materials might be more costly and the economic benefit of recycled materials is marginal compared to virgin materials.
Overall, "green" products tend to be more costly at the beginning.
- **Customer demand and sales:** Customers are not necessarily willing to pay a higher prices for green products, and might question the environmental benefit. Overall, the demand for environmental sustainable products is low. Furthermore, customers tend to perceive "green" products as of lower functionality, performance and aesthetics or might misinterpret the sustainable features (e.g. lower power is perceived as lower performance and not as lower energy demand). That means single sustainable alternative products or a product range in the companies' product portfolio are tricky to sell and market because the other "normal" products of that company might be perceived as being not sustainable or inferior.
"Even with evidence for a niche market demand [for sustainable products], our developer think and design in global market terms." (Anonymous, 2017a)
- All those aspects make it more difficult to communicate the sustainable features of a product. Furthermore, vendors might not have the relevant information or information is simply not passed on to the

customer. Or, retailers might simply not include environmental sustainable products in the product range, which means that there is no "alternative" available during the purchase decision.

- **Policy barriers:** Complex and fast changing policies as well as unawareness of and uncertainty regarding existing policies hamper sustainable product development. There is limited market surveillance for minimal legal requirements, which gives an advantage to those which not follow the rules. Furthermore, there is a lack of public funding sources for sustainable product development, for example technology development funding schemes do usually not address sustainability. Besides, the multitude of labels are hard to grasp for consumers.

The different categories show that it needs a systemic understanding in order to facilitate and enable eco-design in companies.

The attempt of a systematic understanding – favourable conditions for eco-design

Figure 1**Fehler! Verweisquelle konnte nicht gefunden werden.** illustrates the variables influencing the integration of eco-design processes into a company, which was developed by the research team on the basis of the results of (Graulich et al., 2017; Marwede et al., 2019; Maurer, 2018):

First of all, relevant agents inside the organisation as well as the production networks (e.g. manager or product developer) has to have the **knowledge** and the **know-how**, in particular

- *strategic know-how*: definition of a eco-design strategy and goals, thorough knowledge of the existing business, good abilities to strategically rethink business models and a good understanding of sustainability concerns which enable anticipation of regulation and public opinion
- *operational know-how* about eco-design tools to use, where to find relevant data, how to engineer technical solutions e.g. for the accessibility of components, and
- system level understanding e.g. life-cycle-thinking, network analysis and complexity reduction.

According to (Jalas, 2016) the skills one would need to have for an integrated eco-design approach are a "*thorough knowledge of the existing business, good abilities to strategically rethink business models and a good understanding of sustainability concerns which enable anticipation of regulation and public opinion*"

Furthermore, the intrinsic **motivation**, **values** and **meanings** of employees and company stakeholder e.g. the willingness to learn and change, conviction to the idea of sustainability and transformation of the company's practices etc. is an important prerequisite for the integration of sustainability into the company's practices, i.e. to take risks, invest, translate barriers into challenges and chances, find new solutions, and to be eco-innovative. It is especially important to communicate the values internally to the employees and externally to your customers, partners and stakeholders.

"*I think that it (eco-design) can be definitely a tool to bring competitive advantages to products today it is seen for many project owner as a constraints more than a business driver so they think about that as cost which is a shame but we need to change we need to make the people change*" (Anonymous, 2017b)

To conclude, if the individual has the know-how, the resources and the legitimacy, s/he has the **power** to alter practices and **processes** within her or his sphere of influence, such as

- *Strategic processes:* Decision processes are fast and flexible and environmental responsibility is built into the decisions making. Development of an ambitioned environmental management strategy together with internal and external stakeholders and translation of this strategy into clear operational goals and definition of performance indicators to measure the level of success which go beyond pure economic indicators, for example development of new skills, creating new contacts, increase of employee or customer satisfaction, or environmental and social benefits for stakeholders. Business developers are able to create a business case, e.g. by developing new business models such as product-service-systems. The business case behind the product is crucial, which means that it is fit to market, i.e. ecodesign does not stand in conflict to the customer demand, that the total-cost-of-ownership or the life-cycle-costs are reduced, or that a higher price can be asked due to a better performance or image.

- *Operational processes:* eco-design criteria are integrated in the early phase of the design process and are of equal value to other criteria such as performance, aesthetics, customer preferences, costs, legal and standards. Procedures are available how to deal with design conflicts, e.g. make compromises, align criteria with strategic goals, or escalate decisions to a higher level.

Those processes are taking place in a certain "**setting**". The setting comprise the entire properties of a certain social or socio-cultural environment in which something takes place or is experienced. The setting in a company is amongst others the organisational culture, the organisational form (e.g. family business or corporation), the product portfolio, the equipment, the buildings etc. The "setting" should give for example the time and space for cooperation between different departments. Is the setting flexible? Is the supporting infrastructure given? It is for example easier for a family owned business to change the business model compared to corporates, which have to resolve more external factors and are dependent on their shareholders (Graulich et al., 2017).

Besides the setting, the **"materiality"** (technical, mechanical, physical and chemical characteristics) of components, products and equipment determines the space of possibilities, i.e are for example more sustainable materials, manufacturing processes, infrastructure or equipment available – in sufficient quantity or in sufficient quality. R&D capacity, resources, funding and partners can help to overcome technical barriers.

Moreover, you need to look for new suppliers and create strategic partnerships – even with competitors – to create the market demand for economies of scale, exchange information on how to eco-design and create common standards for an equal playing field. The latter means a change in how to deal and manage your partner-**networks**. It's a collaboration on an equal footing instead of a buy-sell relationship. They are partner in the value creation process. Engaging with stakeholders such as policy makers, NGOs, customers and scientists can help to solve many technical, legislative and brand issues.

Of course, the companies and stakeholder act in a certain political **framework** which regulates the market. Here several political instruments are available: measures such as (see (Winzer, 2015)):

- Laws and directives, which set minimal environmental requirements on product and process level (e.g. ban of hazardous substances or limits for emissions)
- Financial and fiscal policies such as taxes, duties and subsidies e.g. tax reduction for repair services, subsidies for renewable energies or tax on emissions
- Normative support (standards) define eco-design requirements such as reparability or recyclability.
- R&D funding and grants for the development and realization of eco-design
- Green public procurement linked to norms or labels (e.g. the EPEAT label or the blue angel) creates a market, which can also increase transparency for other purchasers. Also independent product tests and benchmarking can increase transparency.
- Exhibition and awards reward forerunners and increase public awareness.

Last but not least, important actors within the **market**, the customers and distributors, play a crucial role. First of all, the distributors has to have green products within his portfolio, s/he is placing those strategically, and sales staff guides and informs customers specifically about those. Of course, private customers also need to demand greener products. In a business to business market the customer can set certain environmental friendly purchase criteria such as energy efficiency or reparability criteria. But also the OEM can offer certain after sales services such as maintenance or repair services especially in the B2B market – at the same time increasing the lifetime of the product and the turnover (product-service-systems).

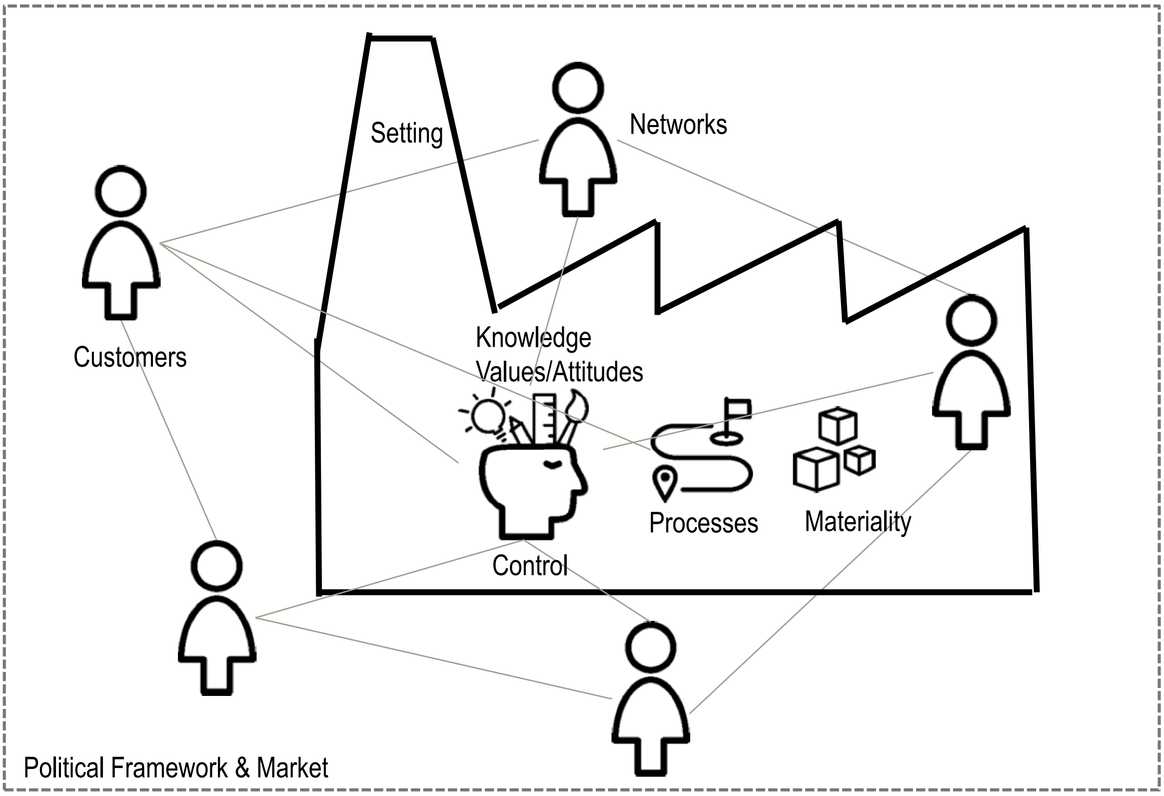

Figure 1. System view on conditions for the integration of sustainability into the product development.

Conclusions: Implications for companies' processes and practices

One cannot deny that eco-design increases the complexity of product development. On the other hand the authors are convinced that implementing eco-design process and practices in a company will make the company more innovative, competitive, resilient and future proof in a global fast changing world.

As (Edman, 2016) states: "*We can´t continue and stay competitive if we are not in balance with the Earth's ecological systems. Ultimately it is about quality of life – for everyone – now and in the future.*"

There are few good practices which can support the implementation of eco-design in companies:

- User centric design: understand the users' expectancies, needs, motivations and problems, their repair and maintenance practices while reflecting on why they buy and discard products. Design the product so that they like to take care and keep the product in use and alive (design for sustainable behaviour, design for product attachment and trust).
- Focus on providing a service instead of selling products: dematerialize by making full use of one product (share products, pay-per-service or pay-per-access).
- Combine product and circular economy business model development: the business model has direct implications on the product design. For example, in case you create a product for short use (disposable product) it should be easily recyclable or biodegradable. In case you "just" use the product to provide a service (pay per service) you want the product to be reliable and easy to maintain.
- Keep the product at high utilization through maintenance, reuse, repair, remanufacturing and cascade use of the product, components and materials. Keep in mind that through recycling you will destroy most of the value you created during the product development and production.
- Design the system (life-cycle thinking) besides the product: which partners, services and costs/benefits do you have to

integrate in order to keep the product alive?

- Create strong partnerships and integrate the network including the user in the value creation process. Open up the design and the value creation process and let partners (e.g. repair centres) and users take part in the development, manufacturing and maintenance of the product and distribute the benefits fair to your collaborators.
- See your company as part of the environment the company relies on. Think about how you can restore that environment instead of how you can exploit it.
- Think about the purpose and the values of your company, your employees and your stakeholders. Integrate those values and your long-term strategy. Balance environmental, social, technical and economic decisions.
- Identify the benefits you create through eco-design within your company and translate environmental improvements on a product level as benefits for your clients.
- Support self-organization and thus enable fast decisions, agile processes, participation and creativity.

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PLATE
Product Lifetimes And The Environment

Generation Scrap: Designing with Waste to Transform the Carpet Industry

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Keywords: Anthropocene; Circular Economy; GenZ; Material Design Pedagogy; Carpet Manufacturing.

Abstract: This paper presents the explorative design process and proposed concepts from the project "Generation Scrap" project at The Ohio State University's Department of Design. This project is positioned within an Interior Finish Materials and Methods course in partnership with the flooring and carpet manufacturer Mohawk Group, part of the global Mohawk Industries. Building upon the work of Mohawk's A&D Design Director, this project first looks at "Scrap Culture," understanding the world today through the lens of the Anthropocene and Plastic Age. GenZ students explore innovative concepts to mitigate waste, proposing new carpet designs that reduce, reuse, or recycle waste to create a more sustainably built and natural environment. Mohawk's extensive knowledge and advancements within sustainable manufacturing and the circular economy provides students with resources to develop innovative solutions for a realistic carpet design that would have a positive impact on the environment. This partnership project highlights the importance of collaboration between sustainability organizations, both educational and industry, to create designs that emotionally resonate with end users who demand sustainable products in the marketplace. Outcomes included concepts ranging from new carpet fibers or backing solutions created from agricultural, industrial, and consumer waste to new patterns based on biophilia, demonstrating the ingenuity and creative problem solving that GenZ possess.

Introduction – A World of Waste

We live in a world that creates more waste than it does reduce, reuse, or recycle. This era, referred to as the Anthropocene, is defined by human's effect on the earth (Merriam-Webster, 2019). Carbon emissions, overpopulation, loss of natural resources, pollution and debris, climate change, biological and chemical influencers impact the planet in devastating ways. Much of this has happened since the Industrial Revolution, but more crucially since the advent of plastics.

Currently, over 5 trillion pieces of plastic litter the ocean, primarily from plastic containers and bottles, fishing nets, and shopping bags (The Ocean Cleanup, 2019). As a marker for environmental impact, plastics are reshaping ecosystems, cohabitating with natural phenomena in a new form of pollution. One such example is "Plastiglomerate," a term created to describe a stone that contains mixtures of natural debris that is held together by fragmented plastic debris (Corcoran, Moore, Jazyac, 2014) (Figure 1).

Figure 1. Image of Plastiglomerate from the *Broken Nature : Design Takes on Human Survival* exhibit during the XXII Triennale di Milano. © Royce Epstein.

Designers and manufacturers are innovating new ways to utilize waste for materials in interiors, architecture, products, fashion, and the arts. These industries are addressing humanity's waste through material innovations and production processes, creating a new design language that moves beyond industry or craft. Taking a proactive stance, designers are using waste and scrap materials, as well as connecting with other social issues, to find solutions in favor of sustainability. Lithoplast (Figure 2), created by Israeli designer Shahar Livne, is another new material emblematic of the Anthropocene. Livne speculates how future generations could react to plastic, envisioning Lithpolast as a valued material mined when virgin plastic ceases production (Chawla, 2019) (Figure 2). Companies such as Adidas are partnering with programs like PARLEY, a collective bringing together different industries that upcycle ocean plastic and fishing nets to replace virgin plastic, transforming them into fibers for shoes or molded into objects (Adidas, 2018).

Figure 2. Image of Lithpolast from the *New Material Award 2018* exhibit at Dutch Design Week, Eindhoven. © Royce Epstein.

Textile waste is also contributing to the Anthropocene. In 2015, over 16 million tons of textile waste was generated in the United States alone. Of this, only 2.62 million tons were recycled and 10.46 million tons were sent to landfills (EPA, 2019). Eileen Fisher is another corporate innovator working under a philosophy of "where others see waste, we see possibility." Introduced in 2018, her "Waste No More" exhibit showcased new ways to utilize reclaimed clothing waste to create a new textile for fashion and commercial interiors (Fisher, 2018).

Figure 3. Image from Fisher's *Waste No More* exhibition during Ventura Centrale, FuoriSalone, Milan 2018. © Royce Epstein.

The interior design industry has witnessed major innovations for interior finishes that reduce waste and contribute to the circular economy. The "Cradle to Cradle" movement by William McDonough charged designers to consider "everything is a resource for something else," that waste is food for new materials and methods (McDonaugh, 2002). Going even further to address the circular economy, creating closed-loop systems for manufacturing allow for industrial waste to become a new valued resource.

With this mindset and advances in technology, new techniques for designing and manufacturing textiles and carpet for have emerged. Addressing textile waste, Kvadrat initiated *Really* in 2013. By 2017, they had created two new materials: Solid Textile Board and Acoustic Tile Felt, both readily made from Kvadrat's own waste stream of wool discards combined with cotton and denim from the fashion industry (Kvadrat, 2017).

Figure 4. Image of textile waste for new acoustic products from *Kvadrat Really* exhibition during FuoriSalone, Milan 2018. © Royce Epstein.

Within the carpet industry, Mohawk Industries is one of the largest recyclers of plastic bottles, diverting over 6 billion bottles yearly into PET carpet fibers which produces 135 million square yards of carpet. Contributing to the circular economy, their ReCover recycling program donates removed carpet to nonprofit organizations, rather than sending it to landfills (Mohawk Group, 2017). Mohawk prides itself as innovators on every level from developing new sustainable and dematerialized backings and fibers to educating their clients and students on the value of sustainable design thinking and making. They believe in an all-encompassing sustainability strategy, handprints over footprints, giving more than they take from the earth while still creating well designed products (Shulman, 2018).

Figure 5. Image of recycling bales of PET water bottles intended for new carpet fiber. © Mohawk Industries.

Scrap Culture

These efforts towards a more sustainable future strongly resonate with the values of younger generations. Millennials and GenZ are driven by their ethical responsibility toward environmental and social sustainability, focusing heavily on a company's purpose towards environmental and social impact (MLSGroup, 2014). In a survey of GenZ, 76% reported that they are concerned about humanity's impact on the planet and that it's the number one issue plaguing the world (Sparks & Honey, 2014). If the Oxford Dictionary defines "Pop Culture" as "modern popular culture aimed particularly at younger people" (2019), one might define this current Anthropocene moment amongst Millennials and GenZ, that of grappling with society's abundance of waste with the aspiration to reduce their ecological footprint, as "Scrap Culture."

Within design, this notion is about looking at waste as currency, a commodity and resource for inventing materials and products. This appreciation and demand for waste spreads across industries and design practices that want to participate in sustainability and the circular economy. Embracing a Scrap Culture mindset, more people can learn to embrace waste as an asset, foreseeing potential implementations for waste streams. As generations who have only known a "Scrap Culture," one could refer to them as "Generation Scrap."

Generation Scrap – A Pedagogical Approach

The building industry is one of the largest consumers of plastic-derived materials and products, thus interior design education is positioned to transform Generation Scrap's relationship with plastic and other waste materials. In order to create a more sustainable built environment, it is critical that a pedagogical approach to interior finish materials include projects that encourage life cycle analysis and exploration of waste reduction. By establishing a sustainable design mindset early on in interior design education, particularly within the Interior Finish Materials course, sustainability will become a building block for all subsequent design decisions.

Mohawk believes that in order to create a more sustainable future, education of sustainability and textile design must go hand in hand by engaging designers of the future. In this spirit, a project was developed in partnership with Mohawk Group, a division of Mohawk Industries. Positioned within an introductory level Interior Finish Materials course at The Ohio State University, this project explores the design process and theoretical design concepts for a carpet that would mitigate waste. This project leverages Mohawk's extensive knowledge and advancements within sustainable manufacturing and the circular economy to improve student outcomes.

Research and Trend Forecast

When you combine design thinking and sustainability, you can solve big problems. Inspired by emerging designers, this asked students to develop a trend forecast report positioning sustainability alongside societal issues, conceptualizing a future that is both environmentally and socially sustainable.

Launching the project, Mohawk's A&D Design Director, Royce Epstein, presented her authored CEU presentation "Scrap Culture." Diving deeper, students individually researched scrap culture to understand how all design industries are addressing waste. Students then looked at the world through their own lens, contemplating personal ethics, social movements globally and locally, art, fashion, and technology to discover what they foresee as leading to the future of design, resulting in their final trend forecast.

Design Concepts

Applying their trend forecast, students designed a carpet concept for a commercial application (workplace, hospitality, retail, higher education, etc.) that would positively impact the natural environment and the human experience of space. Taking longevity into consideration, the design addressed durability, meeting industry high traffic standards. Designs also considered the overall aesthetic, including patterns, colors, and textures that are relevant today and ten years from now. As a theoretical project, students were encouraged to propose new manufacturing materials and methods, such as solutions for backing or fibers. The design concepts needed to create a meaningful dialogue between industry, craft, sustainability, and social challenges.

Outcomes

Juried by a team of design professionals at Mohawk Group, the following projects were awarded first, second, and third place amongst the students in the class. These examples demonstrate a breath of theoretical approaches for how carpet design can be both beautiful and meaningful while contributing to the reduction of global waste.

Example 1: Terra Haven Trail

Trend Forecast

Concerned for the plight of refugees facing displacement due to global warming, Katherine Hunter's design addressed the sustainability and humanitarian challenges surrounding the mass migration crisis. Her trend research focused on climate refugees, highlighting a subset of refugees that are forced to migrate due to inhabitable conditions related to climate change, which includes rising sea levels, hurricanes, drought, rising temperatures, and the melting arctic ice.

Figure 6. Image of Hunter's trend forecast from her final presentation. © Katherine Hunter and The Ohio State University.

Design Translation

Hunter's design objective was to bring Climate Migration to the surface, literally, through pattern language and fiber construction. Inspired by forging a trail to a new beginning, the design started by understanding the physical and emotional journey of a refugee. Translating migration maps, the surface pattern become a means for wayfinding within an interior. The color collection was derived by two paths of travel, across water and land. These natural color palettes, based on biophilia, create a sense of calm. The application is intended for healthcare spaces where refugees seeking a new life would feel at home in their new environment.

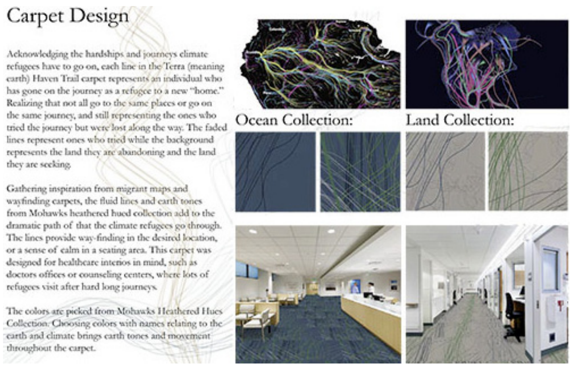

Figure 7. Image of Hunter's carpet design from her final presentation. © Katherine Hunter and The Ohio State University.

Sustainable Strategy

In further researching the waste stream caused by the refugee crisis, Hunter discovered that lifejackets are polluting beaches and oceans along migration paths. Thus, Hunter's sustainable strategy uses discarded life jackets as raw material for a new carpet material. Commercial carpet is made from nylon – instead of using virgin nylon, Hunter proposes recycling the nylon from refugee's lifejackets for new carpet fiber and the foam interior as a backing material. Once again physically connecting to the refugee story, each 24" carpet tile would metaphorically represent one refugee whose life was forever affected by climate change.

Figure 8. Image of Hunter's sustainability strategy from her final presentation. © Katherine Hunter and The Ohio State University.

Example 2: Bending Lines

Trend Forecast

The sharing economy and technology have enabled the demolition of many boundaries. As GenZ looks to the future, they envision a more evolved society, one that is cross cultural and more accepting of differences in race, age, and gender. They desire a society that is fluid, a term that speaks to people who are not of a single place but part of many, not defined by a preconceived idea of identity but one that moves between previously defined boundaries. Definitions and depictions of male and female are being transformed and even erased through gender bending as design and fashion is embracing androgyny, gay rights and acceptance of transgendered people. Abigail Bouton explored these ideas for her trend forecast.

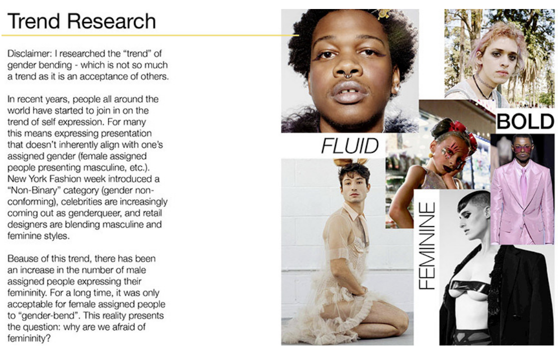

Figure 9. Image of Bouton's trend forecast from her final presentation. © Abigail Bouton and The Ohio State University.

Design Translation

Interpreting this cultural trend, Bouton explored gender as binary and non-binary, translating these concepts into pattern-work using line, hierarchy, and space. The gridded pattern moves from heavy to thinner lines, creating a fluid pattern that can be seen as blurring the boundaries between what is traditionally male vs. female. This collection was designed as modular tile and broadloom, showing the versatility and fluidity of installation types. Seeking to further push the idea of non-binary and redefine perceptions of feminity, the monochromatic color palette is in shades of pink as well as black and white.

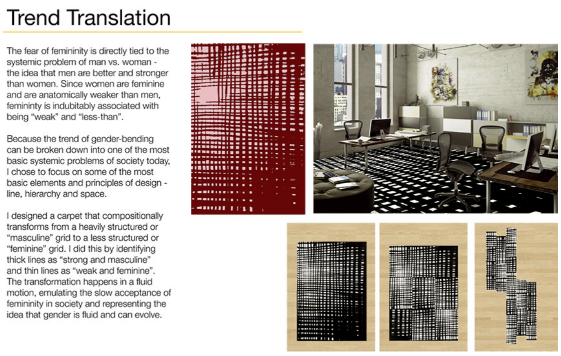

Figure 10. Image of Bouton's carpet design from her final presentation. © Abigail Bouton and The Ohio State University.

Sustainable Strategy

While the fashion industry is a leader in forging a non-binary world, Bouton recognizes that textile waste from their industry is negatively impacting the environment. Thus, striving to reduce fashion's waste as well as greenhouse gas emitions from virgin polyester production (a fiber used for carpet), Bouton's strategy reclaims polyester textiles destined for the landfill to be recycled into new carpet fibers.

Figure 11. Image of Bouton's sustainability strategy from her final presentation. © Abigail Bouton and The Ohio State University.

Example 3: Ocean Floors

Trend Forecast

One of the greatest sustainability challenges today is the volume of non-biodegradable plastics polluting our oceans. As humanity understands the consequences of their throwaway lifestyle, as evident in the Great Pacific Garbage Patch and other such occurrences around the world, efforts to swiftly patch our ecosystem must be addressed by all industries. Scientists and designers alike are tackling this through new material explorations using ocean plastic as a raw material for new products. As a global issue, it will take industries collaborating to make a major change. Thus, Serena Schwallie's forecast builds on the notion of "team work to make the dream work."

Figure 12. Image of Schwallie's trend forecast from her final presentation. © Serena Schwallie and The Ohio State University.

Design Translation

Schwallie's Mohawk + Parley Ocean Floors carpet collection reflects the eight primary regions around the world (Hawaii, Maine, the UK, Jamaica, Alaska, Maldives, Indonesia, and Australia) whose beaches and surrounding oceans are most impacted by plastic waste. Highlighting that this is indeed a global problem, the pattern and colors relate to each other but each colorway is unique to the beaches of the specific regions. Applied within an office interior, each colorway defines a conference room or brainstorming area where the polluted beach and its story becomes the room identity and environmental graphics. This concept further illustrates the power of interior finish materials to transform a space into a more meaningful and impactful place.

Figure 13. Image of Schwallie's carpet design from her final presentation. © Serena Schwallie and The Ohio State University.

Sustainable Strategy

Conceived as a partnership between Mohawk with Parley, the collection would leverage Parley's work to recycle debris from the eight beaches to create carpet fibers. Each color/pattern in the collection would be made from reclaimed ocean plastic from that specific region, directly linking people standing on the carpet to the beach where the raw material originated. This sustainability story is relevant as everyone can relate to oceans and plastic waste, and feel they are contributing to circularity.

Figure 14. Image of Schwallie's sustainability strategy from her final presentation. © Serena Schwallie and The Ohio State University.

Conclusions

From proposals of new carpet fibers or backing solutions created from agricultural, industrial, and consumer waste to new patterns based on biophilia, this project demonstrates the ingenuity and creative problem solving that GenZ possess. This partnership highlights the importance of industry collaboration between sustainability organizations, both educational and industry, to create designs that emotionally connect to end users who demand sustainable products in the marketplace. By incorporating projects such as this into our university curriculums, we can make a tangible impact on the environment. As experienced practitioners of interior and product design in a sustainability context, Mohawk believes it is imperative to inspire the next generation of designers and design thinkers to tackle the dire environmental and social challenges of our time. Generation Scrap aims to do just that – instill a combination of global insight, cultural context, current and future sustainability initiatives, and design practice into a cohesive project that redefines the scope of materials for the built environment.

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Emotional Fashion: an Exercise in Understanding what Values Drive Youth Generations' Consumer Behaviors

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Keywords: Slow Fashion; Sustainable Fashion; Millennials and GenZ; Consumer Behaviors; Product Lifecycles.

Abstract: With social media and online shopping, brands have more opportunities than ever to emotionally connect and educate their customers. Brands are able to be more transparent about their sustainable mission and the lifecycle of their garments through these platforms. In turn, this provides customers transparent access to companies with shared values. As the Gen Z market continues to grow, the garment industry needs to address the disconnect between the sustainable values of Millennials, the deepening values of Gen Z, and that of their brands' sustainable message. This paper presents an exercise in understanding why emotional connections to our clothing are created. The objective of this exploration was twofold: to understand how empathetic ties are formed, which could aid in designing more emotionally connective sustainable fashion, and raise awareness in the participants regarding their consumer behavior and its environmental impact. This paper presents a three-part study of Millennials and Gen Z. A balance of quantitative and qualitative questions provided for comparative analysis and individual expression. By understanding their philosophical relationship with clothing, business models can be designed to promote meaningful and empathetic ties between people and their clothing. As a secondary objective, these questions encouraged behavioral self-reflection but shows the potential of utilizing this study format as a creative tool.

Introduction

The Slow Fashion movement speaks of linking pleasure with an awareness of environmental sustainability through educating consumers on product life cycles (Fletcher, 2008/2014). These ideas resonate with the values of the youth generations, Millennials (b.1982-1995) and Gen Z (b. after 1995). In a 2014 survey, 78% of Millennials in 17 different countries said they would recommend a company they believe is a good citizen and 71% would be loyal to that business (MLSGroup, 2014). A survey by Sparks and Honey (2014) shows 76% of Gen Z are concerned about humanity's impact on the planet. However, within the American fashion industry, businesses primarily rely on encouraging fast consumption. From a garment's concept, design, production, marketing, and its waste cycle, American fashion brands struggle to connect with younger generations' values, identifiers, and their drive for environmental responsibility.

With social media and online shopping, brands have more opportunities than ever to emotionally connect and educate their customers. Technology enables brands to be more transparent about their sustainable mission and the lifecycle of their garments providing consumers access to companies with shared values. Between 2016 and 2017, brands increased spending on social media by 60%, and by 2020, it is expected that companies will focus 50% of their marketing on online campaigns (Alemany, 2019). However, information overload is a norm in today's fast paced digital world, especially for digital native youth generations. As Fletcher and Grose state, "The fast-paced and visually noisy marketplace depletes the psychic attention of the shopper; elements that might signal emotional attachment to a garment, as quiet as they often are, can easily be drowned out by the competition for a shopper's attention" (2012). The daily barrage of information coming from the fast fashion industry causes consumers to struggle with making choices that align with their values: grasping the environmental impact of their consumer habits and making mindful purchases to reduce their impact. As these generations' buying power continues to grow, the garment industry needs to address the disconnect between the sustainable values of Millennials, the deepening values of Gen Z, and that of their brand's sustainable message.

While research shows that people forge emotional connections with their garments (Fletcher and Grose 2012), this paper presents a study in understanding why those emotional connections are created amongst youth generations. The study's exercises take a deeper look into the emotional mindset of these generations, asking "what parts within the current fashion system inhibit Gen Z and Millennials to emotionally connect to fashion sustainability throughout the entire clothing cycle?" The objective of this exploration is twofold: to understand how empathetic ties are formed in order to design more emotionally connective and sustainable fashion models; and to raise awareness in the participants regarding their consumer behavior and its environmental impact. By understanding consumer's philosophical relationship with clothing, business models can be designed to promote meaningful and empathetic ties between people and their clothing.

Methods

This research study was comprised of three different self-reporting exercises (survey, daily log, and daily journal) regarding participants' daily fashion. The kind of clothing recorded included tops, bottoms, outerwear, hats, and shoes. Accessories and intimates were not measured during this study. Millennial and Gen Z participants were recruited for exercise one and two through Facebook, Instagram, and Reddit. Participants anonymously completed all sections. Each exercise uses a combination of quantitative and qualitative questions to record a comprehensive experience for each wearer. While the data is shallow on its own, giving individuals the time and space to have their thought process creates more nuance and depth within the numbers.

Exercise One

Participants answered 16 questions that guided them through the entire process of *finding, buying*, and *disposing* of clothing. Within these three sections, participants recorded their habits and preferences through decision matrices, multiple choice questions, and short answer questions to capture rationale. This balance of quantitative and qualitative responses provided for comparative analysis and individual expression. As a secondary objective, these questions encouraged behavioral self-reflection.

Exercise Two

Participants submitted a picture of the outfit they wore for a single day and answered four supporting questions:

1. Describe the articles of clothing?
2. Where did you purchase each piece?
3. How much did each one cost?
4. How long have you owned each article?

The objective was to assess participants' current consumer behaviors. By collecting one day's worth of data from multiple sources, a small population sample average was determined for each question.

Exercise Three

This exercise followed one slow fashion aware student for 30 days. This participant recorded the four questions above for each day. The objective of this study was to compare the differences in clothing choices from one slow fashion aware person to the sample from exercise two.

Results

Introduction

A difference in behaviors, preferences, and impact is illustrated by comparing the average numbers from each sample set. Exercise One focuses on the youth's cumulative habits and perceptions throughout a garment's life cycle, collecting 162 responses. Exercise Two analyzes the average preferences of multiple participants on the same day. Exercise Three closely evaluates one individual's wardrobe choices and patterns over 30 days.

Exercise One: Survey – Part One

This series of questions addressed the *finding* process. Question one asked how important personal style was on a scale from most important (1) to least important (6). Over 64% of participants marked 2 or 1 (Figure 1).

Figure 1. How Important is Style? © Tiffany Lau and The Ohio State University.

When asked why they believe style to be important or not, over 85% of individuals found it as a meaningful form of self-expression - this includes comfort, self-identifying, personal expression, nonverbal identifier, and creative medium (Figure 2). A common response was that fashionable comfort lead to wearers exuding self confidence in the phrase, "look good, feel good."

Figure 2. Why is Style Important? © Tiffany Lau and The Ohio State University.

The second series of questions gathered information regarding personal taste, trends, and brand alignment. Question one inquired about the average price participants paid for their clothing: 30% paid between $21- $40 and 22% paid $41- $60 for their clothing (Figure 3).

Figure 3. Average Price Range for Clothing. © Tiffany Lau and The Ohio State University.

A decision matrix than had participants report which of eight resources they most frequented for fashion information, 1 being the most and 8 the least (Figure 4). Reinforcing brands' use of social media for connecting to youth generation, 36% reported finding trends through social media. One quarter of participants reported in-store as their primary means. Through their short answers, 39% of participants responded that they valued accessibility to choices and 22% reported they desired seeing what was available. Many individuals enjoyed being able to do comparative market research for style, price, and quality before buying an item.

Figure 4. Finding Trends. © Tiffany Lau and The Ohio State University.

Exercise One: Survey – Part Two

The second section, *buying*, walked participants through four main aspects of their consumer experiences. The first question asked how frequently they bought clothing. 40% of participants buy clothing less than once a month while only 26% reported making purchases a few times a month (Figure 5).

Figure 5. How Often Do You Buy Clothes? © Tiffany Lau and The Ohio State University.

A decision matrix presenting eight options surveyed where participants bought their clothes,1 being the most and 8 being the least. 40% of participants prefer online shopping. However, 21% recorded thrift stores as their primary place to buy clothing (Figure 6). The follow up question asked participants to explain their top choices. 30% reported that their preferences were convenience, echoing the preferences reported in *finding.* 18% reported that variety and browsing was important.

Figure 6. Buying Trends. © Tiffany Lau and The Ohio State University.

Exercise One: Survey – Part Three

Part 3, *disposing*, asked participants to consider their fashion waste. The first question asked participants how often they disposed of their clothing. 27% reported 2-4 times a year (seasonally) and 26% annually (Figure 8).

Figure 8. How Often do You Get Rid of Clothes? © Tiffany Lau and The Ohio State University.

Participants then indicated how many articles are being discarded at a time. 38% discarded 5-8 articles of clothing from their wardrobe and 20% averaged 9-12 articles (Figure 9).

Figure 9. How Many Articles of Clothing are Disposed of at a time? © Tiffany Lau and The Ohio State University.

The third question sought rationale for why individuals discarded clothing. 33% reported clothing as damaged and/or old. A quarter reported "doesn't fit" as the cause (Figure 10).

Figure 10. What is Your Main Reason for Disposing of Clothing? © Tiffany Lau and The Ohio State University.

To understand disposal locations, a decision matrix with eight options was presented. A large majority donate their clothing, 63% to charity and 22% to family members (Figure 11). Providing rationale, 40% said they desired reuse while 20% said it was easy.

Figure 11. Disposing Trends. © Tiffany Lau and The Ohio State University.

Exercise Two: Outfit Log

The second exercise recorded 35 participants' outfits for one day. Out of 139 articles of clothing reported - including tops, bottoms, outerwear, and shoes - the average price spent on each piece was about $35.34. The following is a breakdown of the averages:

Boots - $60.56
Jeans - $35.89
Tennis shoes - $82
T-shirts - $10.44

Regarding garment lifecycle, the 139 articles averaged 1.73 years (Figure 12).

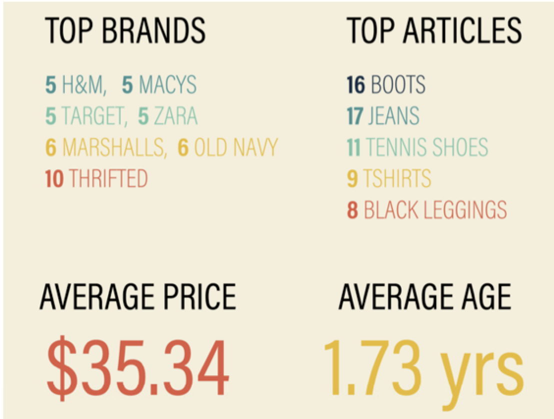

Figure 12. What is Your Main Reason for Disposing of Clothing? © Tiffany Lau and The Ohio State University.

Exercise Three: Daily Journal

One Millennial slow fashion conscious participant documented what they wore each day for 30 consecutive days. The following illustration (Figure 13) visualizes all 30 outfits.

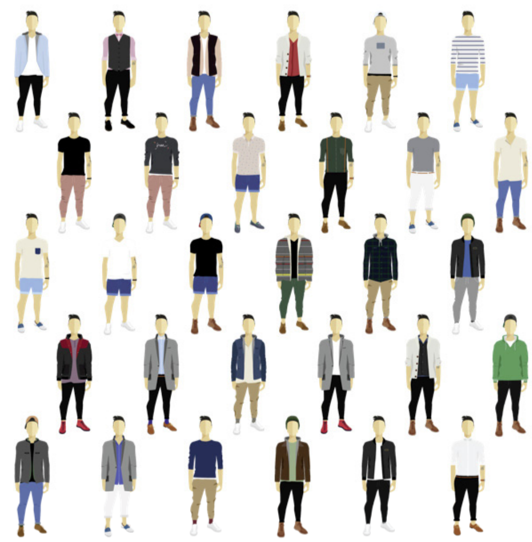

Figure 13. Daily Journal - 30 Days of Outfits. © Tiffany Lau and The Ohio State University.

In total, 66 different articles were worn throughout the month. The participant reported 70 garments in their wardrobe that were unused: garment utilization was only 48.5%. Of the pieces worn, 24% were from second hand / thrift stores and 20% were gifted or handed down (Figure 14). The average price across the 66 garments was $11.2 per article (Figure 14).

Figure 14. Top Brands and Average Price. © **Tiffany Lau and The Ohio State University.**

More nuanced data can be analyzed from this study. For example, they reported that 47% of clothing was worn only once. Figure 15 illustrates the articles that were worn the most/least, highest/lowest priced, and newest/oldest pieces.

Figure 15. Most/Least of Clothes. © Tiffany Lau and The Ohio State University.

Conclusions

Based on the research collected from this study, there were three clear takeaways. These three strategies can be leveraged by the fashion industry to strengthen emotional connections between garments and people.

Self-Expressive Fashion = Product Longevity

Using style as a medium for self-expression and value communication is nothing new. Slow fashion research shows that fashion is a communication tool: the more it represents an individual's authentic expression, the stronger the relationship. The stronger the emotional tie, the longer one keeps and cares for that item. The outcomes from this research supports this concept of self-expression equates to product longevity. This form of non-verbal communication was described poignantly as not only a reassurance of self-confidence and utilitarian comfort but also self-affirmation of their own identity to themselves and others. Shoppers, both on-line and in-store, can establish an emotional connection before an article of clothing is even purchased. Providing opportunities for customization or alteration of new or used garments both in-store and on-line would tap into this generation's desire to express their identity and own a garment longer.

Cut Through the Digital Noise

Millennial and Gen Z shoppers are fiercely loyal to brands they believe they can trust and have similar values to their own. However, the visual noise of digital channels causes difficulty navigating which brands are authentic and trustworthy. This study showed that youth generation consumers prefer browsing and buying clothes through digital channels that are easy to see and compare options. Technology gives consumers the power to research and confirm the reliability of their investment. Brands can strategically use social media and digital touchpoints inside stores as a sustainability storyteller, being more transparent with their sustainable methods while inspiring and educating customers to live their values. Creating digital tools that are easy, accessible, and truthful is a way to attract youth generations to invest and forge a relationship with sustainable businesses.

Design Circular Economy Experiences

The participants in this study made it clear that they donate or give away their unwanted clothes. The data from the 35 participants along with the daily journal exercise illustrates the gap between Millennial and Gen Z intentions and actions. Driven by a social responsibility, people desire their personal garments to have a life beyond their ownership; however, they want the process to be easy and rewarding, expressing that they have not yet been given the correct and convenient tools to do so. Brands such as Madewell and H&M have implemented drop boxes in their stores to incentivize customers to recycle clothing. The reclaimed clothing can be reused or upcycled into a different product and the customers are given an instore discount. This concept can be more readily implemented to further attract and encourage customers to be mindful of their habits. Throughout the clothing shopping experience, both online and in person, brands should design moments to inspire emotional responsibility.

This study illustrated that younger generations want to buy from second hand stores. However, current thrift store are not designed in the same manner as branded retail environments. They do not allow for easy browsing nor is the customer journey aesthetically pleasing. To further encourage people to buy reused and reclaimed clothing, digital tools could be leveraged, providing an online stock of what is available. As the shared and circular economy begins to permeate the American marketplace, new opportunities for branded thrift store experiences could captures these youth generations and extend the customer base as well.

Future Survey Implications

Consumer Mindfulness

After the research study concluded, multiple participants reported having benefited from reflecting upon their consumer habits. Prior to their participation, these individuals did not explicitly contemplate the reasoning for their clothing preferences and the impact of their actions. For future research studies, it would be advantageous to conduct a post research survey to observe if their behaviors were positively impacted by.

Mindful Design

Utilizing surveys that indirectly mirror individual's reasoning through simple exercises has the potential to establish a precedence before designing. By taking a moment to slow down and consider what we perceive, believe, and the reasons why, we can confront both our positive and negative biases before the design process begins. Ensuring that creatives are acutely aware of their perspective and comprehension of the problem, designers can make more adept and empathetic design decisions leading to more successful ideas.

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Influence of Usage Patterns on Ecoefficiency of Battery Storage Systems for Electromobility and Home Storage

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Keywords: Electromobility; Second Use; Battery Electric Vehicle; Electricity Mix; User Behavior.

Abstract: This publication investigates the eco-efficiency of a battery electric vehicle (BEV) in comparison to an internal combustion engine vehicle (ICEV). The focus is on global warming potential, based on greenhouse gas emissions. For both vehicle types SMART cars are used, such that structurally identical vehicle types are compared. All three phases of lifespan are considered: production, operation and recycling. During operation different sources of electricity are investigated. This includes using renewable energy generation timely matched to the typical charging behavior. As the main finding, the operation phase dominates the emission of greenhouse gases for all usage patterns of the German 2017-2026 electricity mix: Even for non optimal charging behavior the BEV generates only 67 % of the emissions of the ICEV for commuting 39 km daily. On the other hand, manufacturing the BEV requires about 1.8 times as many emissions as producing the ICEV. However, even without possible recycling bonus, the ICEV production amounts to 10 %, and, when charging with the German electricity mix 2017-2026, BEV production only contributes to 27 % of the cradle to grave emissions. Thus, total emissions sum up to 16.1 t CO_2 equivalent for the BEV and 22.3 t CO_2 equivalent for the ICEV. Further reductions of the BEV's emissions ranging from 1.7 to 12.2 t CO_2 equivalent are achieved by optimized charging times, greener electricity mix or prolonged use of the aged battery in either the BEV or second use in home storage. This demonstrates that battery electric vehicles already today contribute significantly less to greenhouse gas emission than conventional internal combustion engine vehicles.

Introduction

"Diesel gate" caused environmentalists to call for a faster market introduction of battery electric vehicles (BEVs). During driving almost no emissions pollute the air. On the other hand, with lignite power plants continuing in Germany and elsewhere, BEVs do continue to cause emissions and relatively high material efforts for the battery, electrical motor and power electronics, themselves cause environmental impacts, mainly during production and recycling phase. The main question of this work is: From a holistic, cradle to grave point of view, in which ways are BEVs or internal combustion engine vehicles (ICEVs) better for our climate?

Existing studies show that the use phase clearly dominates global warming potential (GWP) of BEVs: (Nordelöf, Messagie, Tillman, Ljunggren Söderman, & Van Mierlo, 2014) reviewed 79 papers on life cycle assessment (LCA) of electrified vehicles out of which 87 % reported that supplied electricity for charging is a key factor for the results. Known studies consider yearly average carbon footprints (Eberle & Mu, 2012; Held et al., 2016; Helms et al., 2011). Since especially renewable generation fluctuates, this work intends to evaluate charging times matching renewable generation. Well timed charging can be more useful with regard to GWP today than once the energy transition has been completed. To complete today's options also "eco-friendly" electricity and self generated photovoltaic energy are compared.

Due to the early adopter phase of the BEV market recycling options will not be established until 2030 and beyond (Bobba, 2019; Natkunarajah, 2015). However, material depletion potential (MDP) of BEVs is about 2-3 times higher than that of ICEVs (Hawkins, Singh, Majeau-Bettez, & Strømman, 2013). Therefore, this work also investigates recycling potentials and component lifespan effects as well as second use potentials in home storage that can possibly relieve material efforts, and thus, improve cradle to grave GWP further.

Methods

The BEV and ICEV are chosen in an exemplary manner, in order to provide for the functional unit of the cradle to grave life cycle analysis: Production, operating and recycling phases of a mini car (two passenger seats) allowing for a daily round trip commute of 39 km. This is the average distance Germans drive on weekdays (Follmer & Gruschwitz, 2019). The use phase lasts the average lifespan of small ICEVs with 999 cm³, i.e. 8.7 years in 2016 (Kraftfahrt-Bundesamt, 2016). Analysis follows the steps defined in ISO 14040 and ISO 14044. Data from literature is modeled in GaBi using processes from the GaBi Educational Database 2017 and evaluated with regard to GWP (based on CML 2001 - Jan. 2016). Time resolved generation profiles multiplied with charging profiles serve for evaluation of the use phase.

Production step	**Input Data**
Materials extraction and vehicle production	material list and production sites (Dietz et al., 2015) energy for battery chemicals (Majeau-Bettez, 2011) electrical motor production steps (Kampker et al., 2012)
Transport between production sites by truck and sea including fuels	Route estimation: searates.com
Electricity emission factors for producing in Europe	(Covenant of Mayors Committed to local sustainable energy, 2010)
Electricity emission factors for producing in Japan	(Brander, Sood, Wylie, Haughton, & Lovell, 2011)
Emission factors for producing in China	GaBi Education Database 2017

Table 1. Sources of input data for production LCA.

Choice of the SMART car as example

BEV and ICEV SMART cars only differ in their power train. Therefore, users are expected to behave the same. The BEV's battery is sized 17.6 kWh (Daimler AG, 2017), sufficient for the daily commute and a size allowing for slightly larger distances as well, important for customer acceptance (Kley, 2011). It uses a lithium ion battery as is now state of the art in BEVs (Held et al., 2016).

Production phase LCA

Table 1 lists input data for each analysis step during material extraction and production phase. A detailed description of the LCA model can be found in (Fuge, Kanz, & Schürheck, 2018).

Usage phase influences

The ICEV SMART uses up to 5.9 l/100 km according to the manufacturer (smart, 2019). Calculations are based on this consumption. Indirect and direct emissions amount to 2877 kg CO_2/l in the GaBi Education Database 2017.

For the BEV: The manufacturer states a specific consumption of 15.1 kWh/100 km including charging losses for the BEV (Daimler AG, 2012). In (Held et al., 2016) mini and small BEVs in different recent German funding programmes consumed between 14.2 kWh/100 km and 17.6 kWh/100 km. In (Helmers, 2017) measured mixed urban and highway operation resulted in 13.4 kWh/100 km including charging losses. At spritmonitor.de 45 users report between 12.50 and 22.73 kWh/100 km of consumption, averaging at 16.08 kWh/100 km (Fisch und Fischl GmbH, 2019). Therefore, in order to account for increased cold winter / hot summer consumption, an average value of 20 kWh/100 km is assumed as in (Helmers & Marx, 2012).

96 % of BEV users charge at home, most of them every evening (Frenzel, Jarass, Trommer, & Lenz, 2015). We simulated charging at 3.6 kW from 5:30 pm to 7:45 pm (so-called “evening charge”) and compared it to charging from 11:45 am to 2 pm (“midday charge”) and charging at 5:30 am to 7:45 am (“morning charge”). For the daily recharge only 2 hours and 10 minutes of charging at full power would be necessary. The remaining 5 minutes represent an estimate for average charging losses over lifetime (roughly 4%), confirmed by (Redondo-Iglesias, Venet, & Pelissier, 2019).

In the proposed use the BEV parks without charging approximately 21 hours per day, or about 90 % of the time. Extrapolated aging data from storage aging at different state of charge levels and temperatures on BEV battery cells results in 87 % to 97 % remaining capacity after 9 years or 83 % to 95 % after 18 years (Keil, 2017). Every day 7.8 kWh or 44 % of a full cycle are charged and discharged, resulting in 162 full cycle equivalents per year. Cyclic aging causes capacity to fade by 3 % to 10 % for 500 full cycle equivalents (Keil, 2017). Thus by averaging these effects, the SMART battery's remaining average capacity value is expected at 70 % of the initial capacity after 8.7 years in operation or at 50 % after double life span. In order to account for uncertainties, both the effect of a 50 % reduced and a 100 % increased battery lifespan are checked.

The German electricity mix was modeled in 15 minutes resolution using SMARD generation data of the year 2017 (Bundesnetzagentur | SMARD.de, 2017).

Energy source	g CO_2/kWh	Data from
Biomass	272	(Memmler, Lauf, & Schneider, 2018), other renewable: geothermal
Hydropower	3	
Pumped hydro	26	
Wind offshore	6	
Wind onshore	11	
Photovoltaics	67	
Other renewable	192	
Lignite	1142	(Icha, 2019)
Coal	815	
Natural Gas	374	
Nuclear	32	(Fritsche, 2007)
Other conventional	486	German mix average (Icha, 2019)

Table 2. Emission factors of electricity sources.

All electricity sources are weighted with an emission factor according to table 2, then summed up and a 15 minutes resolution GWP profile of the 2017 electricity mix results. Until 2026 the yearly electricity mix GWP is expected to decrease by 2 %/year in order to comply with the German government's climate protection plan (Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit (BMU), 2019).

The emission factor of 67 g CO_2/kWh (Memmler et al., 2018) for photovoltaic generation also serves as reference value for fully self generated electricity. For the potential of green electricity, the hydropower value of 3 g CO_2/kWh is referenced (Memmler et al., 2018).

Recycling and material reuse aspects

This study evaluates recycling and reuse according to the substitution method: Reused materials can be (partly) reintroduced into the production cycle, saving energy and resources. Thus, in the substitution view recoverable materials count as bonus (Brander & Wylie, 2011).

Whereas ICEVs have recycling and reuse routes established in decades (Sander, Kohlmeyer, Rödig, & Wagner, 2015), battery and power electronics recycling of BEVs has not yet been established. Reliable data on an economically and ecologically optimized way of reusing BEVs, their components and their materials does not exist yet. Therefore, research results are used for estimating recycling bonuses for battery and power electronics. The remainder of the BEV can be recycled on the conventional path.

Battery recycling of lithium ion batteries has been demonstrated in funded German research in LithoRec (Buchert, Jenseit, Merz, & Schüler, 2011a) and LithoRec II (Arno Kwade et al., 2016): Dismantling the 150 kg (Dietz et al., 2015) provides metals that can be reused, i.e. a bonus for the process. During cell disassembly a solvent with positive GWP is used for material recovery. Combustion of the solvent and the separator also increases GWP. Recovery of aluminum and copper foils eases the burden on GWP. Hydrometallurgical processing requires energy and auxiliary material, again raising GWP. Overall, this recycling process gives a bonus of 0.16 t CO_2 equv.. Another research project, LIBRI uses pyrometallurgical recycling as the last step, resulting in a *negative* bonus of 0.19 t CO_2 equv. (Buchert, Jenseit, Merz, & Schüler, 2011b). This analysis compares the positive and negative options as ranges for battery recycling.

Up to 0.23 t CO_2 equivalent are avoidable in further production by recycling the 23 kg of power electronics in the BEV according to the research project ElmoRel (Bulach et al., 2020). This work analyzes the effects of full and no recycling credit.

Material composition of the remainder of the BEV and the ICEV (Dietz et al., 2015) results in a potential GWP bonus of 1.62 t CO_2 equv. for the BEV remainder including the electric motor and 1.55 t CO_2 equv. for the ICEV, assuming that 95 % of the materials can be recovered, as prescribed in the Directive on End-of Life Vehicle 2000/53/EC. GWP obtained is a potential not only because recycling is limited (Graedel, Allwood, Birat, Buchert, & Hagelűken, 2011; Unterreiner, 2016) but also because recycling itself consumes energy, thus contributing to global warming depending on the energy source and electricity mix.

Second use of battery or longer use in BEV Instead of recycling, the (Casals, Amante García, & Canal, 2019) aged battery could be reconfigured in order to be used again in a photovoltaic home storage system. From a 17.6 kWh battery with 70 % remaining capacity 3 modules of 4.4 kWh effective capacity could be obtained. Such a battery (Jäger, 2013) can avoid about 1000 kWh of grid electricity depending on photovoltaic (PV) system size, household size and load profile. The remaining lifetime in the PV system is highly uncertain. Therefore a conservative estimate of 50 % of the original lifetime of 8.7 years is considered.

Since 70 % of initial capacity might not cause a user to stop driving the BEV (Saxena, Le Floch, MacDonald, & Moura, 2015), alternatively a 100% prolonged battery lifetime is analyzed. Accordingly charging losses are increased to 20 % in order to account for the aged battery behavior, extrapolating (Redondo- Iglesias et al., 2019). Since vehicle electronics and other parts tend to require replacement, it is assumed, that the power electronics module needs to be replaced after 8.7 years. So, another 0.39 t CO_2 equv. (Dietz et al., 2015) are needed for prolonged use of both the BEV and the ICEV.

Results

This section sums up the results of the three lifetime phases and, in the end, describes the result of the holistic system analysis.

Production phase life cycle analysis
Figure 1 shows the GWP of the production phase. Most dominant is chassis production from steel. Next important are the Lithium ion battery and the electrical motor for the BEV due to their high metal content. This is why the BEV impacts GWP almost twice as high as those of the ICEV. Since the vehicle structure is identical chassis and gears have the same GWP value.

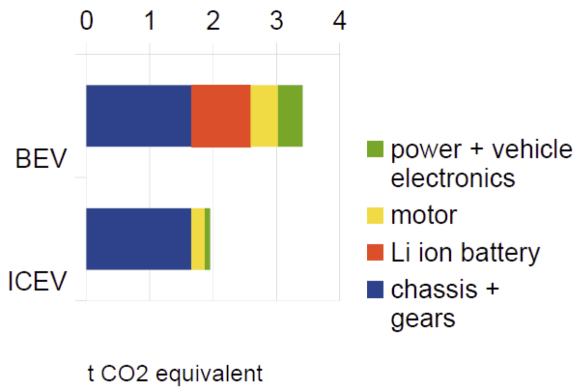

Figure 1. Production phase GWP.

Influences of usage phase
Hourly average emissions of the German 2017 electricity mix in figure 2 show that scheduling charging to midday will minimize emissions.

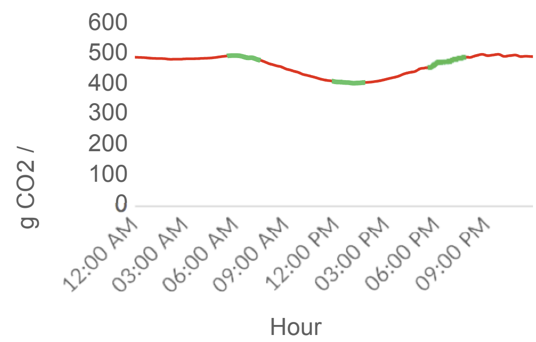

Figure 2. Red: Average emissions 2017 resulting from time resolved electricity mix multiplied with GWP of every electricity source. Green: Investigated charging windows.

Figure 3 shows that charging at midday decreases use phase emissions by 13 % when compared to evening or morning charge. Charging in the morning does not improve GWP compared to charging in the evening.

In the future, with increasing share of renewable energy in the electricity mix, lower GWP impact will arise from the use phase: Figure 3 shows the potential of the use phase if electricity is almost carbon free as is the case for hydropower already today. However, even with 2017's electricity mix and non-optimal charging behavior the BEV in all cases analyzed has a significantly lower GWP than the ICEV.

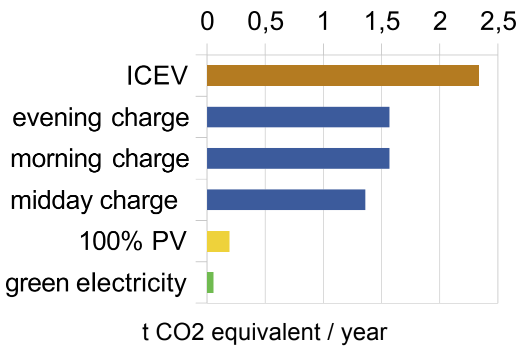

Figure 3. Charging electricity based emissions for different charging schedules on the German electricity mix 2017, compared to green electricity (100 % hydropower), 100 % generated in own PV system and ICEV emissions for commuting 39 km daily.

Recycling phase

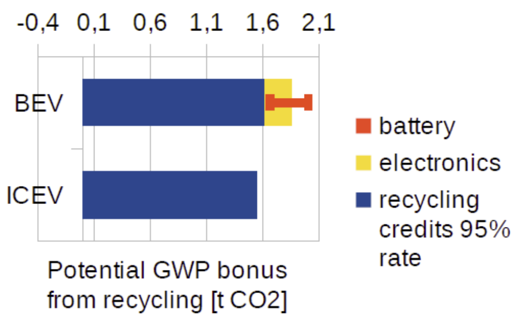

Figure 4. *Potential* of recycling bonus if 95 % of material can be regained and energy is carbon free.

Figure 4 shows the potential of optimized recycling: GWP bonuses due to reuse in the order of 1.8 t CO_2 equv. could be avoided in further production steps. If, as it is the case today, recycling cannot take place yet for the battery and the power electronics, this number is lowered by 0 to 0.4 t CO_2 equv.. The overall GWP will show the most optimistic potential GWP.

Reuse or prolonged use of battery

Reusing the battery in 3 PV home storage systems during 4.35 years avoids 6.3 t CO_2 equv. With increased battery aging or increasing share of renewable generation in the German electricity mix avoided GWP decreases.

Prolonged BEV use implies 10 % longer charging times in order to account for increased charging losses, i.e. an increase by 0.14 to 0.16 t CO2 equv. per year in 2017. The halved effective capacity of the battery even after twice the assumed lifespan is still enough for the 39 km commute.

Cradle to grave overview of all phases

Figure 5 shows that already today the BEV is less harmful regarding GWP. Recycling may offer a small bonus on the GWP. The ICEV in all cases analyzed shows a higher GWP than the BEV.

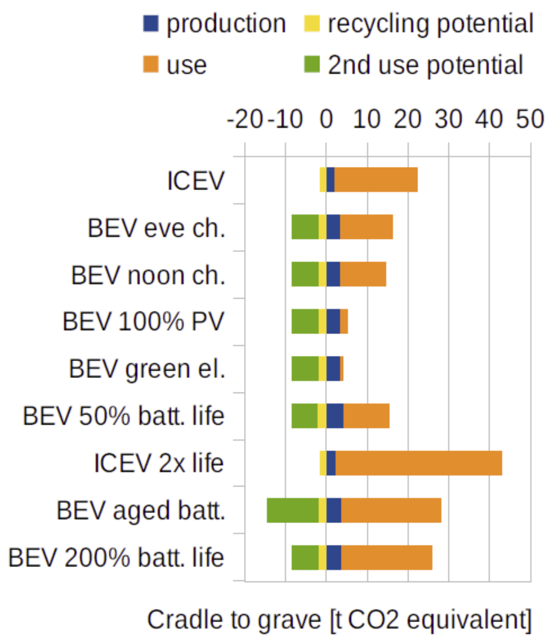

Figure 5. Holistic view: the BEV SMART wins for a daily 39 km commute even if charged in the evening's with German electricity mix 2017-2026 or if the battery lasts only half the usage time of 8.7 years. Also, for prolonged use of double lifespan (17.4 years) the BEV SMART wins even if two charges per day are needed because of an aged battery. A longer lasting battery which does not require charging twice a day, improves this effect further.

Sensitivities show:

- 50 % battery lifetime (i.e. 4.35 years) means that within the BEV's lifespan two batteries need to be produced. The cradle to grave GWP in this case is still lower than that of the ICEV being used for 8.7 years.
- If the BEV is used for a prolonged life of twice the original lifespan (i.e. 17.4 years), aging of the battery might cause the user to charge twice a day. Even then, the BEV still has a better cradle to grave GWP than the ICEV.

Discussion

Our calculations confirm that GWP improves with increasing share of renewable energy in the electricity mix. Further studies show that other factors related to fossile fuels also improve, such as acidification, summer smog potential, eutrophication (Helms et al., 2011; Van Mierlo, Messagie, & Rangaraju, 2017). If electricity mix is based on fossile fuels, BEV use even worsens particulate emissions (Ashnani, Miremadi, Johari, & Danekar, 2015). However, material depletion parameters impair for BEVs (Hawkins et al., 2013). Therefore, keeping materials in useful operation as long and as often as possible, is more important for BEVs than for ICEVs.

Since it is feasible to even charge a BEV twice a day, it is more likely that users will continue to use an aged battery with faded capacity in their vehicle than that reconfiguration efforts will be made to fit it into a PV system. The PV system would profit from such a battery since the battery in such a system helps avoid grid electricity emissions. From every aged SMART battery 3 PV systems could profit by avoiding 6.3 t CO_2 equv. in another 5 years of operation. This is confirmed and foreseen for some time in the future also by (Jülch, 2015).

Alternatively, doubling the useful life of the battery in the BEV, despite higher charging losses, is still causing a significantly lower GWP than driving the ICEV for double the lifespan. Since battery aging depends on driving profiles (charge/discharge behavior, temperatures, operating point specific losses), further investigations should include an aging model of the battery and charging/discharging losses, as suggested e.g. in (Held et al., 2016) and also model LCA of necessary repairs.

Even 95% recycling rate cannot provide a large bonus (around 15 % if German electricity mix 2017-2026 is used) to the cradle to grave GWP. And, even while not being recycled yet, the BEV has the lower GWP, compared to the ICEV which is being recycled. However, if material depletion is considered, recycling is expected to be crucial and further research should include design for recyclability options as well as recycling logistics, so that when BEV market uptake is there, recycling potentials can be used.

Since users prefer charging in the evening hours and there is no advantage if they do so during morning hours with regard to GWP, the recommended optimization of behavior is charging during midday. This is feasible for employees who either spend lunch at home or if employers offer solar carport solutions. Results also strongly advocate for green electricity tariffs: More than 99 % of the use phase emissions when charging green electricity.

Conclusions

Main findings of the comparison of the cradle to grave LCA of a battery electric (BEV) and a petrol engine (ICEV) SMART car are:

- For both vehicles, the use phase dominates impacts on global warming potential. This confirms other studies in that, even with German electricity mix 2017-2026 the BEV's GWP is lower by 33 % than the ICEV's GWP.
- If high recycling (and reuse in BEV production) can be achieved, then especially the BEV, profits from material recycling due to the high material effort for battery, motor and power electronics. This is also reflected in bonuses on the GWP.
- Charging times today can improve a BEV's carbon footprint. This effect will shift with increasing share of renewables towards supporting fluctuating flexibility demands.
- Due to the high amount of valuable material content the BEV profits from increased lifespan of components and parts as this directly reduces efforts for new production. Likely users of the 39 km commuter scenario will continue using their battery even after the calculated lifespan:

Extrapolating today's aging research indicates that 50 % of initial capacity will be available even after twice the vehicle lifespan considered here. An increase of charging losses by 20 % still allows for a significantly lower GWP than if the ICEV is used twice its average lifespan.

- Reusing the battery in second life applications, such as photovoltaic home storage provides an important bonus due to saved electricity carbon emissions from the German footprint. This will be the case for some time in the future.

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Is there a Need to Legally Define Practices of Premature Obsolescence?

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Keywords: Premature Obsolescence; Legislation; Legal Definition; Unfair Commercial Practices.

Abstract: There are nowadays general suspicions that consumer goods do not last as long as they should. Premature obsolescence is increasingly used as a buzzword to justify this belief. Although a growing number of empirical studies have confirmed that the median lifespan of certain products is in decline, the understanding of the phenomenon is too often biased and incomplete. Premature obsolescence is generally confined to a deliberate action taken by producers to urge consumers to purchase substitute products. The roots and causes of this phenomenon are however much more complex. Both EU and Member States have adopted and proposed initiatives to curb the accelerating obsolescence of products. French law is the most striking example as it includes a legal definition of 'planned obsolescence' and criminalizes the practice. This legislative act has inspired some EU institutions and national legislators, which suggest to follow the same approach. The need to adopt such legislation could nonetheless be called into question, especially since the two Italian decisions from September 2018 sanctioning companies for practices of premature obsolescence. After describing the complex phenomenon of premature obsolescence, the paper will delve deeper into the French legislation on 'planned obsolescence', as well as on the two recent Italian cases against Apple and Samsung. Confronting these two measures, the paper will then attempt to draw a conclusion on the need to introduce a legal definition of premature obsolescence.

Introduction

There are nowadays growing and widespread suspicions about the decreasing product lifetime. Empirical studies have confirmed the shortening product lifetime, at least for certain consumer goods (Prakash et al., 2016; Schridde et al., 2014; Wang et al., 2013; Wieser & Tröger, 2015). The notion commonly identified as the main cause of this issue is 'premature obsolescence'. While becoming a hot topic in the media and everyday discussions, the concept of 'premature obsolescence' has also been echoed in the legal field. Major legal developments and proposals have been adopted within the European Union (EU) and its Member States over the past few years to tackle the phenomenon. In 2015, France became the first country worldwide to legally define and outlaw 'planned obsolescence' (Loi n°2015-992). No such explicit legislation has been adopted at the EU level. Nonetheless, many EU legal instruments – from various legal branches - (indirectly) contribute to the quality and durability of products by regulating the different stages of product lifecycle (Michel, 2017). The Unfair Commercial Practices Directive (UCPD) is among them. Its importance in the fight against premature obsolescence has recently been confirmed in two decisions issued by the Italian Competition Authority (*Autorita Garante della Concorrenza e del Mercato*) against Apple and Samsung.[1]

The paper will focus on these two legislative measures and confront them. After clarifying what kind of practices are encompassed within the concept of premature obsolescence, the paper will bring the reader up-to-date on the most recent legal developments related to the issue. Most specifically, it will delve deeper into the French law on 'planned obsolescence', before analysing the two recent Italian cases against Apple and Samsung based on the UCPD. The aim of this paper is to give (or at

[1] Autorita Garante della Concorrenza e del Mercato, 25 September 2018, Apple ; Autorita Garante della Concorrenza e del Mercato, 25 September 2018, Samsung.

least to attempt to) an answer to the main question as to whether there is a need to legally define practices of premature obsolescence to adequately curb this phenomenon.

The Concept of Premature Obsolescence

The recurrent use of the concept of premature obsolescence as a buzzword within the last couple of years is striking.[2] The civil society and the media generally confine the phenomenon to a fight between product suppliers, on the one hand, and consumers, on the other. In this scenario, producers and designers play the role of the culprits, accused of deliberately integrating predetermined weak points into products to increase their replacement rate, at the expense of consumers (Consoglobe, 2016; Positivr, 2017; Welt, 2013). Studies have however shown that the reality is much more complex, making these assertions biased and/or incomplete.

Narrowing the focus on business is not sufficient to accurately explain the accelerating obsolescence of products. The behaviour of all economic actors, traders and consumers, has to be taken into account. For example, the way consumers choose, use, look after and replace their products has an impact on their lifetime. Nowadays, consumers are rarely keen on and/or skilled in repairing, causing earlier replacement of products (Cooper, 2004; Mugdal et al., 2012). Moreover, studies have revealed that decisions on product replacement are not necessarily motivated by a defect in the product (Van Nes & Cramer, 2005).

Acknowledging the significant role played by all economic actors in the premature obsolescence of products, it would be inappropriate to restrict its definition to its blatant cases which mainly depend on the will and actions of traders (European Parliament, 2016; Wieser, 2016). Products can, nowadays, have their lifetime shortened due to different causes. The various types of premature obsolescence occurred at different historical times and developed along different lines (Pope, 2017). The first well-known type is material obsolescence, which affects the material quality of the product. Consumers are forced to buy a whole new product due to either an electronic device that makes the product stop working after a certain period of use,[3] too fragile components[4] or product design resulting in (almost) inaccessible wear parts.[5] Premature obsolescence can also be technological, which typically arises when spare parts or accessories are not available anymore or not compatible with the product.[6] Another factor that causes the premature replacement of products is when the costs for the necessary repair and maintenance measures are perceived as too high when compared to the purchase costs for a new appliance. These products become economically obsolete. [7] Finally, premature obsolescence encompasses cases of psychological obsolescence whereby still functioning products are thrown away because no longer attractive or satisfying in consumers' mind. These categories of premature obsolescence are not watertight, but closely linked. While some products become obsolete due to one specific cause, others have their lifetime shortened because of a combination of them, which makes the phenomenon even more difficult to overcome.

The shared responsibility of all actors and the different aspects of premature obsolescence (material, technological, economic and psychological) should be considered when dealing with the issue. Consequently, the wording 'planned obsolescence' and its variations do not appear appropriate. On the one hand, it focuses on one side of the coin – the traders' behaviour, whereas it should be looked at the whole product lifecycle, from production to disposal. As J. Cox explained, improving product durability (through the design and manufacturing) alone is unlikely to deliver the kind of step-change in sustainable consumption, because unlikely to overcome the very significant psychological, emotional and social factors which underpin the rapid churn of products in the modern 'throwaway society'

[2] See for ex. the diagram on Google trends which shows the revival of interest for the word 'obsolescence' from 2004 onwards.

[3] Such practices were identified in the printer sector, some being designed with a smartchip.

[4] For example, some smartphones are built with a more fragile display assembly, battery, audio control and power button cable or screen protector (Prakash et al., 2016).

[5] In Germany, an analysis carried out by Stiftung Warentest in 2013 and in 2014 showed that more than a third of the examined smartphones had battery that could not be (easily) replaced (Manhart et al., 2016).

[6] Empirical studies show that typical reasons for technological obsolescence of smartphones are a technically limited memory or limited battery lifespan (Wieser & Tröger, 2015).

[7] Such practices are commonly encountered in the sector of smartphones, for which the replacement price of screens is often higher or at least not proportionate to the price of a new device.

(Cox et al., 2017). On the other hand, 'planned obsolescence' is provocative towards the industry sector. Terms with negative connotations should be avoided as they create difficulties for those willing to change laws and policies. T. Brönneke rightly highlighted that proving the existence of producers' intent behind product obsolescence is irrelevant since the repercussions on consumers and the environment remain identical in either case (Brönneke, 2014; Brönneke, 2017). The only concern to bear in mind is that products do not last as long as they should. A more neutral and general wording should therefore be used when adopting rules framing the phenomenon. The words 'premature obsolescence', which were already used by some scholars and the European Commission (C(2017)7124), seem to meet all these criteria and will thus be preferred in this paper.

The French case

Through the adoption of the Energy Transition Act (Loi n° 2015-992), France stood out from the crowd by embodying the concept of premature obsolescence in its legislation. Such a measure was described as indispensable to prevent waste and foster the shift towards a green and circular economy (Programme national de prévention de déchets 2014-2020). 'Planned obsolescence' (*obsolescence programmée*), defined as "*the set of techniques by which the person responsible for placing the product on the market seeks to deliberately reduce the lifetime of this product to increase its replacement rate*", is now a new case of fraud (Art. L. 441-2 Consumer Code). By deliberately shortening the lifetime of their products, producers mislead the other contractual party on product nature and essential qualities (Art. L. 441-1 Consumer Code). If a producer is caught pursuing a strategy of 'planned obsolescence', he could be held guilty of a criminal offence, reaching two-year imprisonment and 300.000€ fine or up to 5% of the average annual turnover (Art. L. 454-6 §1-2 Consumer Code). Additional sanctions could be taken, including the prohibition of practicing the activity in the exercise of which the offence was committed (Art. L. 454-6 §3 Consumer Code), the posting of the judicial decision in shops (Art. L. 454-7 1° Consumer Code) or the withdrawal of the concerned products from the market (Art. L. 454-7 3°).

During the legislative process, the Energy Transition Act and its definition of 'planned obsolescence' generated heated debate before the two chambers of the French Parliament (the National Assembly and the Senate). The definition formulated by the French Environmental Agency (ADEME) served as a basis (Mugdal et al., 2012). In its study, the ADEME distinguishes between planned obsolescence *stricto sensu* (material obsolescence) and other cases of obsolescence which do not depend on producers' will, namely functional obsolescence (corresponding to technological, economic and regulatory [8] obsolescence) and obsolescence due to consumers' changing needs and desires (psychological obsolescence). With such a basis and words like 'planned' and 'deliberately', it could be presumed that the scope of Article L. 441-2 is restricted to cases of material obsolescence. [9] Ambiguity might have been avoided by adding a non-exhaustive list of practices considered as 'planned obsolescence' (Maitre-Ekern & Dalhammar, 2016). The National Assembly had initially voted for such clarifications, mentioning in a second paragraph "*the intentional introduction of a defect, a wear part, a planned or premature product death, a technical restriction, an impossibility to repair or an incompatibility*" (Art. 22 *ter* A Projet de loi n°412). The impossibility to repair had even been further elaborated in a later amendment from the same chamber, specifying that it included cases where the product cannot be disassembled or where spare parts necessary to its functioning are not available (Art. 22 *ter* A Projet de loi n°519). The current definition will nevertheless prevail at the end of the legislative process.

Pursuant to the French definition of 'planned obsolescence', consumers must bring three pieces of evidence to successfully invoke Article L. 441-2 of the Consumer Code. First, they must prove that product lifetime has been shortened, which raises difficulties especially when the violation is not due to blatant material obsolescence, but to incompatibility issues (Martin, 2015). The primary step to achieve this is to objectively determine the (average?) lifetime of the concerned product. Law could help getting such information by defining

[8] Regulatory obsolescence consists of limiting product lifetime through legislation. The study gives some examples relating to the development of technology and safety regulations (Mugdal et al., 2012).
[9] Such presumption seems to be confirmed by the French Governement (Rapport du Gouvernement au Parlement sur l'obsolescence programmée, sa définition juridique et ses enjeux économiques, 2017).

product lifetime through Ecodesign requirements (Directive 2009/125/EC), legally obliging producers to provide such information[10] or by allowing the intervention of product-specific experts who would compare the lifetime of similar products (regardless of product series and producers) (Wrbka, 2017). Second, consumers must demonstrate that unlike them, the producer was aware of the poor quality of the products. The producer might not have correctly controlled or verified product quality, considered as committing fraud under French law (Ambroise-Castérot, 2016). Yet, apart from a few blatant cases such as the Phoebus cartel, [11] it is very difficult to furnish such evidence (Maitre-Ekern & Dalhammar, 2016). In most cases, manufacturers can argue that there was no intentional design choice, invoking either risk prevention, economic, aesthetic or technical reasons – all credible to justify the practice being criticised.[12] Third, consumers still need to show that the strategy was specially intended to boost sales and not to lower production costs (Maitre-Ekern & Dalhammar, 2016). The demonstration of these intentional and material elements might constitute a too heavy burden on consumers' shoulders, especially because of their lack of access to relevant information.

Taking all these points into consideration, the French definition on 'planned obsolescence' hardly corresponds to the complex and multifaceted phenomenon of premature obsolescence as previously described.[13] The definition is *a priori* not general, as it focuses on material obsolescence, nor neutral, as it requires to prove the producer's intent. Judicial interpretation should bring some clarity on the provisions and confirm (or not) these findings. So far, two claims have been brought by the consumer association *Halte à l'Obsolescence Programmée* (HOP) on the basis of Article L. 441-2, one against printer producers[14] and another against Apple.[15] In its claims, HOP accuses the two companies of using techniques of premature obsolescence from different types (material and economic for Epson and technological, technical and stylistic obsolescence for Apple).

The Italian decisions and the Unfair Commercial Practices Directives

Without any explicit legislation banning premature obsolescence, the Italian Competition Authority recently condemned Apple and Samsung for practices falling within the definition of premature obsolescence.[16] After both companies had strongly encouraged and even forced their consumers to install new firmware updates on their smartphone, some of them witnessed a reduced functionality and usability of their device, without having received any (adequate) information on the characteristics, risks and solutions related to the updates. The decisions were based on Articles 20, 21, 22 and 24 of the Italian Consumer Code transposing the Unfair Commercial Practices Directive.

The UCPD prohibits and sanctions any unfair business-to-consumer commercial practice adopted within the EU internal market. The goal is to promote and maintain the smooth functioning of the EU market by protecting consumers and the other (fair) competitors. To determine the unfairness of a practice, the Directive establishes a three-tiered "cascade system" (Art. 5 UCPD). Firstly, the practice is deemed unfair if it corresponds to one of the practices mentioned in Annex I of the Directive, which are prohibited in all circumstances. If the practice is not included in this black list, the second step consists of checking whether it constitutes an aggressive or misleading practice as set out in Articles 6 to 9 of the UCPD. A practice that does not fail any of these previous tests can still be considered unfair through the definition given by Article 5(2) of the Directive, provided that it is contrary to the requirements of professional diligence and it materially distorts or is likely to materially distort the economic behaviour of the average consumer.

If the UCPD does not explicitly mention the concept of premature obsolescence, this instrument from 2005 does contribute to its

[10] The idea was initially suggested by the National Assembly, but finally rejected (Art. 19 II 1° Projet de loi n° 412).
[11] In this case from the 20's, light-bulb companies had decided to collude with the aim of deliberately making light bulbs more fragile and shorter-lasting (from 2500 hours to 1000 hours).
[12] See for ex. the preview of Epson's arguments (Le Monde, 2018).
[13] Cfr supra, section 2.
[14] Tribunal de grande instance de Nanterre 17 september 2017, Plainte au Procureur de la République, HOP v. X.
[15] Tribunal de grande instance de Paris 27 décembre 2017, Plainte au Procureur de la République, HOP v. Apple France.
[16] Autorita Garante della Concorrenza e del Mercato, 25 September 2018, Apple; Autorita Garante della Concorrenza e del Mercato, 25 September 2018, Samsung.

fight. [17] When limiting the lifetime of their products, traders adopt practices "*directly related to influencing consumers' transactional decisions in relation to products*" (Recital 7 UCPD). Traders implementing strategies of premature obsolescence are therefore exposed to lawsuits on the basis of the UCPD. Contrary to what the European Commission asserted about 'planned obsolescence' in its Guidance (SWD(2016) 163 final), some cases of premature obsolescence correspond to practices forbidden by Annex I. Besides cases of "*built-in obsolescence in industrial design*" (material obsolescence) (SWD(2016) 163 final), two practices that limit product lifetime are in the black list: (1) when the trader describes a product as 'gratis' (…), although the consumer has to pay anything other than the unavoidable cost of responding to the commercial practice and collecting or paying for delivery of the item (Pt 20 Annex I) and (2) when the trader makes persistent and unwanted solicitations (Pt 26 Annex I) (Michel, 2019). In addition to these, other practices of premature obsolescence could be qualified as aggressive or misleading. The Commission mentions this option in its Guidance but is far from covering all the possibilities enshrined in Articles 6 to 9, referring only to misleading omissions (SWD(2016) 163 final). Finally, some cases of premature obsolescence left aside by the two first tiers of the cascade could be considered as unfair if they match the definition contained in Article 5. In fact, the main purpose of this provision is to be used as a safety net for innovative practices emerging due to changing technologies and market developments (COM (2003) 356 final). Concerning the sanctions, the UCPD leaves room for discretion to Member States, requiring only effective, proportionate and dissuasive penalties (Art. 11 and 13 UCPD). Hence, compared to the French legislation, the UCPD seems to correspond more closely to the concept of premature obsolescence, covering many of its practices, though it still focuses on producers' behaviour.

Applying provisions transposing the UCPD, the Italian Competition Authority used the second step of the cascade to sanction Apple and Samsung. In these cases, consumers faced problems with their smartphones after the release of updates. The lack of information provided by Apple and Samsung was qualified as a misleading practice. The aggressive aspect of the practice stemmed from the fact that the companies (1) constantly invited consumer to install the updates without leaving them the possibility to refuse, (2) did not allow consumers to restore the original functionality of their smartphones afterwards, and (3) hindered repair and replacement of the smartphones and their batteries.

Despite the lack of explicit reference to 'premature obsolescence' or any of its variations by the Italian Authority,[18] the different types of the notion (material, economic, technological and psychological) can be clearly identified in both decisions (Michel, 2019). The Authority even acknowledges the necessity for companies to follow such commercial strategies.[19] According to it, "*the process of replacing old smartphones assumes an absolute and ever-increasing importance for sales volumes, given that increased competition, lower technological innovation and maturity of the market make it extremely difficult to acquire new consumers*".[20] In that regard, the Italian Authority identified how Apple and Samsung would gain benefits from accelerating the replacement of old devices. For Apple, the easy transferability of content between all Apple devices incites consumers facing a defective product to buy a later model of the same brand.[21] Samsung granted a 25% discount for the online purchase of a new product on the its website to customers who did not accept the repair conditions of a defective product. [22] The pecuniary administrative fines applied by the Italian Competition Authority reached 10 million € for Apple and 5 million € for Samsung. Both companies were also ordered to stop their unfair behaviours and communicate initiatives undertaken in that sense. Finally, they were obliged to publish the declaration related to the decisions on their website.

[17] As already highlighted by the European Commission in its Joint answer of 8 July 2011 on planned obsolescence given by Mr Potočnik, replying to written parliamentary questions E-001284/11 and E-002875/11.

[18] The wording 'planned obsolescence' (obsolescenza programmata) is only used by the defendants.

[19] See for ex. Autorita Garante della Concorrenza e del Mercato, 25 September 2018, Apple, paras 68 to 74; as well as Autorita Garante della Concorrenza e del Mercato, 25 September 2018, Samsung, para 84 to 87.

[20] Autorita Garante della Concorrenza e del Mercato, 25 September 2018, Apple, para 149.

[21] Autorita Garante della Concorrenza e del Mercato, 25 September 2018, Apple, para 67.

[22] Autorita Garante della Concorrenza e del Mercato, 25 September 2018, Samsung, para 87.

Conclusion

It is of utmost importance to fully grasp the notion of premature obsolescence in all its complexity, especially when adopting, modifying, applying and interpreting legislation. Without giving a precise definition of premature obsolescence, this paper strived to shed light on this too often misunderstood phenomenon. It is noteworthy that premature obsolescence finds its source and support in the behaviour of all economic actors and encompasses a wide array of practices.

Such a definition manifestly did not guide the actions of the French legislator when adopting the Energy Transition Act banning 'planned obsolescence'. Unless proved otherwise by the courts, the definition given by Article L. 441-2 of the French Consumer Code is deemed to focus on cases of material obsolescence and requires proof of the producer's intent. Admittedly, the French legislation on 'planned obsolescence' constitutes a significant step forward in the fight against the issue. On the one hand, it sanctions and stops strategies accelerating product obsolescence. In the long term, consumers' confidence on the market could be restored. On the other hand, and that is its most far-reaching effect, it raises awareness and responsibility among consumers and businesses about product lifetime. Consumers are encouraged to purchase and consume good quality products, while producers are deterred from developing strategies of premature obsolescence to rather devote their resources to the production of durable and sustainable goods. Those coercive and preventive effects would nevertheless be mitigated if Article L. 441-2 was too strictly interpreted, confining the scope of the provision to material obsolescence and/or placing a too heavy burden of proof on consumers. The legislation would then be deprived of its intended results, leaving suspected companies out of criminal offence.

By contrast, the Unfair Commercial Practices Directive tackles business-to-consumer practices of premature obsolescence in a more flexible manner, without any legal definition of the concept in its provisions. This approach allows covering a broader range of cases of premature obsolescence, as exemplified by the two decisions issued by the Italian Competition Authority against Apple and Samsung. Not only do these decisions underline the key role played by the UCPD to prevent and combat limited product lifetime, but they also raise doubts about the necessity of legally defining premature obsolescence like in France. The UCPD and its case-law on premature obsolescence does produce the same coercive and preventive effects, with similar, if not identical sanctions. Consequently, the French legislation overlaps with the UCPD (Ambroise-Castérot, 2016). The most illuminating example comes from the claims brought by HOP which alternatively invokes fraud (a transposition of the UCPD) by directly referring to all the arguments put forward for the claim on 'planned obsolescence'.[23] To avoid overlaps, some scholars interpret the new prohibition of 'planned obsolescence' as not covering cases where producers give false information on product lifetime, as they are already dealt with by rules on misleading commercial practices at the criminal level and by rules on hidden defects guarantee at the civil level (Martin, 2015). However, such reasoning does not seem convincing enough to overcome the incompatibilities between the two legal instruments (Michel, 2019). Furthermore, the French legislation adds an extra piece to the already complicated legal jigsaw, lowering the level of legal certainty for consumers and traders. Hence, It seems preferable to use existing EU legislation like the UCPD to cope with premature obsolescence rather than to adopt a new specific law on the topic. The UCPD covers more cases of premature obsolescence and is more responsive to change in case (additional) practices of premature obsolescence would be developed in the future. Such characteristics help to avoid that legislation becomes prematurely obsolete.

Although the flexibility and general nature of the UCPD must be preferred, some improvement and clarifications could be brought within the Directive to fight more effectively against limited product lifetime. For example, some blatant cases of premature obsolescence could be included in the black list. Product lifetime could also be explicitly mentioned as one of the main characteristics of the product in the information obligation enshrined in Article 6(1) of the UCPD. Hopefully, decisions and legislative measures will be taken in that sense at the EU and national level in the following years.

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[23] Tribunal de grande instance de Nanterre 17 September 2017, Plainte au Procureur de la République, HOP v. X, pp. 14-15; Tribunal de grande instance de Paris 27 December 2017, Plainte au Procureur de la République, HOP v. Apple France, pp. 6-7.

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PLATE
Product Lifetimes And The Environment

Constructing an Assessment Framework for Environmental and Economic Impacts of Product Price Increase Associated with Product Lifetime Extension Design Policy

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Keywords: Product Longer Use; Product Price Increase; Material Consumption; GHG Emissions, Product Sales.

Abstract: Policies and measures for achieving a sustainable society have been proposed and established, one of which is to encourage longer product use through product design improvements described in the EU action plan for circular economy by European Commission (2015). Such product design improvements for longer product use probably require high-quality materials and retention and management of repair parts. These will lead to increase in production and management costs. Accordingly, the product design improvements for longer product use will also lead to product price increase which can be an incentive for longer product use. Therefore, analyzing impacts of product price increases on environment and economy in advance is beneficial to discuss achievements of a sustainable society. This study proposes an analytical framework for environmental and economic impacts of product price increases with a dynamic discrete choice model. Focusing on air conditioners in Japan as a case study, this study estimates impacts of the product price increase on product replacements of air conditioners. Based on the results, this study analyzed environmental (material consumptions and GHG emissions) and economic (monetary sales of air conditioners) impacts of the product price increase, and a trade-off among effects of the product price increase on the three factors are clarified.

Introduction

Efforts are underway to transform society into one that is more sustainable, characterized by a circular economy and consistent with the UN's Sustainable Development Goals (SDGs). Accordingly, substantial research is being conducted on developing production systems to aid in that transformation (Bocken et al., 2016; Matsumoto et al., 2017; Gómez et al., 2018; Kirchherr et al., 2018). It is crucial to observe how consumption behavior changes in places where the transition to a sustainable society is underway in earnest, and consequently how it affects the environment and the economy.

In this study, we focus on encouraging longer use and extending the lifetime of products by improving product design that are more durable and easier to repair. Encouraging long-term use by creating product designs that result in longer-lasting products has been noted in the action plan for a circular economy put forth by the European Commission (2015) as one of the key issues in achieving a circular economy. However, developing product designs that encourage long-term use will require a major shift from conventional designs. Then, a serious commitment to the research and development, and high-quality materials and components will be required to achieve the shift. For these reasons, products designed to be longer lasting are deemed to involve higher production costs than conventional products. Furthermore, in order for products designed for long-lasting use to be widely circulated in the market, a system supporting long-term use by consumers, including extensive product warranties and long-term retention and management of repair parts, will also have to be made more substantial. The increase in management costs from such changes will likely make the cost of products rise as well. In view of the above, products designed to be longer lasting are nearly certain to require higher costs than conventional products.

On the other hand, wider use of products with long-lasting designs will lead to lower demand for product replacement as the consumer product replacement cycles become longer. Considering the above possible situations, maintaining production while keeping the current prices of products that are designed to be longer lasting will be economically difficult for companies. Therefore, efforts by concerned companies and industries to improve product design for longer-lasting products need to be acknowledged and included in the product price as added value.

Thus, recognizing the added functional value given to traditional products by concerned industries dedicated to improving product design for long-term use and sufficiently reflecting the value in the product price (i.e., by adding to the price) are important from the perspective of the environment as well as the economic sustainability of the industries and companies supporting the sustainable society. Such product price increase will suppress purchases of product replacements (i.e., will encourage longer use of the product) and further raise awareness of their impact on the environment and the economy, which will likely be extremely important when discussing policies to encourage long-term use of products and realizing a sustainable society.

Based on the research background discussed above, we provide a framework for quantitatively analyzing the impact of such price increases on the economy and environment. Focusing on household air conditioners in Japan as an illustrative case study, we quantitatively show the effects of higher household air conditioner (AC) prices in Japan on metal resource consumption and GHG emissions derived from ACs, as well as on the sales of ACs. We also show the direction of policies regarding long-lasting product design as it relates to comprehensive sustainability that includes both environmental and economic aspects.

Methodology and Data

Methodology

We first estimate a dynamic discrete choice model (DDCM) for ACs in Japan in order to quantitatively analyze the relationship between rising product prices and consumer replacement choices. In the AC replacement decision in this study, we assume that the consumer chooses either to "keep (not replace)" the originally-owned AC produced and sold in year i or "replace" the unit with new one considering annual electricity consumption of the originally-owned AC for year t, $e_{i,t}$, annual electricity consumption of a newly manufactured and sold AC with electricity consumption for year t, e_t^{new}, and a price of the new unit for year t, p_t^{ac}. The consumer's choice is represented by a binary variable $a_{i,t}$, such that $a_{i,t}=0$ if the consumer chooses to "keep (not replace)" the unit in year t, and $a_{i,t}=1$ if the consumer chooses to "replace" the unit with new one. The respective utilities associated with the decision to "keep (not replace)" or "replace" a unit in year t can be expressed by Equation (1):

$$u_{i,t}=u_{i,t}\left(e_t^{new},p_t^{ac},a_{i,t}\right)=\begin{cases}\alpha_0+\alpha_1\left(e_{i,t}-e_t^{new}\right)p_t^e & \text{if } a_{i,t}=0\\ \alpha_2 p_t^{ac} & \text{if } a_{i,t}=1\end{cases} \quad (1)$$

where α_0, α_1, and α_2 denote the dynamic discrete choice model parameters, and p_t^e denotes the price per unit of electricity consumption in year t.

Following the previous studies (Rust, 1987; Rapson 2014), the probability that the consumer who owns the AC produced in year i chooses in year t to "replace" the unit and to "keep (not replace)" the unit, $P\left(a_{i,t}=1\right)$ and $P\left(a_{i,t}=0\right)$, can be expressed in the form of the logit model probability shown in Equation (2):

$$\begin{cases}P\left(a_{i,t}=1\right)=\dfrac{\exp\left\{u_{i,t}\left(e_t^{new},p_t^{ac},a_{i,t}=1\right)+\beta EV\left(e_t^{new},p_t^{ac},a_{i,t}=1\right)\right\}}{\sum_{\tilde{a}_{i,t}=0,1}\exp\left\{u_{i,t}\left(e_t^{new},p_t^{ac},\tilde{a}_{i,t}\right)+\beta EV\left(e_t^{new},p_t^{ac},\tilde{a}_{i,t}\right)\right\}}\\ P\left(a_{i,t}=0\right)=1-P\left(a_{i,t}=1\right)\end{cases} \quad (2)$$

where β is a discount factor and EV is the expected value function in DDCM. For the case study, we use the DDCM parameters for ACs estimated by Nishijima et al. (2019a, b). The estimated parameters are for air conditioners produced during a period from 1995 to 1999 and disposed during a period from 2005 to 2013. Therefore, it should be noted that the results in this case study are also based on these ACs.

Using the parameters, we estimate the changes in metal resource consumption, GHG emissions and sales of ACs when the product price increases as the circular economy progresses. Assuming that the percentage rise in the product price from the case where there is no rise in product prices (hereinafter referred to as the baseline), is $(\Delta p^{ac} \times 100)\%$, the probability of the consumer owning the AC produced in year i choosing in year t to "replace" the unit and to "keep (not replace)" the unit when product prices have increased, $P(a_{i,t}=1|\Delta p^{ac})$ and $P(a_{i,t}=0|\Delta p^{ac})$, can be expressed by Equation (3):

$$\begin{cases} P(a_{i,t}=1|\Delta p^{ac}) = \dfrac{\exp\left\{u_{i,t}\left(e_t^{new},(1+\Delta p^{ac})p_t^{ac},a_{i,t}=1\right)+\beta EV\left(e_t^{new},(1+\Delta p^{ac})p_t^{ac},a_{i,t}=1\right)\right\}}{\sum_{\tilde{a}_{i,t}=0,1}\exp\left\{u_{i,t}\left(e_t^{new},(1+\Delta p^{ac})p_t^{ac},\tilde{a}_{i,t}\right)+\beta EV\left(e_t^{new},(1+\Delta p^{ac})p_t^{ac},\tilde{a}_{i,t}\right)\right\}} \\ P(a_{i,t}=0|\Delta p^{ac}) = 1-P(a_{i,t}=1|\Delta p^{ac}) \end{cases} \quad (3)$$

When product prices have increased by $(\Delta p^{ac} \times 100)\%$, the probability that the AC produced in year i is replaced in year t, $\tilde{P}_{i,t}(\Delta p^{ac})$ — with the "keep" option (i.e., $P(a_{i,l}=0|\Delta p^{ac})$) chosen from year $i+1$ until $t-1$ and the "replace" option (i.e., $P(a_{i,l}=1|\Delta p^{ac})$) chosen in year t — can be expressed as a joint probability by Equation (4):

$$\tilde{P}_{i,t}(\Delta p^{ac}) = \prod_{l=i+1}^{t-1}\left\{P(a_{i,l}=0|\Delta p^{ac})\right\} \times P(a_{i,t}=1|\Delta p^{ac}) \quad (4)$$

If the number of unit sales of ACs produced in year i is N_i, the number of ACs produced in year i and replaced in year t, $R_{i,t}(\Delta p^{ac})$, can be expressed as $R_{i,t}(\Delta p^{ac}) = N_i \times \tilde{P}_{i,t}(\Delta p^{ac})$.

When the price of ACs produced have increases by $(\Delta p^{ac} \times 100)\%$, consumption of metal resource j in year t, $M_{t,j}(\Delta p^{ac})$, can be expressed as:

$$M_{t,j}(\Delta p^{ac}) = \sum_i R_{i,t}(\Delta p^{ac}) \times MI_j \quad (5)$$

where MI_j indicates the content of metal resource j included per manufactured AC unit. As a case study, we focus on consumption of iron, copper and aluminum for production of ACs.

As to the impacts of the product price increase on GHG emissions, we consider GHG emissions derived from production and use of ACs. GHG emissions related to the production and use of ACs, $G_t^{prod}(\Delta p^{ac})$ and $G_t^{use}(\Delta p^{ac})$, are estimated using Equations (6) and (7):

$$G_t^{prod}(\Delta p^{ac}) = \sum_i R_{i,t}(\Delta p^{ac}) \times g^{prod} \quad (6)$$

$$G_t^{use}(\Delta p^{ac}) = \left[\underbrace{\sum_i \left\{\left(N_i - \sum_{s=i+1}^{t} R_{i,s}(\Delta p^{ac})\right) \times e_{i,t}\right\}}_{\substack{\text{Electricity consumption} \\ \text{using } \textit{owned} \text{ air conditioners}}} + \underbrace{\sum_i \sum_{v=i+1}^{t}\left\{R_{i,v}(\Delta p^{ac}) \times e_v^{new}\right\}}_{\substack{\text{Electricity consumption} \\ \text{using } \textit{replaced} \text{ air conditioners}}}\right] \times g^{use} \quad (7)$$

where g^{prod} denotes the embodied GHG emission coefficient per AC produced, and g^{use} denotes the embodied GHG emission coefficient per unit of electricity consumption.

When product prices increase by $(\Delta p^{ac} \times 100)\%$, the amount of sales of ACs due to replacement demand in year t, $sales_t(\Delta p^{ac})$, can be calculated by the following equation:

$$sales_t(\Delta p^{ac}) = \sum_i R_{i,t}(\Delta p^{ac}) \times (1+\Delta p^{ac})p_t^{ac} \quad (8)$$

Comparing values of each factor (metal consumptions, GHG emissions, and product sales) when the product prices increase with those in the baseline (i.e. product prices do not increase, $\Delta p^{ac} = 0$), we estimate the impacts of product price increase on those factors.

Data

We used the "Energy-saving performance catalog" by the Agency for Natural Resources and Energy of Japan (Agency for Natural Resources and Energy of Japan, 2010, through 2014) to obtain values of annual electricity consumption of ACs produced between 1995 and 2013.

As to the AC unit price, we used values of average AC unit price for each year obtained from Japan Refrigeration and Air Conditioning Industry Association (JRAIA).

For the number of sold household air conditioners, we used data of the number of domestic shipments for the targeted production year (i.e. 1995, 1996,1997,1998, and 1999) by Japan Refrigeration and Air Conditioning Industry Association (JRAIA).

For the embodied GHG emission coefficient, we used embodied GHG emission coefficients obtained from the "Embodied energy and emission intensity data for Japan using input–output tables (3EID)" (Nansai, 2018).

For the content of metal resource included per manufactured AC unit, we calculated average amounts of iron, copper and aluminum included per a unit of air conditioner in Japan by the Annual report of home appliance recycling in 2017 fiscal year by the Association for Electric Home Appliances (AEHA) in Japan (AEHA, 2018).

Results

Figure 1 shows the changes in consumption of each metal resource for production of ACs (left graph) and GHG emissions (relative to the baseline case) associated with the manufacture and use of ACs (right graph) when product price increases due to improving product design to encourage and facilitate the longer-lasting use of products. In terms of the metal resource consumption, the increase in product price contributes to a reduction of cumulative metal resource consumption associated with AC replacement over the case study's target period of 2005-2013 in all of the product price increase cases. These decreases are due to the fact that product price increases raise the cost that consumers face when choosing to "replace," thereby suppressing the replacement of older units with new products.

Looking at the graph on the right side of Figure 1, the results show that the GHG emissions increases as the product price increases until a case when the product price increases by 10%. However, the emissions start to reduce from a case when the product price increases by 15% and the emissions becomes lower than those in the baseline when the product price increases by 30%. It is noted that most of life cycle GHG emissions of ACs are derived from use phase (Nakamura and Kondo, 2006) and longer use of ACs results in the longer use of older, less energy efficient ACs. Therefore, the longer use due to the product price increase is basically considered to increase the life cycle GHG emissions. A reason why we obtained the above GHG emission results is come from the study period in this case study (i.e. 2005-2013). Average product lifetime of ACs in Japan is estimated as 12.6 years (Ministry of the Environment, Japan, 2011), while the study period in this study is only 9 years that are shorter than the average product lifetime. It means that the ratio of GHG emission at use phase on the life cycle emissions of ACs becomes smaller than usual and the GHG emission increase effects due to longer use of old less energy efficient ACs are relatively limited. For more accurate analysis, we need to collect data for a longer period related with the estimation of the dynamic discrete choice model and this point is one limitation of this study.

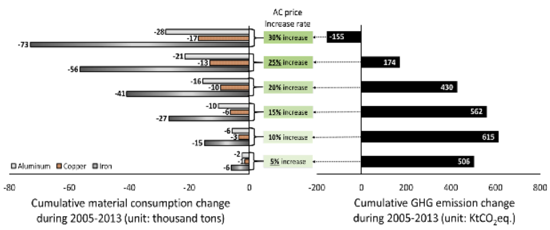

Figure 1. Changes in cumulative material consumption and GHG emissions during 2005-2013 for cases of product price increase of AC.

Figure 2 shows the change in cumulative sales due to the replacement of ACs in the years covered in the study (2005-2013) when of AC prices increase above the baseline. The AC sales shown in the figure are the result of calculations after adjusting the product price of ACs for each year based on the CPI of ACs for 2015. From Figure 4, it can be seen that the sales associated with the replacement of ACs covered in this case study (ACs produced from 1995 to 1999) decreased as product price increased. This is conceivably because the decrease in total revenue due to the decrease in the number of ACs replaced by consumers associated with the increase in product price is larger than the increase in revenue resulting from the higher per AC unit price.

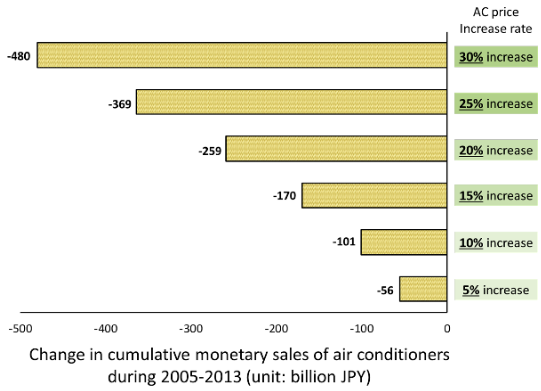

Figure 2. Decrease in cumulative air conditioner sales during 2005-2013 due to AC price increase in this case study (unit: billion JPY).

Discussion and Conclusion

From the results of this case study, we could find that the product price increase contributed to reducing the material consumption during the study period. In this sense, adding values of product design improvements for longer product use to product prices can reinforce longer product use and value retention of the materials in our society. As to GHG emissions, whether effects of increase in AC prices on the emissions is positive or negative depends on the amount of the price increase rates. On the other hand, this case study also showed that promoting longer product use by product price increases along with product design improvements for longer use cannot keep the same level of product sales of ACs. This indicates that if a current business system of Japanese AC industry remains, value addition of the product design improvements for longer use to product prices cannot support economic competitiveness of Japanese AC industry. Since the increase in product prices shown here assumes that the product price increases are associated with improvement in product design for long-lasting use, the increase in sales revenue per AC unit produced by product price increases can be considered money to support the producer's investment in materials, parts and technological development for long-lasting product design. However, to accomplish the task mentioned above, it can be argued that the increase in sales revenue per unit of product realized from an increase in the product price should also be utilized to overcome the sales reduction. For example, Japanese AC companies would better use the increase in sales revenue per unit to improve the profit rate of the product by such measures as increasing production efficiency, or to develop their business models including other businesses than AC production such as repair or warranty services. Although finding a best measure for overcoming the sales reduction for the AC industry requires more detailed analyses, Japanese AC industry may need to consider strategies to mitigate the possible sales reduction on transition toward a more circular economy.

In discussing how to transition to a sustainable society, it is important to discuss these systems and policies in terms of the full range of changes that may take place if the measures are fully implemented. In this regard, focusing on encouraging longer use and extending the lifetime of products by improving product design in the circular economy as a policy to move us toward a sustainable society, we showed the environmental and economic impacts of the product price increase along with the product design improvements. From the results of this case study, we can find a trade-off among the factors and such information will be beneficial for stakeholders to go toward a sustainable society from a comprehensive perspective.

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A Product Lifetime Model for Assessing the Effect of Product Lifetime Extension Behavior by Different Consumer Segments

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Keywords: Consumer Durables; Lifetime Modelling; Lifetime Extension; Weibull Distribution; Estimation.

Abstract: Product lifetime extension would contribute to establishing a circular economy by reducing the environmental impacts of mass consumption. This study developed a product lifetime model that can explicitly deal with the proportion and the longer-use behaviors of different consumer segments. The developed model expressed the product lifetime distribution as the composite of two distribution functions for longer-use promoters and normal-use consumers. The model explicitly deals with two parameters of longer-use actions: increasing the proportion of longer-use promoters and prolonging product lifetimes. A scenario analysis with the developed model showed that if the proportion of longer-use promoters, who uses their products 1.4 times longer than normal consumers, increases to 20%, the domestic demand for new product and the EoL generation will decrease by approximately 5%–10%. The results demonstrated that the model can quantitatively analyze the effects on the domestic demand for new products and the EoL products generation by the tow parameters for longer-use actions. By incorporating this model into a material stock and flow analysis model, it will be possible to assess the effects of promoting longer-use of durable goods on natural resource consumption, greenhouse gas emissions, reduction of final disposal of wastes, etc.

Introduction

Product lifetime extension would contribute to establishing a circular economy and reducing the environmental impacts of mass consumption. Past studies often modelled the actual product lifetime distribution by using a certain statistical function. However, to quantitatively evaluate the impacts of the promotion of longer-use of products on the amount of natural resources consumed, greenhouse gas emissions, and final disposal of waste, evaluation of such impacts will require explicitly incorporating progress in increasing longer-use and reuse of products in the model.

The purpose of this study was to develop a product lifetime model that can explicitly deal with different behaviors of different consumer segments by expressing the product lifetime distribution as a composite distribution for two different consumer segments, longer-use promoters and normal-use consumers. In addition, the developed model was used to quantify demand for new products and analyze the impact on reduction of EoL products under scenarios in which longer-use of consumer durable goods was promoted.

Materials and methods

Model

Product lifetime distribution has been modelled by using a single statistical distribution function such as the Weibull distribution function (e.g. Oguchi et al., 2010; Oguchi and Fuse, 2016). Product lifetimes in a circular economy, however, would have different distribution shapes according to the consumer segments with different behavior of prolonged use of products. In this case, product lifetimes would be expressed by a bimodal or multimodal distribution.

When the observed automobile survival rate distribution based on statistical data was approximated by a single distribution function, observed values were found to exceed approximated values for high vehicle ages. This gap is thought to be the result of longer use due to maintenance and reuse. Based on the assumption that the survival rate distribution for products can be represented by compositing the survival rate distributions for the normal-use and longer-use consumer groups, we estimated the distribution for automobiles as an example.

Expressing the survival rate distribution for all automobiles (survival rate for products that have been used for *i* years at the end of year *t*) as in equation (1), we estimated the scale and the shape parameters of the survival rate distributions for the normal-use and longer-use groups, which were expressed by using the Weibull distribution functions in as equations (2) and (3), respectively.

$$s_t(i) = (1 - Y) \cdot s_{t,N}(i) + Y \cdot s_{t,L}(i) \qquad (1)$$

$$s_{t,N\ or\ L}(i) = \exp\left\{- \left(\frac{i}{a_{N\ or\ L}}\right) b_{N\ or\ L}\right\} \qquad (2)$$

$$y_{av,N\ or\ L} = a_{N\ or\ L} \times \Gamma\left(1 + \frac{1}{b_{N\ or\ L}}\right) \qquad (3)$$

Here, $s_t(i)$ is the survival rate for products that have been used for *i* years at the end of year *t*, *Y* is the proportion of longer-use consumers in whole total consumers, *a* and *b* are the scale and shape parameters of the Weibull distribution function, Γ is the gamma function, subscript *N* and *L* indicate the normal-use and longer-use consumer groups.
The observed values for survival rate distribution are calculated by dividing the number of surviving automobiles at the end of the year by the number of newly registered automobiles for the corresponding fiscal year. The data was obtained from the Automobile Inspection & Registration Association (AIRIA, n.d.). The estimation was conducted for passenger cars (excluding subcompact cars) and cargo trucks during the period from year 1988 to 2009.

Scenario analysis

We conducted scenario analyses which estimated the change in the demand of new products when longer-use of products was promoted. The analyses were conducted for six products: passenger cars, air conditioners, refrigerators, washing machines, televisions and mobile phones (including smartphones). Specifically, we analysed impact on reduced domestic demand units when the proportion of the longer-use group increased linearly to 20% between 2015 and 2030.
The details of the analytical method outlined in Figure 1 are described below.

1) The proportion of the longer-use consumer group, *Y* and the average lifetimes for the normal-use and longer-use consumer groups, $y_{av,N}$ and $y_{av,L}$ were set.
2) The lifetime distribution and the number of EoL products in the year *t*, E_t, were calculated from the number of sales in the past S_{t-i} (equation (a) in Figure 1).
3) The number of sales in the next year was calculated from the calculated E_t and the change in the number of in-use products, N_{t+1}-N_t (equation (b) in Figure 1).
4) The number of sales from 2015 to 2030 was calculated by repeating steps 2) and 3).

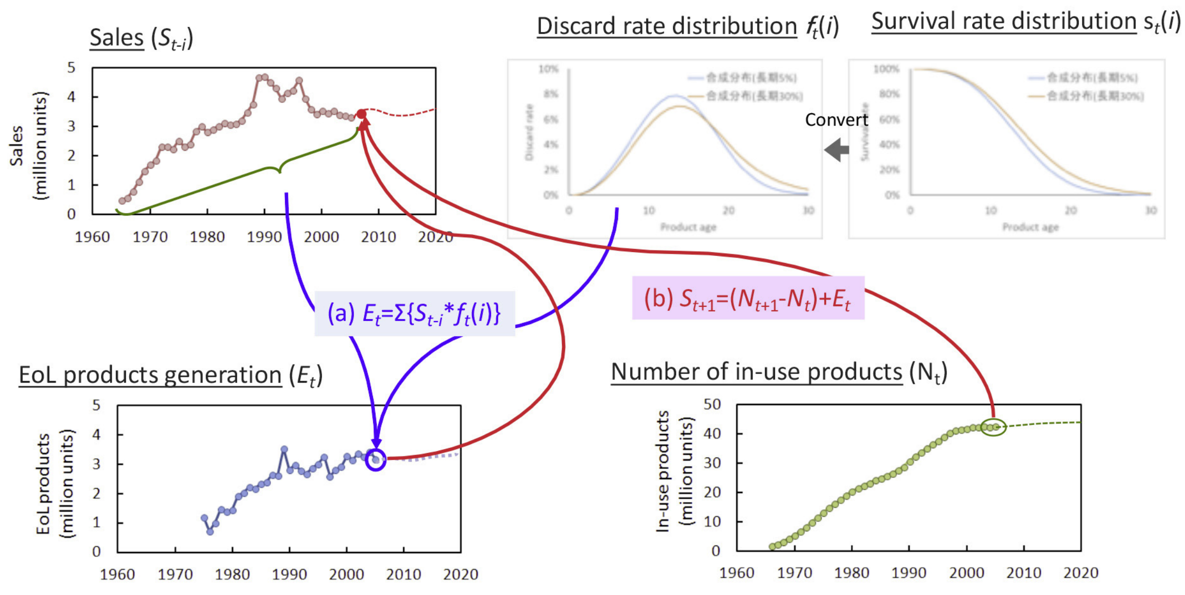


Figure 1. Outline of the scenario analysis for the case in which longer-use behaviors are promoted.

Since the penetration level of products would not be affected by the longer-use activities, the number of in-use products was set according to the trend of statistical data (AIRIA, n.d.; CAO, n.d.). Sales data was obtained from statistics by the related associations (AIRIA, n.d.; JEITA, 2016; JEMA, n.d.; JRAIA, n.d.). The proportion of the longer-use consumer group was assumed to increase linearly to 20% from 2015 to 2030; the initial proportion in 2015 was set to 5% for passenger cars based on the estimation results of the above-mentioned analysis, and the proportion for electrical and electronic equipment was set to 0%.

The average lifetime for the normal-use and longer-use consumer groups were set as Table 1. The average lifetimes of passenger cars were set based on the above-mentioned estimation. The average lifetimes of electrical and electronic equipment for the normal-use consumer group was set to the average lifetimes estimated when the survival rate distribution for 2015 was approximated by a single distribution function. The average lifetime for the longer-use consumer group was set at 1.4 times the value for the normal-use consumer group. This assumption was based on the following facts.

- In the case of passenger cars, the survival rate corresponding to the average lifetime for the longer-use consumer group was around 15%;
- In the case of electrical and electronic equipment, the product age corresponding to the 15% survival rate was 1.35-1.45 times greater than the average lifetime in the whole lifetime distribution.

Product	Average lifetime (years)	
	Normal-use	Longer-use
Passenger cars	13.0	18.0
Air conditioners	16.5	23.0
Refrigerators	14.0	20.0
Washing machines	11.5	16.0
Televisions	11.0	15.5
Mobile phones	3.5	5.0

Table 1. The average lifetimes used in the scenario analysis.

Results and discussion

Applicability of the proposed model

Figure 2 shows an example of the approximation results of the survival rate distribution of automobiles by a single distribution and the composite of distributions for the normal-use and longer-use consumer groups. In the case of the single-distribution approximation, a gap was observed for product ages greater than 13 years. The composite-distribution approximation showed a good agreement with the observed survival rate, including for product ages greater than 13 years. These results demonstrate the applicability of the model proposed by this study.

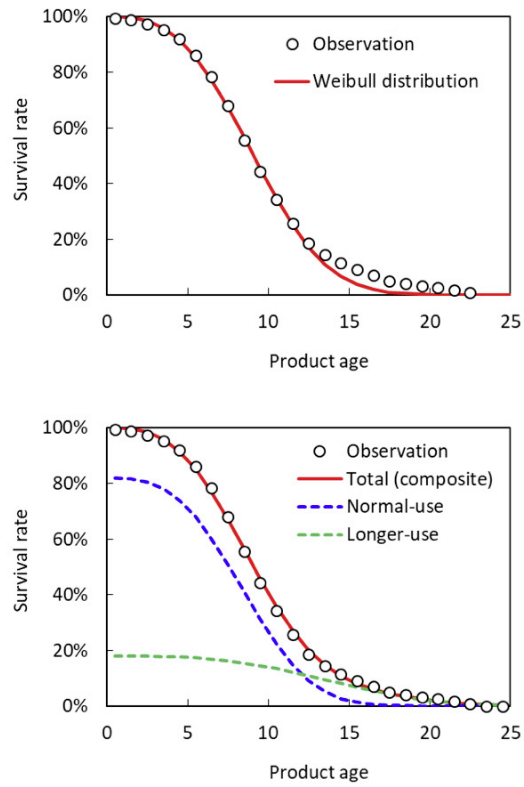
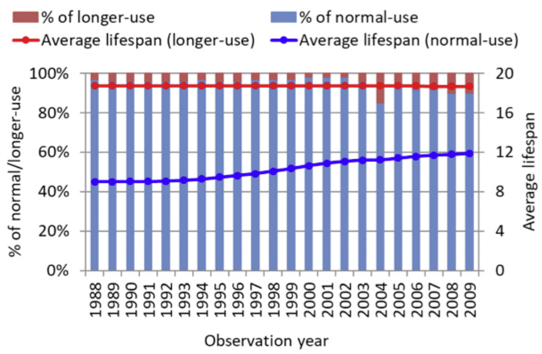


Figure 2. Approximation of survival rate by using the Weibull distribution function (a case of freight vehicles at the end of 1995, upper: approximation using a single distribution, lower: approximation using the proposed composite distribution for normal-use and longer-use consumer groups).

Figure 3 shows the estimated proportions (Y) and the average lifetimes (y_{av}) for normal-use and long-use consumer groups. The proportion of longer-use consumer group was relatively high for freight vehicles (13%–31%, 20% on average), whereas that for passenger cars was relatively low (2%–15%, 5% on average). This suggests the possibility that maintenance and other actions to achieve longer-use were being carried out for freight vehicles. These results indicate that functionality or economic rationality—i.e. the idea that even an old vehicle is useful "as long it moves"— may be more important in the case of freight vehicles used for business. The results also suggest that the proportion of consumers taking actions to achieve longer-use is small for passenger cars and indicate that there would be room for increasing the proportion of longer-use. The average lifetime has been increasing for both passenger cars and freight vehicles, which suggests that the durability and maintainability/reparability has been improved.



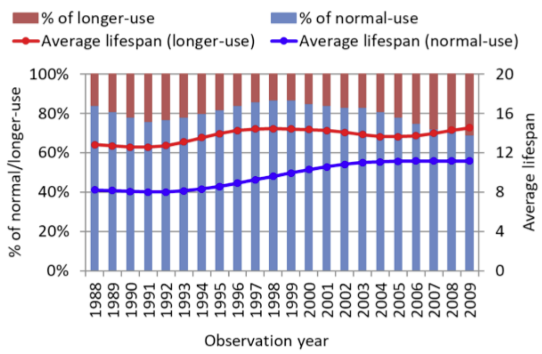


Figure 3. Proportions and estimated average lifetimes for normal-use and longer-use consumer groupgs (upper: passenger cars, lower: freight vehicles).

Scenario analysis

Figure 4 shows the results of the scenario analysis. The figure shows the calculated domestic demand for new products for the case in which the proportion of the longer-use consumer group increases linearly from an initial value in 2015 to 20% in 2030 (case 1) and the case in which the proportion of the longer-use consumer group does not change from the initial level in 2015 (case BaU). The results show that the demand for new products decreases with increasing proportion of the longer-use consumer group.

The difference (reduction) in the calculated domestic demand of for products and EoL products generation from 2015 to 2030 between the two cases was 5%–10% on average. This result indicates that, if the proportion of longer-use promoters, who uses their products 1.4 times longer than normal consumers, increases to 20%, the domestic demand for new product and the EoL generation will decrease by approximately 5%–10%.

Conclusions

The developed model explicitly deals with two parameters of longer-use actions: increasing the proportion of longer-use promoters and prolonging product lifetimes, separately. This study demonstrated that the model can quantitatively analyze the effects on the domestic demand for new products and the EoL products generation by the tow parameters for longer-use actions. By incorporating this model into a material stock and flow analysis model, it will be possible to assess the effects of promoting longer-use of durable goods on natural resource consumption, greenhouse gas emissions, reduction of final disposal of wastes, etc.

The "longer-use" covered by the developed model only includes the longer-use on a user level, i.e. just using products longer as well as extending the use time of products by repair or reuse. Further research is needed to develop a component-level model, which enables to analyze the effect of lifetime extension of parts/components by remanufacturing, etc. The effects of sharing and lease business could also be considered. These activities entail change in not only the product lifetime but also the number of in-use products. The developed model can also be applied such activities by changing the settings for the number of in-use products in scenario analysis which we conducted in this study.

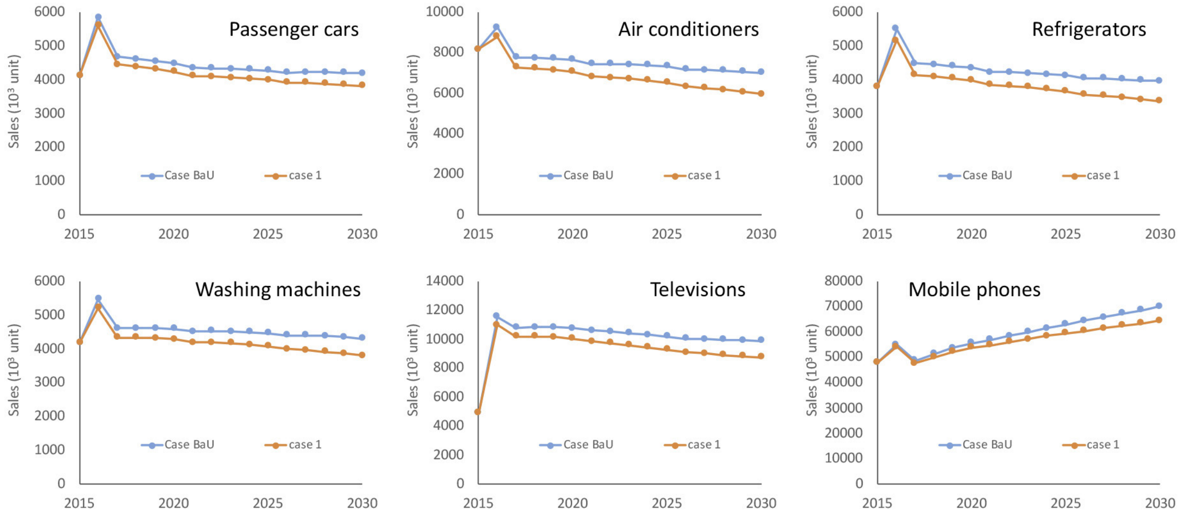


Figure 4. Change in domestic demand for new products due to the promotion of longer-use action (the business-as-usual case in which the proportion of the longer-use group does not change from 2015 (case BaU) and case in which the proportion increases linearly to 20% (case 1).

Acknowledgments
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Centers for Urban Re-manufacture: Lessons from the CURE Pathfinder Project

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Keywords: Reuse; Remanufacturing; Secondary Material; Circular Economy; Urban Resources.

Abstract: The reuse and remanufacturing of materials in urban areas is an important step towards closing local material cycles. Despite high potential, the use of these materials is currently hampered by various reasons, such as lack of coordination or insufficient exchange between the actors. There is no central point of contact at city level for bundling competencies in this field. The importance and possibility of establishing a central Center for Urban Re-manufacture (CURE) for sorting, storing and preparing for reuse and re-manufacturing of these materials was investigated in Gothenburg and Berlin, in a EIT Climate-KIC Pathfinder project. This article summarizes the findings and lessons of that project, which include an initiative review, market analyses, and participative workshops in both cities. The studies show that Gothenburg had a strong local authority engagement in the topic, while Berlin counted with several independent organizations already providing reuse services. The project managed to generate interest in this topic among local actors in both cities, which will hopefully result in the future establishment of some type of CURE in these locations. The article concludes that a combination of bottom-up and top-down engagement is needed to provide material recovery services at a city scale, involving stakeholders from across the existing material value chains.

Introduction

A Center for Urban Re-manufacture (CURE) is a place for experimentation, where locally available secondary materials are sorted, stored, and prepared to be reused and/or re-manufactured. These centers intend to increase the amount of secondary material used, helping redirect waste volumes into value creation activities. CUREs do not yet exist as such; they are merely a recurrent idea among actors engaged in reuse and re-manufacturing practices. Being a common idea, it has been named and described in many ways: Zero-Waste centers (ZWIA, 2013), urban resource centers (Partnership on Circular Economy, 2019), maker spaces, and repair cafés being a few examples.

Some of these places have a particular focus on making or tinkering, while others focus more on recovering materials locally through reuse practices. Activities such as repair cafes and maker spaces directly address product life extension at the hands of the user. The maker movement has in some ways lifted the discussion around the right to repair products, which has seen increased attention regarding mainly electronic products (Wiens, 2015).

The locations that focus on material recovery are more akin to warehouses than workshops. Second hand shops of all kinds help products and materials find a second lifetime, extending their use phase by relocating items to new users. Even though second hand has a long history and continue to grow, they seem not to affect the production of new items significantly. Rather, they represent a "positive" way for users to get rid of their unnecessary items, not hindering or providing a reflection about over-consumption (Bekin, Carrigan, & Szmigin, 2007).

Few places exist, where the focus of recovering material is directly associated to making and new production. Examples of companies that engage in upcycling are abundant (DeMano, n.d.; Etsy, n.d.; Freitag, n.d.; SchubLaden, n.d.), but not so open spaces where several actors could engage in such activities. That is what makes the CURE idea slightly different. The CURE concept was further developed during an EIT Climate-KIC funded Pathfinder project that ran from August to December 2018. The Pathfinder project aimed to explore the possibility of establishing CUREs in different cities, estimate the potential benefit these centers may generate and engage local consortia to implement these centers in targeted locations. Additionally, a study of initiatives that already use secondary material and/or have open workshop spaces was done to provide inspiration and some understanding of the existing tacit knowledge in this area. The CURE concept was described in the project by four main composing aspects, as shown in Figure 1.

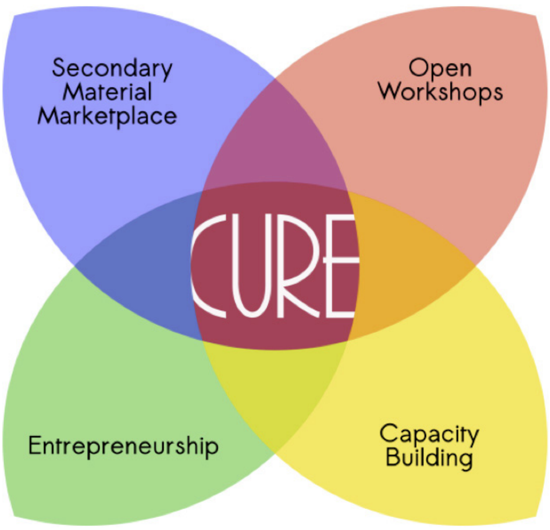

Figure 1. The four main composing aspects of a CURE.

The Pathfinder project was done in collaboration between Technische Universität Berlin, Chalmers University of Technology, the Sustainable Waste and Water office of the Municipality of Gothenburg, and the Berlin-based business Material Mafia. Therefore, the targeted locations were Berlin and Gothenburg.

This article collects the results obtained from the Pathfinder project, divided into the three following sections: initiative review, market analyses, and participative workshops.

Initiative Review

The initiative review compared fifteen existing initiatives that provide access to secondary materials and/or open workshop spaces, resulting in an overview of how these initiatives are operated, financed, what types of activities they perform, and what sort of tools and spaces they use. Data about the initiatives was collected through their official webpages and by semi-structured interviews. More information about the review results can be found in Ordonez et al., 2019.

Thirteen of the fifteen initiatives analyzed actively engage in facilitating material reuse. Three ways in which initiatives enable re-circulation were identified:

- Direct reuse by other actors (e.g. exchanging items).
- Offering materials for other actors to re-manufacture (e.g. doors made into tables by others).
- Use secondary material in their own product development (e.g. re-manufactured furniture).

The initiatives that use secondary material to do their own product development typically work more like design firms or manufacturing spaces, than material marketplaces. The materials that the initiatives focus on vary and include household items, clothing, and bikes, among other materials. The control on circulated materials is however low, as only six of the initiatives keep an inventory system, and these systems in some cases have rather vague categorizations.

Of the fifteen initiatives analyzed, six are not dependent on external funding to operate. The main strategies for financial independence identified were: (1) Selling materials and/or products, (2) membership fees, and (3) organizing workshops and courses. Among the nine initiatives that depend on external funding, four are run or supported by municipalities, while the others are dependent on sponsorship from industry, research initiatives or non-profit organizations. It is important to notice that these initiatives vary greatly with regards to what they need to finance, since there are large variations in rent, staffing, opening hours, etc.

Overall, the study illustrates how heterogeneous these initiatives are. While this is, of course, dependent on how they were sampled, they still differ greatly, particularly in how they operate, what services they provide and how they are financed. What the initiatives have in common besides recirculating material is that their drive to do so is mainly environmental sustainability, and not 'doing business'. As described by many of the reviewed initiatives, there is no lack of public interest and the enthusiasm and driving spirit is high among the people who work in these initiatives. However, how all this is optimally orchestrated is still relatively unknown, with most initiatives learning as they go. Additionally, they do not really learn from each other. There are no 'manuals' or other sorts of documentation available on how to successfully run an operation of this kind. Many of the initiatives often get asked to answer some questions about their activities, which results repetitive and time consuming in the long run.

Market Analysis

Two market analyses were done to estimate the potential benefit of establishing CUREs in Berlin and Gothenburg. These analyses provide a brief overview of: local initiatives that support material recovery, current material streams, and local industrial characteristics, resulting in location-specific recommendations for potential CUREs establishment. More information about both market analyses can be found in the project reports (Decker et al., 2018; Rexfelt et al., 2018).

Gothenburg Market Analysis

One of the most important aspects in Gothenburg is that there is a political will to increase recycling, but also other types of material reuse. While there are private and industrial reuse and remanufacture initiatives, it is clear that municipal initiatives are the biggest and most significant in this location. Another aspect of Gothenburg (and Sweden as a whole) is the public's general interest in sustainability and environmental issues. Looking at the number of sharing initiatives and second-hand shops in Gothenburg, it is clear that the public is interested in more sustainable alternatives to consumption. However, while a number of designers/firms working with material reuse were identified, they are only a small part of the market. Large companies in the region dominate the design community, and today have no connection to the initiatives reviewed. In addition, large companies employ most designers in this region, and that may act as a barrier for designers to make a business out of urban remanufacturing. This could be tackled in different ways. First, one could strive towards engaging large companies in the region in CURE-related activities, through sponsorships or other means. Another way could be to make use of the fact that the city of Gothenburg hosts a number of renowned Design education programs. If designing with secondary material played a larger role in these programs, this knowledge would then diffuse into the large companies when the graduates are hired. Overall, the market in Gothenburg is suitable for a CURE, with existing municipal support, a plethora of initiatives already in place, and public interest.

Berlin Market Analysis

The economic activity review of Berlin shows that there are many material-intensive businesses in the city. Such companies use material inputs and most likely incur in generating secondary materials. These companies are mostly in trade fair and creative industries, higher education institutions, as well as the craft trade and construction sectors. Statistics show that Berlin hosts over 180 fairs and congresses a year, and is home to over 100 universities and research institutes. More than 6,000 member companies of the Berlin Chamber of Crafts correspond to material consuming and processing crafts, with about 10,000 companies from the creative sector considered material-intensive. It is expected that at least a fraction of these companies could use secondary raw materials instead of virgin ones. The number of companies that carry out material-intensive activities is assumed to be higher than what is accounted for in official reports, since these only include companies with annual sales over 17,500€, leaving many small and micro enterprises unaccounted for.
The review of the official Berlin waste statistics lead to the following conclusions: 1) preparation for reuse and recycling needs to

be strengthened and 2) high-quality materials from trade and industry (that are currently not obliged to be handed over to public waste management authorities) must be captured by an additional data collection tool. Currently recovered secondary materials are not accounted for anywhere in official statistics, making them to some extent invisible. If reuse and remanufacturing increases, the recovered streams should be covered by some official statistics to transparently evaluate these measures.

Participative Workshops

Two participative workshops were done in the targeted cities, as a first step to facilitate the creation of CUREs in these cities. The workshops had three main goals: to gather actors interested and/or already engaged in reuse and remanufacture, get feedback from these local actors about the CURE idea, and help define how the participants would want to engage in a local CURE. The input generated during the workshops was summarized and shared with the participants and is presented in this section.

Gothenburg Workshop

The event took place in the cafe associated to Gothenburg's recycling center Alelyckan. Over a four-hour period 27 participants from local NGOs, initiatives involved in reuse or remanufacture, academia, small design and architecture firms, and representatives from the public sector engaged in ideas to understand and promote the CURE concept.

To inspire engagement, participants were presented with the background to the CURE idea and preliminary results from the initiative review and the Gothenburg market analysis. Participants were asked to engage in a brain-writing session where they could write any comment about the CURE idea, and it's composing aspects. Next, the participants were asked to describe themselves or their organizations using the four CURE aspects, to later define the challenges they face and finally suggest potential solutions.

The meeting promoted the idea of CURE to a relevant audience in Gothenburg. Participants generated large amounts of input to what they would like to see in a local CURE and suggested how they would like to get involved. This material will be the base of future co-creation meetings, where project partners, together with engaged participants, will continue and hopefully implement a CURE center.

Given that Gothenburg City has plans of building a new recycling center; it intends to include there the ideas suggested by the CURE Pathfinder project. However, implementation times for the commune to build this center might take up to 10 years before it is actually available. This seemed to participants like an unnecessarily long time, that suggested it was possible to, in some way, take more immediate action. "We should start doing something like this tomorrow!", commented a participant. After the event conversations with representatives from Gothenburg City and the research team suggested that quick action to continue with the CURE momentum, would be to build a workshop space at the recycling center Alelyckan, next to their secondary material warehouse Återbruket.

Berlin Workshop

The Berlin CURE workshop was organized with Circular Berlin, Material Mafia, and OMA e.V. During the preparation phase, project relevant stakeholder groups were identified and reached, such as local NGOs, initiatives involved in reuse or remanufacture, open workshop spaces, academia, design and housing companies, funding institutions, and Berlin municipalities. As a result, more than 70 people participated in the workshop.

The event was structured into three main parts. The first one covered the findings of the Berlin market analysis. The second part targeted the potential objectives of a Berlin CURE. Participants were divided into 4 groups around CUREs composing aspects. Group work was organized around what type of materials are mostly possible to locally reuse, how to engage the local community, what are the existing skills and potentials and what is necessary to develop to professionalize work in waste prevention. In the third part of the workshop, participants were asked how they would like to contribute to a local CURE.
The workshop demonstrated a high interest in contributing to establish a Berlin CURE. Some highlights were the interest to focus on

recovering wood, textile, and fair discards. The centers should be open and generate knowledge for the community about materials, but also serve as a multiplier for a circular economy in the city. The creation of a physical warehouse with a pick-up area for companies was considered a key aspect. The physical warehouse would serve for connecting initiatives, material sorting, and inventory keeping. Quality assurance of used materials was also considered a key issue. Testing and evaluating materials for safety and harmless use was considered necessary. The workshop results were shared with the participants and have served as a base for following co-creation meetings.

Conclusions

The CURE Pathfinder project detailed the CURE concept further based on the studies here presented, but most importantly, it generated interest in the topic among local actors. This interest has resulted in concrete continuation steps taken by stakeholders in Berlin and Gothenburg. Hopefully, presenting this experience will inspire other actors to also engage with the CURE idea, beyond the initial reach of the Pathfinder project.

Reflecting on the results, it seems relevant that CUREs are established as open centers recognized, supported or regulated by local authorities. This official status would facilitate that CURE activities get institutionalized, establishing these services at the city level. Gothenburg waste authorities were already involved in the Pathfinder project, providing official support. However the number of organizations in the reuse sector was not high. In contrast, Berlin has several organizations in the sector, but no clear engagement from local authorities. Official institutions tend to act slower, but have the potential to stay longer than independent organizations. Non-governmental organizations rarely scale up to address re-circulation at an urban scale, but provide a rich variety of recovery options. Therefore a combination of top-down and bottom-up engagement is needed to implement re-circulation in cities.

Ideally, recovery services would be economically sustainable to ensure their permanence over time. Acceptance of reuse and re-manufacturing by all actors in the material value chain is indispensable to implement economically independent CUREs. So, the value generated by recovery activities should engage and complement existing material value chains, rather than compete with them, to foster a wide spread acceptance of these practices.

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PLATE
Product Lifetimes And The Environment

Alternative Consumption: a Circular Economy beyond the Circular Business Model

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Keywords: Alternative Consumption; Circular Economy; Material Circulation; Economic Growth.

Abstract: Studies for the circular economy have focused consumption from the perspective of acceptance of business models. However, consumers can engage in waste prevention, reuse and reparation in modes of consumption outside existing market-networks. This paper proposes a shift in perspective for studies on the circular economy, from production to consumption. Taking alternative modes of consumption as its starting point, it explores what the circular economy may entail when explored from a consumption perspective. More specifically, it presents the results of a literature review in which literature on alternative consumption has been reviewed and analyzed based on circularity principles and a framework of six moments of consumption. In this review, two main modes of alternative consumption were identified – one based on the meaning given to purchases made within the existing market structure, and one centered on engagement in taking care of community commons. These two modes are relevant to reduction and slowing down of material cycles. Based on these findings, recommendations are made regarding how the results can be used in further theoretical and empirical research on consumption in the circular economy, beyond business models.

Introduction

The circular economy concept covers strategies and principles for the efficient use of resources (MacArthur et al. 2015). One of the most reproduced models of the circular economy is proposed by the Ellen MacArthur Foundation (Ellen MacArthur Foundation, 2017). In this model, consumers are required to take responsibility on discarding and keeping goods in conditions for re-use, remanufacture, or recycling, while producers provide the infrastructure for recovery of material resources (Singh & Ordoñez, 2016).

Much existing research on consumers in the circular economy focuses on the acceptance of business models (Tunn et al., 2019; Camacho-Otero et al., 2018). Many of these models are based on reuse of resources in services that are accessed by consumers through fee-based schemes that modify ownership (Kjaer et al., 2019). Although consumption is the subject, it is studied from the perspective of production.

This paper proposes a shift in focus for studies on the circular economy, it begins an exploration on what a circular economy focused on consumption may entail, beyond the study of business models. Material recovery networks have an important role in the transition to a circular economy. From a consumption perspective, the circular economy should focus on riddance, especially on waste prevention and preparation for reuse and repair, the most preferable activities in a waste hierarchy (Williams, 2015). These are activities which could be carried out by consumers without the intermediation of third parties (businesses). Doing so, also requires looking at how resource utilization serves consumers' everyday life, and not just the viability of alternatives focused on revenue or profit.

In this paper, we report on a literature review conducted to identify modes of consumption that challenge the currently dominant market-based commodity consumption mode (Arnould & Thompson, 2005, p.869). We focus on the concept of "alternative consumption" as a starting point. Alternative consumption modes are responses to established forms of consumption. Within a dominant market structure, alternatives are options given to individual actors enabled by multiple competing providers, where even sustainable alternatives

are in competition (Spaargaren, 2003). From the point of view of Toffler (1990), the economy is divided in two sectors, one dominant (or visible) comprising all production of good and services for sale or swap through an exchange network or market, and one passive (invisible) comprising all production done for self, familiar or community consumption.
In the following section a framework to approach consumption is presented. This framework is later used to review the literature on "alternative consumption".

Consumption

Consumers and their reasons to consume are at the center of most literature about consumption. Images of the consumer as a rational purchaser of goods and services, as an exploited subject constrained by the market, as a constructor of symbolic value through goods, or as a creative producer of self-expression can be found (Campbell, 2005). But most of these images are inscribed and understood within the dominant market structure, and do not allow to see the process of consumption as one that unfolds in parallel to production.
According to Warde (2005) consumption takes place as part of social practices. Everyday life is constituted by social practices. Specific practices include activities required for consumption, in acquisition, storage, use and even riddance.
Warde (2005) distinguishes between three moments of consumption:
1) Acquisition: includes the activities for access, delivery, exchange and, even, production of material resources.
2) Appropriation: includes the activities that are enacted making use of the acquired material resource.
3) Appreciation: includes the meaning or motives that emerge from the use or access of material resources.
The set of moments of consumption is expanded is expanded by Evans (2018). These three moments complete consumption by extending it to the process of de-consumption (riddance). These are:
4) Devaluation: includes the negative meaning or motives that emerge during the use or access of material resources, as it loses its original value (even its symbolic one).
5) Divestment: includes the activities or non-activities that take place while the material is taken out of use.
6) Disposal: includes the activities of riddance.

These six moments can be used as a framework for the identification of alternative modes of consumption. The attributes of the moments of consumption influence the practices that take place in relation to them.
This framework of six moments can be better understood with an example: One can take a practice, such as running, and look at how it takes place within the dominant mode of consumption. The basic material element required in running is a pair of sneakers, and they are usually: 1) acquired from big producers, branded or not, as part of a provision system, in stores. At the moment of 2) appropriation, sneakers are evaluated by sport efficiency and by aesthetic judgement. It is in this evaluation that consumption is 3) appreciated. Over time, something in the use can change, or in the product or in an external affecting factor. This may result in 4) devaluation of the initial appreciation, and lead to 5) divestment from consumption (use), and eventually resulting in 6) disposal of the material resource.

Practice	Running
Consumption mode	Dominant – market network
Material resource	Sneakers
1) Acquisition	Bought from a store (money exchange)
2) Appropriation	Comfort when running or adequacy to fashion trend.
3) Appreciation	The sneaker is comfortable.
4) Devaluation	Sneakers' color is no longer in fashion.
5) Divestment	Sneakers lay stored in a closet
6) Disposal	Sneakers go to a waste bin

Table 1. Example of attributes of consumption moments.

These six moments of consumption are tightly related to the three phases of consumption framed by Evans & Cooper (2010, p.324) as acquisition, use and disposal. But to have these six moments as framework permit a separation of factors related to meaning, found in the moments of appreciation and devaluation, from the factors of use, found in appropriation and divestment. The other two factors, found in acquisition and disposal, are directly related to the existing structures of provision and collection.
The attributes that fill each of these six moments are dependent on a mode of consumption. Modes of consumption can be regarded as existing alternatives, and each of them includes a system of provision and riddance that influences the paces of material

replacement permitted. Faster production paces facilitate faster consumption paces, underpinning faster processes of devaluation and divestment.
In alternative consumption modes, at least one of the attributes in the moments is different from the dominant or conventional ones. For example, by replacing monetary exchanges for collective access, or by setting appreciation on wider benefits for the environment and not on personal satisfaction.

Method

For this literature review, the surveyed databases were Scopus and Web of Science. The search was limited to journal and conference papers, with no specific timeframe defined, but limited to the latest update on both databases by May 2019. The search was done with the key terms “alternative consumption” and “alternative consumption practices”. An overview of the search results is presented in Table 2. In Scopus the search results were filtered by “article title, abstract and keywords”, and “all fields”. In Web of Science the results were filtered by “all fields” and “topic”. In both databases the terms used were inside quotation marks to ensure that they appear as such in the text. The research results are limited to these key terms, which may have excluded out other relevant modes of consumption that could have been studied.

Key terms	“Alternative consumption”	“Alternative consumption practices”
Total papers	558	61
First selection	73	40
After elimination of repeated ones	80	
Final sample	47	

Table 2. Overview of search results from Scopus and Web of Science.

A sample of 80 papers were selected and reviewed to answer two questions:
1. Which moments of consumption (Evans, 2018) can be identified?
2. Which principles of circularity can be related to the moments of consumption?
After this, a total of 33 papers were rejected for not offering a description of a consumption case. The 47 remaining papers were qualitatively evaluated searching for aspects representing alternatives in one or more of the six moments of consumption.
As a final step, the papers were clustered according to the moments of consumption identified. The clusters were used to identify topics that can concern strategic and structural aspects of the circular economy.

Results and discussion

In all papers, aspects considered relevant to the moment of appreciation, i.e. motivation or meaning of consumption, were identified. This indicates that consumption studies in general are oriented towards the meaning of consumption. An overview of the identified thematic clusters is presented in Table 3.

Moment identified	**Number of papers**	**Considerations**
Appreciation	8	Only meaning and motivations. Can be inscribed within the dominant structure.
Appreciation Appropriation	8	
Acquisition, appropriation appreciation	12	The provision structure is different from the dominant one. It is not possible to extract anything about what happens in riddance
Appropriation, appreciation, devaluation, divestment, disposal	7	These studies offer aspects that fill almost all the moments but are based on regular consumption as purchase.
Acquisition, appropriation, appreciation, devaluation, divestment, disposal	12	These studies offer alternatives in the six moments. And connect the consumption and production by offering insights about the structure of provision and riddance.

Table 3. Overview of evaluated papers clustered by identified moments.

Only 12 of the 47 papers include aspects that can be considered attributes that modify all the six moments of consumption (Table 4). These are studies that relate consumption across practices within the lifestyle of individuals, even present in the formation of community and social bonds. Consumption mode cases found in these studies can be regarded as complete alternatives to the conventional market mode. This is a mode of consumption that is motivated by the formation of community commons (as shared values).

Authors (Year)	Topics
Edwards & Mercer (2007)	Freeganism
Casey, Lichrou, and O'Malley (2016)	Ecovillage and structural changes
Moraes, Szmigin & Carrigan (2010)	Consumption and Production Communities
Moraes, Carrigan & Szmigin (2012)	Consumption and Production Communities
Nelson, Rademacher, & Paek (2007)	Downshifting as Voluntary simplicity and Freecycle.org
Isenhour (2010)	Sustainable consumption: rational reflections vs cultural conditioning
Lane & Watson (2012)	Material circulation, reuse and public stewardship
Vaughan, Cook & Trawick (2007)	Stewardship as a form of communal participation
Zademach & Annika Musch (2018)	Bicycle sharing systems, city mobility, public-private provision
Sabaté Muriel (2009)	Exchange circles and Freeshops as de-commodification outside markets
McArthur (2015)	Consumer to consumer sharing not mediated by money exchange
Albinsson & Yasanthi Perera (2012)	Free markets, community building, no monetary exchanges

Table 4. List of authors and topics of papers in which an alternative in all the six moments of consumption is identified.

At the opposite end, there are 16 papers (Table 5) in which only attributes corresponding to the moments of appreciation and appropriations are identified. These are based on market activities, such as buying ethical products, or acquiring products with fair trade labels, or by participation in product or brand boycotts and buycotts. These papers present the consumer as a subject of purchase decisions, a form of consumerism within the dominant market mode. In this mode of consumption, the alternative is in the product or service as an available option for purchase.

Authors (Year)	Topics
Gray (2017)	Food Activism
Grosglik (2017)	Organic Food
Haucke (2017	Fairtrade and technology
Humphery (2017)	Commerce and ethical consumption
Adams & Rais-borough (2010)	Ethical consumption and feeling good
Andorfer & Liebe (2013)	Ethical consumption and coffee Fairtrade
Baumeister, Scherer & Wan-genheim (2015)	Branding of products that are not owned
Becker-Leifhold & Iran (2019)	Second hand clothes and sharing services
Brenton (2013)	Ethical consumer modes
Lyon, Ailshire & Sehon (2014)	Fairtrade as movement
Schmelzer (2010)	Fairtrade Labelling
Geysmans & Hustinx (2015)	Fairtrade as commodity
Balsiger (2014)	Ethical consumption in Boycotts and Buycotts
Hutter & Hoffmann (2013)	Carrotmobs as anti-consumption
Elias & Saussey (2013)	Fairtrade in commodification
Bryant & Goodman (2004)	Fair or socially responsible consumption in the North

Table 5. List of authors and topics of papers in which an alternative in appreciation or appropriation is identified.

The rest of the papers reviewed (Table 6) describe modes of consumption that do not offer a complete alternative to the dominant market mode, but that could be complemented to be complete alternatives if the acquisition and disposition attributes were replaced.

There are two main alternative consumption modes that emerge from this review. One is based on the meaning given to products and services that are purchased. From the perspective of Spaargaren (2003), these can be regarded as alternative consumption options in the market. These options are appropriated as part of the lifestyle of individuals and allows them to maintain and reinforce identities based on ethical concerns about the social and environmental impact of consumption within the market structure.

Authors (Year)	Topics
Leiper & Clarke-Sather (2017)	Farmer Markets
Wided Batat (2016)	Alternative Food Consumption
Tchoukaleyska (2012)	Farmer Markets
Kajzer Mitchell, Low, Davenport & Brigham (2017)	Alternative Food Networks and Wild Food
Sarmiento (2016)	Alternative Food Networks
Pottinger 2013	Urban food spaces
Jarosz (2017)	Alternative Food Networks Rural/Urban
Watts, Little & Ilbery (2018)	Alternative Food Networks
Steinkopf Rice (2013)	Fair Trade, localism, co-operative: produce
Sonnino & Marsden (2005)	Alternative Food Networks
Guiot & Roux (2010)	Motivations for acquiring secondhand products

Williams (2008)	Paid provision of services by acquaintances
Catulli, Cook & Potter (2017)	Product service systems and ownership change
Marzella (2015)	Reuse in western societies driven towards new
Williams & Paddock (2003)	Motivation to participate in Second hand markets
Williams & Windebank (2005)	Motivation to participate in Second hand markets
Waight (2014)	Mothers providing of secondhand clothes to children
Fischer (2015)	Vintage clothes: second had
Park & Armstrong (2017)	Shared consumption and diffused ownership

Table 6. List of authors and topics of papers in which an alternative mode of consumption is not fully identified.

The second mode derives from the papers in which all the six moments of consumption were identified. In this mode, consumption requires the active engagement of the individuals for the acquisition and use of material resources, which are also shared values under the responsibility of a community. The active engagement also includes, to some extent, knowledge about production for the use of resources. This mode can be related to the concept of the prosumer (Toffler, 1990).

These two modes can serve as a departure point for studies on the circular economy. Keeping the cycles of the circular economy small means focusing on the strategies for reduction and reuse, which entails less resource use in slower paces of consumption. From the papers reviewed, the alternative mode of consumption that seems more adequate for resource use reduction is the one based on active engagement as part of a community. In this consumption mode, the centrality of consumption is the utilitarian value of resources and the care for shared commons.

Other forms of consumption in this review, that are not based on community shared commons, are also important for understanding the meaning of goods and structures of provision and riddance competing with the dominant ones.

Conclusion and proposal for research

Initially, a shift in perspective from production to consumption in studies on the circular economy was proposed. To approach this shift, a literature review was conducted on a sample of papers containing the terms "alternative consumption" and "alternative consumption practices". The resulting sample of papers were reviewed based on circularity principles and using a framework of six moments of consumption to find alternative modes of consumption. Although two modes of consumption were identified, an extended review is advised, including more search terms as well as extending the framework to include provision and riddance structures as part of the analysis.

A proposal of strategies for the circular economy cannot be reached with the present results. The modes of consumption identified do however represent two possible points of departure: 1) Reduction in material consumption as an ethical exercise when purchasing goods. 2) Reduction in material consumption as an effect of engaging in care for community commons.

For a circular economy the recognition of alternative modes is important for the establishment of consumption strategies based on the structuration of distribution and riddance systems that maintain products and materials in the use loop for longer periods of time. Consumers engaged in practices that blur the lines of production and consumption unifying what is seen as an ontological divide may shed light on how to deal with materials as resources and not as waste.

For further research, two paths are proposed:

1) Extend the literature review or focus on specific modes of alternative consumption that are known but did not emerge from the used key terms such as minimalism and self-sustainable movements.

2) Conduct field studies to observe the actual practicalities of the moments of consumption, and related practices in cases that are not framed by current market activities and its underlying logistics.

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Lifetime Extension by Design and a Fab Lab Level Digital Manufacturing Strategy: Tablet Case Study

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Keywords: Eco-design; Circular Economy; Digital Fabrication; Manufacturability; Decentralized Business Model.

Abstract: MicroPro Computers, an Irish SME working in the design and manufacture of computer equipment based on circular economy principles over the past 20 years, is successfully manufacturing a long-life miniature computer (the iameco D4R tablet), which addresses the three key areas of product design, manufacturability and sustainable business model. These factors are interlinked, and all are crucial to bringing the product to the market: A major barrier for local production of sustainable IT is the inherent complexity of mobile electronics, so innovative approaches are required to enable small-scale production. As part of the SustainablySMART Project, (H2020 – FoF) MicroPro is working with GMIT Letterfrack and Designing Berlin, to adapt the design of a green tablet, the iameco D4R tablet, for digital design and manufacture, using equipment typically found in a FabLab or similar non-commercial manufacturing environment. Combining a localized smart design and manufacturing approach with robust green credentials will allow for higher margins, as well as flexibility in terms of production numbers and costs, and provide a replicable production and business model for the green electronics sector

Introduction

MicroPro proposes a 'regenerative design' paradigm, that will ultimately give rise to the following:

- A reduction in the consumption of raw materials by using renewable materials and by extending the use lifetime of products and components
- A reduction in the generation of e-waste because of a) longer life and b) ease of recycling
- A reduction in the consumption of energy during manufacturing and during useful life

There are indications, that combing a localized manufacturing approach with robust green credentials which will allow for higher margins, and more flexibility when it comes to manufacturing costs. Euromonitor International published a report in 2012 (Euromonitor, 2012) which indicated a significant shift in consumer behaviour towards more environmentally friendly products. Factors such as climate change, health awareness and environmental issues, are influencing consumers to reconsider the most important factors guiding their purchasing decisions. Nearly 70% of respondents across the globe said they were 'somewhat to very willing' to spend more on a green product, compared to the same product without green features.

MicroPro Computers has a long history of design and manufacture of computer equipment based on sustainable and circular economy principles. This design strategy has been developed over the past 20 years and include the design and manufacture of iameco desktop and laptop computers. These case studies are well documented in previous articles and reports. However, despite successful prototype development, and some small-scale sales, it has been impossible to sustain the production and marketing of these computers, due to the high costs associated with outsourcing design changes and manufacture of computers. The conclusion is that small-scale, localised design, production and marketing of innovative computers if dependent on outsourcing design and manufacture, proves financially unviable

MicroPro is currently participating in the SustainablySMART project with the express intention of developing a new approach to design and manufacture, based on localised digital design and manufacture, that could make commercialisation of its ecological computers viable.

Eco-Design Principles

MicroPro has developed, designed and manufactured a number of prototypes for desktop, laptop and more recently tablet computers over the past 20 year. Through these practical experiences, MicroPro developed a comprehensive and proven eco-design approach, which included a range of elements, relating to design, choice of materials, parts and components, and post-sale services to customers.

MicroPro's aim is to reduce environmental impact not only "in operation", but over the entire lifecycle of the product. Both the iameco V3 desktop and the D4R laptop were manufactured primarily mainly from wood and recycled materials. The D4R Laptop was estimated to have 66% less CO2 emission, use 65% less fresh water in manufacture, and use 87% of materials that could be reused or recycled, with respect to equivalent commercial laptops.

Maximising reuse and extending operational life

In addition to the environmental gains made by selection of materials and components, a key circular economy strategy is design for upgrading and for ease of repair and for reuse. Iameco computers are designed to be easily disassembled using tools commonly available. This enables quick and affordable repair, upgrading and also the reuse of the housing, parts and components. This design strategy has been applied to all models. The disassembly of the iameco v3 desktop, for example, could be carried out in 11 seconds using conventional tools. The design allowed for flexibility in the repair and replacement of parts and components. The D4R laptop included a generic "universal motherboard", that allowed diverse components to be connected to it. The housing was designed to accommodate some variation in the size and shape of new components.

Additional eco-design considerations

As partner in the SustainablySMART Project, MicroPro has undertaken the design and manufacture the iameco D4R tablet, based on findings from its previous models. MicroPro also undertook to scope the possibility of design for reparability by repair shops and on a DiY basis, of design for longevity of wear-prone components (such as the battery), of design for reliability and design for robustness. MicroPro aims to achieve ease of manufacture by developing a design that is appropriate for manufacture in a digital fabrication environment, accessible to SMEs or in Fab Labs, by practically testing the manufacturability in a semi-industrial environment

Design iterations for the iameco D4R tablet

The iameco D4R tablet has been developed through a series of design iterations:

Iteration 1: The Alpha Prototype (AP)

The AP is designed to incorporate all of MicroPro's eco-design principles of upgradability, updateability, reusability, repairability, recyclability, ease of disassembly, long life and elimination of most plastics. The AP embodies these principles and is designed to anticipate future changes of components, so the chassis can be used again and again and have different lives. It has also been designed so that the mainboard and ancillary components can be replaced using simple tools. Use of glues or plastics other than those embedded in essential components were reduced where possible. The housing was screwed together using standard Phillips type screws. Design ensured natural ventilation and prevents overheating. Connectivity is maximised. The wooden frame provides a protective standoff for the display. A kill switch is provided for Bluetooth, Wi-Fi, microphone and camera enhancing security. The AP is manufactured primarily from maple and has an interior aluminum frame for robustness and stability. The AP is fully functional and manufactured to a high specification. It exceeds Project requirements by providing fully functional electronics. Assembly of the electronics was carried out in-house by MicroPro. The manufacture was outsourced to a commercial engineering workshop that uses digital design and CCR manufacture. Commercial outsourcing was an intermediate step in the process, aimed at ensuring that the AP was correctly manufactured, and that drawings, specifications and assembly were accurate and fit for purpose. The AP was not the definitive prototype but aimed at providing a baseline for further design improvements of the housing, frame and electronic design, as well as manufacturing strategies, which have been the basis of subsequent iterations.

Figure 1. CAD drawing of the AP.

Iteration2: The Beta Prototype (BP)

The BP is designed and manufactured using the AP as baseline. Development took place from March to September 2017. The manufacture of a 2nd prototype was not originally envisaged in the project, but subsequently agreed by the consortium. It has proven to be a valuable way of progressing the final design. For the sake of continuity, MicroPro employed the same prototyping company to produce the BP as produced the AP.

The main aim of the BP, was to iron out design short comings in the AP. MicroPro improved the AP design by streamlining the wooden housing and the aluminum chassis making the device less bulky and appealing, lighter, thinner and more robust. A new sliding back cover was introduced (without screws or fasteners) for ease of access for removable battery, and a fingerprint sensor There was also a material change of the seal-inlay to cork to reduce moisture and dust penetration. Additional ventilation holes were added to maximise the life of the battery and electronic parts and the number of parts overall was reduced (simplification).

The BP aimed at providing an improved template for design fabrication, leading to the production of the Kappa Prototype.

Figure 2. The Beta Prototype.

Iteration 3: The Kappa Prototype (KP)

The KP was designed and manufactured using the BP as baseline. It was developed from September 2017 to March 2018. The manufacture of the KP, the 3rd iteration of the iameco D4R tablet, was also not originally envisaged in the project, but likewise proved a practical and effective method for arriving at the final design.

The KP incorporates all of MicroPro's eco-design principles of upgradability, updateability, durability, reusability, repairability, recyclability, ease of disassembly, long-life, carbon capture and elimination of most plastics. By using a wooden chassis instead plastic it not only incorporates carbon capture (carbon from our time) but allows us to modify and change the chassis. The KP is designed to anticipate future changes of components, so the chassis can be used again and again and have many different lives. It has also been designed so that the mainboard and ancillary components can be replaced or repaired using simple tools. The battery can be replaced in 30 seconds.

Use of glues or plastics other than those embedded in essential components have been successfully avoided. The housing is screwed together using 4 x standard Phillips type screws. Design ensures natural ventilation and prevents overheating. Connectivity is

maximized. The wooden frame provides a protective standoff for the display.
The KP is manufactured primarily from walnut and has an interior recycled aluminum frame for robustness and stability. The KP is fully functional and manufactured to a state-of-the-art electronics specification. Assembly of the electronics was carried out by MicroPro in-house. Re-design and manufacture of the KP was carried out by MicroPro and GMIT in the university's own engineering workshop, using CAD design and computer-controlled routing, and has ensured that final drawings, specifications of housing and frame are fit for purpose. The metal frame is being manufactured in Designing Berlin's own facilities.

Design improvements to the KP

Design for Manufacturability

The AP and the BP were designed and manufactured by a commercial prototyping company under MicroPro's direction. These prototypes were designed in CAD and the CAD files of both were provided to GMIT Letterfrack for review, in order to assess the ability to machine the prototype on the Homag CNC at GMIT campus.

GMIT Letterfrack has introduced the concept of Design for Manufacture (DFM) that is the practice of designing products with manufacturing in mind. Embedding this principle will allow for simpler manufacturing, assembly and/or design of the proposed product with the aim of reducing waste and minimising production costs.

The correct implementation of DFM will lead to reduced manufacturing costs, reduced lead-time and improved quality. DFM should also help to minimise waste and maximise yield from raw materials, which lowers production costs as timber waste from production is not recoverable for re-use. DFM is an important consideration when working under the Ecolabel logo, which considers products from the extraction of the raw materials, to production, packaging and transport, right through to your use and end of life. Not all DFM principles are applicable to all production of the iameco D4R tablet. Currently, these principles can only be related to the manufacture of the wooden housing and the metal frame, but not the electronic or metal components, which are sourced from external suppliers, over which MicroPro has little or no control.

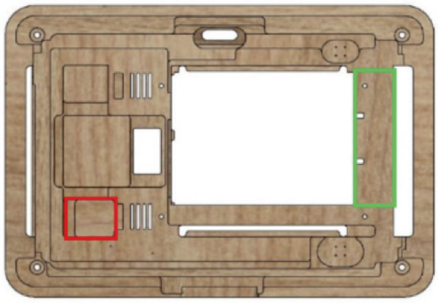

Figure 3. BP wooden frame interior Section.

Choice of Materials for the KP

MicroPro's preference from the start was for solid wood. This was guided by an initial survey of customer preference undertaken at the start of the project. In selecting the wood, the following considerations were taken into account:

- Use a species with closed grain (e.g. maple or beech)
- Use timber with straight grain, free of knots and defects
- Grain direction should be perpendicular to surface to minimise movement (radially cut)
- Reduce moisture content to maximum 10% (to minimise distortion in service)
- To deduce tendency of cupping in service, it may be worth using glued strips of solid wood.

It was also considered important to use ethical procurement when specifying timber materials. Only timber from certified sustainably managed forests would be used. Forest Stewardship Council (FSC) and Programme for the Endorsement of Forest Certification (PEFC) schemes are those most recognised for ensuring chain of custody of sustainably sourced forest material. It would also be possible to use off-cuts from the furniture industry and second life woods, although these were not used in any of the prototypes produced. MicroPro decided to use **walnut** as the material for the Kappa as it has a deep lustre and warm and attractive grain.

KP Wooden Frame Design n
The design of the wooden frame for the KP was based on an analysis by GMIT of the frames design and produced for the AP and the BP. This phase involved detailed design work on the wooden chassis, aimed at simplifying the design in order to reduce the tooling complexity and time required.

Multiple design changes were required for the KP to adapt it to manufacture in a Fab lab environment. This is explained in detail in the paper produced by MicroPro for the Going Green Electronics Conference in February 2019, so will not be repeated here

Further consideration and research
Originally, the BP prototype took a total of 163 minutes approx. to machine on the CNC, with the iterations to the KP design this has been reduced to a total of 118 minutes. The sanding of the Beta was estimated to be 180 minutes due to the difficult areas to reach. The redesigned elements of the KP reduced the sanding process to 90 mins approx., depending upon individual grain pattern and species selection. The lamination process that created the blank was done by manual clamping and therefore does not provide an accurate estimate on the time it requires to produce in batched or higher quantity production runs. However, the time it took to dimension, plane, and finally calibrate the blank manually was about 75 minutes per blank.

This is a total of 283 minutes for creating the KP's unfinished wooden chassis (based on a production of a single unit). This brings the total time of wooden chassis in its current form to 308 minutes with a water-borne lacquer finish. This will be further improved and reduced in the implementation of the Small, Batch production, which is currently underway.

Metal frame design and manufacture

Metal Frame design improvements
The metal frame from the AP and the BP were designed and produced by commercial prototypes, who had access to the required manufacturing equipment. The initial KP frame was also produced in this way. The production of frames in this way would not be commercially viable for marketing the tablet.

The BP metal frame (produced commercially) however had to be modified at GMIT to match changes in the wooden frame and the electronics. Initially this was achieved by designing and printing a re-designed frame in plastic. The frame was then manufactured commercially for the first KP version.

Fortunately, for the Small Batch Production (explained below) MicroPro identified a metal designer and fabricator who had been working with Fab Lab Berlin, Designing Berlin. After a meeting a partnership was formed, and Designing Berlin went on to review and improve the metal frame design and manufacture it.

The overarching four objectives in the redesign of the metal frame: reducing the weight of the metal frame, reducing the visibility of the frame, improving its modular and upgradable features and simplifying the manufacture, to be adapted to typical Fab Lab equipment. Additionally, updated electronics had to be integrated. The final objective involved fixing the new electronic components onto the surface plate to identify the precise location of the relevant components. The results were then fed back to the 3D model of the revised KP design.

An updated electronics setup allows the frame to be visually narrower than the initial KP version (which was a design objective). The main reason for that is a different mounting method for the touchscreen and the actual screen.

In order to keep the CNC machining of the part simple, all features can be machined with basic 3 axis CNC machinery from only 2 sides. The required side cut-outs for the connectors are turned into independent, modular parts. Otherwise they would require 5 axis machining or 3 axis machining from 4 more sides

Various modular parts are mounted in the actual frame and can be exchanged without screws. In case future electronics offer new interfaces, the modular frame parts can be redesigned accordingly and exchanged along with the electronics. The mainframe stays as it is.

The weight reduction of the frame is improved by adding several triangular shaped holes, that results in a thin wall, lightweight frame. Where the user touches the tablet, that strategy would result in a strange haptic as well as dirt attracting surface. Those areas have only one long cut-out with nicely filleted transitions. The final weight is about half of the KP version, roughly 150g.

Figure 4. New metal frame for the KP, improved by Designing Berlin.

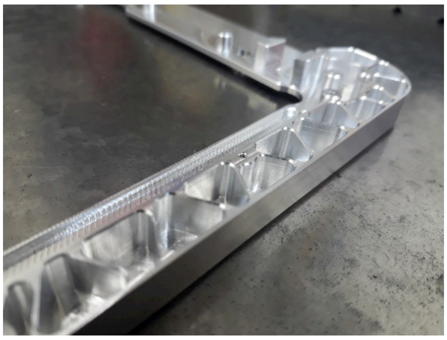

Figure 5. Detail of material reduction design in KP Metal Frame.

Small batch manufacture of the D4R tablet

Towards the end of the SustainablySMART Project (May – October 2019), MicroPro and Project Partners took a further step in advancing the commercialisation of the D4R Tablet, by sampling a small batch manufacture. This involves the production of 30 working units of the Tablet, that will be tested and certified by Grant4 Com to demonstrate compliance with EU market regulations. For this final step, MicroPro is carrying out the entire design and production process working with FabLab equivalent bodies. For this to happen, it was necessary to identify an additional non-commercial contractor that would review and improve the metal frame design and produce the 30 frames for the proposed small batch. With the help of Reuse-IT (Berlin), a Berlin FabLab maker, Stefan Knorr (trading as Designing Berlin) was identified as having the necessary skills and equipment, but also commitment, to work on the project and produce the required metal frames for the initial small batch. The wooden frame would be reviewed, improved and manufactured by GMIT Letterfrack, and the electronic components would be improved, sourced and assembled by MicroPro.

This final review of the metal frame design led to overall design improvements in the final version. The weight of the metal frame was reduced by around 50%, and a number of operating details improved. The review of the design of the wooden frame design by GMIT also resulted in some improvements and required a re-calibration to take the new metal frame into account, as well as improved electronics. The electronic design was also upgraded, to encompass the ever-rising standards of computer components on the world market and need for improved multi-functionality from the initial Kappa design.

Evaluation of the D4R tablet

In order to gain added value from the sample small batch manufacture, MicroPro and Partners decided to undertake a Customer Evaluation exercise, to be rolled out during the final three months of the SustainablySMART Project (August, September and October 2019). This will involve the identification of a number of private companies, universities and public computer outlets in some Partner regions, who will carry out a short evaluation of actual D4R Tablets, for a limited period of time. These agencies will collect consumer information and feed it back to MicroPro, aimed at establishing customer reaction to the product.

The Key target groups that will be targeted are:

- Private companies with an interest in ecological products
- University students and lecturers
- The general public

A number of agencies have been identified for the Evaluation exercise that are representative of, or able to access the 3 Target Groups in a number of Partner regions. The Questionnaire and interviews proposed aim to secure the view of potential users regarding the design, materials, weight, functionality and pricing of the tablet.

A viable design and manufacturing strategy

A main objective in the SustainablySMART project has therefore been to demonstrate that digital fabrication in a local, non-commercial digital fabrication workshop is a potential solution to the viability challenges so far encountered.

The use of digital design and fabrication per se does not generate viability, and indeed commercial prototype developers already employ digital design and fabrication as a method for producing prototypes (for example, the company that produced the original AP and BP models was a commercial prototyping company using digital fabrication). But this company would not be able to manufacture the final prototype at a commercially viable price.

The final stage of the SustainablySMART Project, and in particular the Small Batch Production, has demonstrated that it is feasible to design and manufacture a fully operational state of the art tablet within SME and FabLab equivalent facilities, as long as non-commercial associates with the right equipment, skills and attitude are identified. This allows the SME to achieve some relaxation of the tight financial constraints that limit commercial outsourcing.

The partnership composed of MicroPro, GMIT Letterfrack and Designing Berlin have proved the viability of the model with the implementation of a small batch production (30 units) of the iameco D4R tablet The assembly of this Team has been central to making this non-commercial process viable and could be the main basis for future manufacture of the iameco D4R Tablet. Also, it demonstrates that a more decentralized model for manufacture, repair, upgrading and production of the tablet, as described in part 7 above.

The SustainablySMART Project has been successful in demonstrating that locally based non-commercial digital design and fabrication can be the basis for more viable manufacture of iameco D4R tablet and possible other iameco models.

We believe this is a major step forward in making sustainable computer manufacture a possibility.

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PLATE
Product Lifetimes And The Environment

Investigating User Perspectives Related to Product Repair towards a Circular Economy

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Keywords: Visible Repair; Product Longevity; Sustainable Behaviour; Phenomenology; Research Through Design.

Abstract: This paper explores user perspectives about product repair to prolong the useful lives of products towards the circular economy. Product longevity can effectively be achieved by repair and reuse, where no virgin materials are required. However, the decision of whether or not to repair something is initiated by the users. Their motivations and choices are vital to postpone product replacement. Therefore, users' motivations and barriers related to product repair were explored in this research with cultural probes, research through design and phenomenology methods. Fogg's Behaviour Model was utilised to get a deeper understanding of the subject. The results were further developed and tested through the workshops with users. New repair methods and examples were created and used to inspire participants to reflect their experiences about repaired and broken products. The findings from this study suggest that repair decision is affected by a multitude of sociological and psychological motivators and barriers including reversibility, endurance, aesthetics and storytelling. This study contributes to the literature through the development of the fifteen design considerations which comprise categories of motivations and barriers that users experience about repair. They suggest opportunities to understand and change user behaviour, through design, to reduce their environmental impact. Overall, the results call into question the prevalent picture of business-focused circular economy literature. Furthermore, it is discussed that users' participation is the key to unleash the potential power of the inner circles.

Introduction

The circular economy is a system-based approach to the industrial economy which offers an opportunity to help reduce our global sustainability pressures (European Commission, 2015; Ellen MacArthur Foundation, 2013). One of the goals of the circular economy is to keep products in circulation for longer and use tighter inner loops. This means maximising the time spent in each cycle by prolonging the use life and enabling maintenance, repair and reuse, rather than recycling. Maintenance and repair preserve the embedded energy and value in the product (Ellen MacArthur Foundation, 2015). Thus, recycling and remanufacturing can be a source of value creation if repair is no longer feasible (Stahel, 2017). When the cycles are lengthened, the material, energy and labour needed to manufacture a new product are avoided (Ellen MacArthur Foundation, 2015).

Repair is an effective strategy for extending the lifespan of products (Bakker et al., 2014; Cooper, 2010; Middleton, 2012; Brook, 2012). Hitherto, the role of the users and the inner loops have been underestimated in circular economy literature (Ghisellini et al., 2016; Piscicelli & Ludden, 2016) However, the decision whether or not to repair something is affected by complex factors, and is dependent upon users' motivations, perceptions and choices. By investigating user perspectives about product repair this research challenges still existing user perception of take-make-dispose model aiming to the transition towards a circular economy.

This research does not focus on a single product category, rather it focuses on physical damage. Broken, cracked or worn-out products, and also torn-apart, unstitched or frayed textiles are examples to physical damage. This categorisation does not include electrical or electronic products; but of course, they can be physically damaged: a mobile phone with a broken plastic housing, for instance. Although there is no single product category focus, this study mainly explores fast-moving consumer goods such as textiles, shoes and leather goods, and ceramic and medium-lifespan products such as glass products, small furniture, utensils and toys.

Methods

In the early phase of this research, cultural probes method was applied to initially explore and broadly map the users' perspectives (Terzioglu, Brass & Lockton, 2015). Then, research through design and phenomenology were used to deeply investigate the topic. The aim of using research through design was to study my repair experience and understand it thoroughly before attempting to understand other people's repair experience. Phenomenology helped me explore the unique and complex character of each repair activity and identify diverse motivations and barriers related to repair.

Motivation and barrier categories were further explored and tested with the participants during the workshops. Four repair workshops were conducted in this research, where participants were asked to bring their damaged products and repaired them by themselves with the presented methods and provided materials.

Results

Cultural Probes

'What do people repair?' and 'Why do people repair things?' were the initial questions in my mind before I decided to use the cultural probes method. A cultural probes kit was prepared including a booklet, a camera, stickers and pens. Participants were asked to take photographs of their broken and repaired objects and answer the questions in the booklet for each object (Figure 1).

In total, fifty kits were sent to participants. Thirty-two of them were completed and received. Affinity diagram was used for analysing the data. Finally, six motivation and barrier categories were developed are:

1. Financial Cost: This design consideration is related to the cost and benefit calculation that users make while considering to repair a product. It includes the cost of the repair, materials, tools that were used in the process and sometimes the expert knowledge or any kind of repair service.
2. Repair Duration: Repair duration represents the time required for completing the repair process. Participants preferred to carry out repairs which do not take a long time.
3. Ease: Ease represents the amount of work required to complete the repair. Participants preferred to carry out repairs which do not require great labour or effort. This category is closely related to that of required knowledge and skills. For example, some kinds of damage may be regarded as easy for a person who is experienced and has the required skills; however, it may also be thought of as a difficult repair when the user has no actual hands-on experience.
4. Personal Pleasure/Satisfaction: Personal pleasure/satisfaction refers to the pleasure experienced by carrying out the repair and the pride felt as a result of doing the repair. It includes the enjoyable aspect of the process, and emotions such as the feeling of relaxation and enjoyment it triggers. Additionally, people often feel proud as a result of accomplishing the repair and enjoy receiving praise from others when they share the experience of the process.
5. Required Knowledge: This category refers to the knowledge that is required about the repair methods, where to get the necessary materials and tools and how to use them.
6. Required Skills: This consideration refers to the ability of using one's hands and fingers to make and manipulate things. Anyone can repair objects using their natural skills and creativity. The quality of work improves in time with practice.

Figure 1. Participants took photos of their broken and repaired objects and answered the questions in the booklet for each object.

Research Through Design

I completed more than one hundred repairs and explored various motivations and barriers during the research through design study. Figure 3 shows some repair examples from this process. Initially, traditional repair techniques were explored. Here I present twelve of the repair methods that I used (Table 1). Some of them were applied in a similar way to the original process, while others were combined with new technologies and materials. The focus was on simple repair methods – in other words, low skill-level repair work, as suggested by Fogg (2009). Fogg's Behaviour Model is a framework to understand human behaviour and the factors underlying behaviour change. In this model, it is important to firstly, target a simple behaviour to increase the possibility of success of behaviour change. Secondly, after selecting the target behaviour, what is preventing it must be identified. Finally, these barriers should be removed.

Research Through Design Repair Methods	
1	3D printing product parts
2	3D printed patches
3	3D printing pen
4	Kintsugi (Traditional Japanese repair method employed to mend broken ceramics with gold and silver.)
5	Kintsugi for textiles
6	Kintsugi sugru
7	Darning
8	Darning sugru
9	Boro (A special way of repairing Japanese traditional clothes)
10	Patching
11	Sugru patching
12	Basket weaving

Table 1. Twelve of the repair methods which were used during the research through design study.

Phenomenology was used to explore the unique and complex character of each repair activity. The process started with phenomenological reduction. Becoming aware of the preconceived ideas is the first and a crucial step to bracket them. Field notes were used to collect data during the design studies (Figure 2). Taking field notes is an effective method that helps researchers to eliminate personal bias and preconceptions during phenomenological studies, which are essential for establishing validity and reliability (Miles & Huberman, 1984).

I would like to explain how the design considerations were created with an example: 'The interest in the method' category was developed while I was working with the teapot with the missing lid in Figure 4. I started the research process by analysing the product, taking measurements and thinking about the repair solutions. My first repair idea was 3D printing the lid. I also developed an alternative idea which was finding another lid from second-hand shops. I designed the lid and created the CAD model. Finally, the repair process was completed after 3D printing the part.

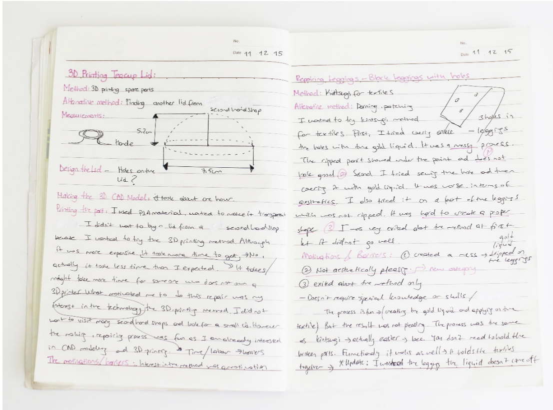

Figure 2. Field notes were used to collect data during the design studies.

Figure 4. The small teapot with 3D printed lid.

My perception (epoche) was the primary source of knowledge in this phenomenological research (Moustakas, 1994). I took notes on what I perceived during the research process and reflected on what was happening, without judgemental evaluation (phenomenological reduction). My brief thought process can be seen in my field notes (Figure 2).

After the repair is finished, I thought about the barriers and motivations that I experienced. I asked myself questions about my choices, the enjoyable parts of the process and the difficulties. I realised that I wanted to try the 3D printing method because I was interested in the technology and CAD modelling. 3D printing technology attracts other people's attention as well. This method can be effective to encourage people to try repairing and to overcome the barriers and negative stigma attached to repair activity. Consequently, 'interest in the method' category has been created.

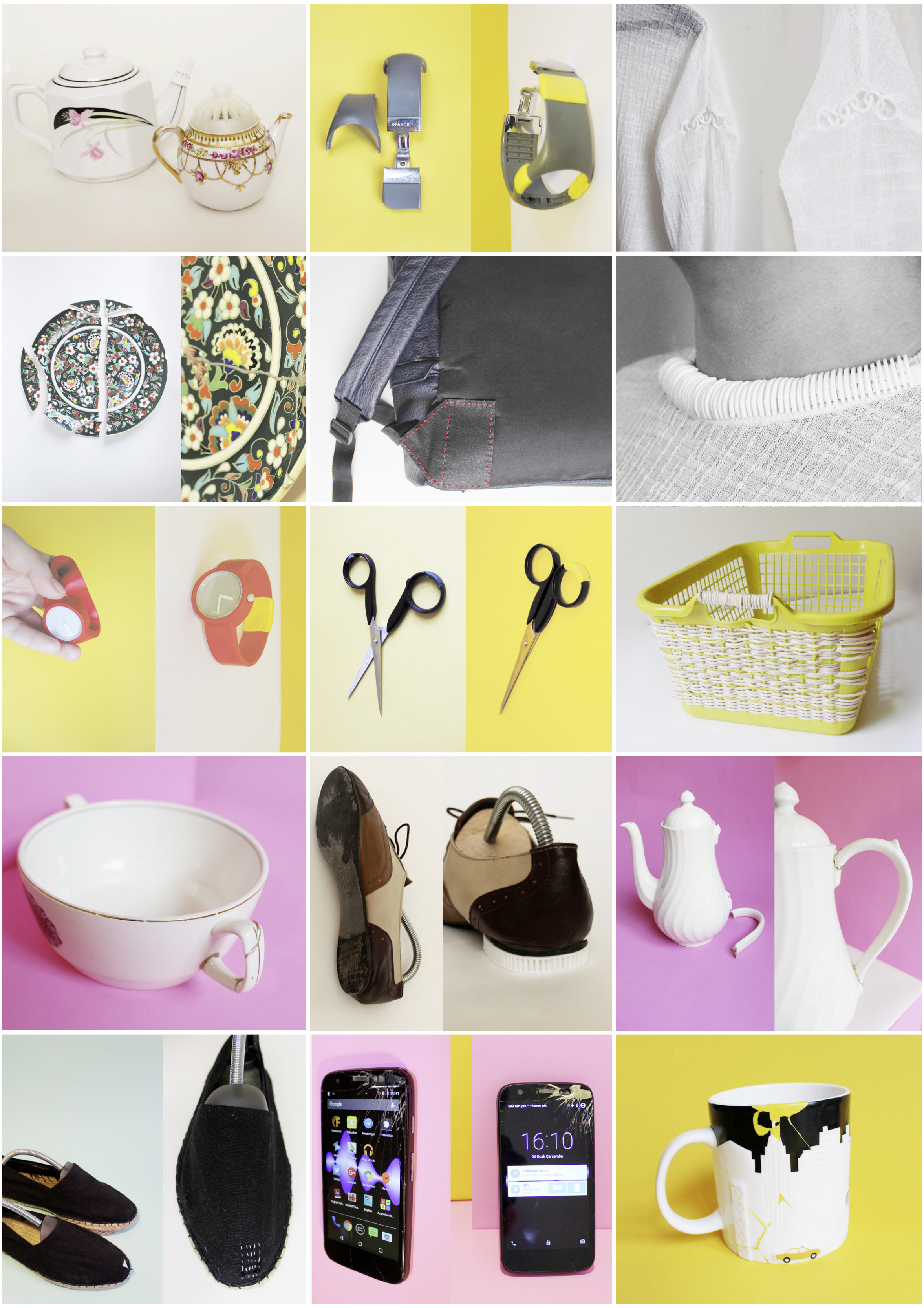

Figure 3. More than one hundred products were repaired during research through design study.

Finally, seven design considerations were developed based on the research through design findings:

7. Aesthetics: During the design studies, I enjoyed the repair process more and wanted to complete it more enthusiastically when the final product was aesthetically pleasing, leading to the development of the 'aesthetics' category. This refers to the pleasure which results from the sensory perception of the repaired object. As physical damage is the focus of this research, the aesthetic quality is mostly related to sight and touch.
8. Attracting Interest: 'Attracting interest' refers to the incorporation of interesting contemporary methods or new technologies into the repair activity. Using interesting methods is an effective strategy to overcome the stigma attached to the act of repair. If people focus on the interesting techniques they are using, it might be easier for them not to experience the barriers, and engage in the activity.
9. Accessibility of materials and methods: In the current economic system, it is often easier and cheaper to buy a new product rather than repairing one that is broken. As a result of this, the methods, materials and tools for repair should be made easily accessible if we want people to repair products more often.
10. Functionality: Products might become non-functional after being damaged. This category refers to restoring the damaged product to working order as much as possible.
11. Negative stigma attached to repair: This category refers to the socio-economic perception of repair (Middleton, 2014). Damaged, frayed and repaired products are associated with economic hardship and poverty (Kelley, 2009; McLaren & McLauchlan, 2015). Therefore, people might feel ashamed of repaired products. This fact might also affect the user's motivation to use a repaired object and discourage him/her from repairing.
12. Improving the design of the object: This category refers to making a product more valuable and more beautiful than a new product by repairing it. Is it possible to make the product 'better than new' through repair? The stigma attached to repair is a socially constructed idea that relates to the current social value system. For example, in a different social context, a repaired product could be regarded as more valuable because it represents our respect for the environment.
13. Storytelling: Every repaired object tells a story. The main aim of this research was to encourage people to repair products more often and to create an awareness of environmental problems. Stories are a significant part of creating awareness and spreading the message. As a result of this, one of the design considerations was the creation of a conversation piece through visible repair.

Workshops

Four repair workshops were conducted in this research with fifty-two participants. The participants were selected from the group of people who were interested in repair, and want to repair products. I concluded that purposive sampling is the most suitable tool for the study. As I found out during the pilot studies, it was not possible to collect data from the people who do not want to repair products and who are not interested in repair. The data about participants' experience was collected from the worksheets that participants filled. The worksheet included qualitative questions such as 'What is your product? Can you explain your process and your work?' The workshops were video-recorded. Photographs of the repair processes and the 'before' and 'after' phases of the repaired objects were taken. Additionally, I took notes on the conversations I had with the participants and my observations. These notes also enabled me to better understand participants' perceptions about repair.

For the workshops, participants were asked to bring damaged products. I provided a tool bag with materials and different tools. I explained the repair methods briefly and showed them the repair examples that I developed during the research through design study. The participants, then, chose the most suitable methods to repair their products. They repaired them and filled in the worksheet according to their experience (Figure 5).

Some participants were worried about taking risks during the repair process. For example, one of the participants said, 'I am scared of doing something that I cannot go back on if I change my mind'. Consequently, similar cases showed that if the repair process was reversible participants found it easier to engage in the activity. Another category, 'endurance', was also added to design considerations after the first two workshops as some participants stated that they were worried about the strength of the repaired part and how long the repair was going to last.

Figure 5. The participants were asked to bring damaged products and repaired them by using the repair methods, tools and materials presented to them during the workshops.

14. Reversibility: If the repair method is reversible it is possible to restore the product to its previous state. This might reduce users' negative feelings, such as worry and stress, which is usually seen when the users are not confident about their skills and experience, or when the product has a special value for the user.
15. Endurance: This consideration refers to the strength of the repair and how long it lasts. Participants preferred long-lasting repair solutions, as they might get frustrated in spending time on the same damage repeatedly.

Finally, design considerations were completed with the addition of these two categories (Figure 6).

Design Considerations

Cultural Probes

1-Financial cost
This consideration refers to the cost of the repair, materials and tools that were used in the process. If the process requires expert knowledge or any kind of repair service, its cost is also considered under this title.

2-Repair duration
Repair duration represents the time required for completing the repair process.

3-Ease
Ease represents the amount of work required to complete the repair. Participants preferred to carry out repairs which do not require great labour or effort.

4-Personal pleasure
Personal pleasure/satisfaction refers to the pleasure experienced by carrying out the repair and the pride felt as a result of doing the repair. It includes the enjoyable aspect of the process, and emotions such as the feeling of relaxation and enjoyment it triggers.

5-Required knowledge
This category refers to the knowledge that is required to carry out the repair activity. It can be about the repair methods, where to get the necessary materials, tools and how to use them.

6-Required skills
Using one's hands and fingers to make and manipulate things is a natural human ability. Anyone can repair objects using their natural skills and creativity. The quality of work improves in time with practice.

Design Studies

7-Aesthetic
This refers to the pleasure which results from the sensory perception of the repaired object.

8-Interest in the method
Using interesting methods is an effective strategy to overcome the stigma attached to the act of repair. If people focus on the interesting techniques they are using, it might be easier for them not to experience the barriers, and engage in the activity.

9-Accessibility of materials and methods
In the current economic system, it is often easier and cheaper to buy a new product rather than repairing one that is broken. As a result of this, the methods, materials and tools for repair should be made easily accessible if we want people to repair products more often.

10-Functionality
Products might become non-functional after being damaged. This category refers to restoring the damaged product to working order as much as possible.

11- Negative stigma attached to repair
This category refers to the socioeconomic perception of repair. Damaged, frayed and repaired products are associated with economic hardship and poverty. Therefore, people might feel ashamed of repaired products. This fact might also affect user's motivation to use a repaired object and discourage him/her from repairing.

12- Improving the object's design
This category refers to making a product more valuable and more beautiful than a new product by repairing it.

13-Storytelling
This category refers to revaluing an object as a conversation piece through visible repair. Every repaired object tells a story. Stories are a significant part of creating awareness and spreading the message.

Workshops

14-Reversibility
If the repair method is reversible it is possible to restore the product to its previous state. If the repair was reversible this might reduce users' negative feelings, such as worry and stress, which is usually seen when the users are not confident about their skills and experience, or when the product has special value for the user.

15-Endurance
This consideration refers to the strength of the repair and how long it lasts. Participants preferred long-lasting repair solutions, as they might get frustrated in spending time on the same damage repeatedly.

Figure 6. Fifteen categories of design considerations with explanations.

Discussions and Conclusions

Circular economy relies on users to be active participants in reuse, recycling or return of products, this is the opposite version of the passive, throwaway society of the current linear system (Shah, 2014). Although both producers' and users' roles and responsibility are crucial for the change, existing research in the field has mainly studied the economic and business aspects of the problem and excluded social issues and user participation (Ghisellini et al., 2016; Piscicelli & Ludden, 2016). Their participation is key to unleash the potential power of the inner circles. Repair is an important field of activity through which values are maintained and transformed, and new values are elicited (Jackson, 2014; Houston et al., 2016). By identifying users' motivations and the barriers related to product repair, this research aims to encourage people to engage in the system through repair to create consciousness about the value of products and raise awareness about environmental and social problems.

It is vital to understand their motivations and the barriers preventing them from doing so to encourage users to repair products more. Fifteen design considerations identified in this paper suggest opportunities to understand and change user behaviour, through design, to reduce their environmental impact. The design considerations can be of value for design researchers as it can facilitate future attempts to 'design for repair', and they can serve as a baseline for future research in this area. Furthermore, this research serves as baseline research for future investigations in how to integrate repair into design processes and business models to extend the product lifespan.

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Again and Again; Triple Perspective on Design and Repair

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Keywords: Repair; Product Design; Circular Economy; Design Education; Learning Perspectives.

Abstract: The world is dominated by the unsustainable model of the linear economy. Our society, the education system even sustainability education is based on take-make-dispose practices. A paradigm shift is required in education to overcome the impacts of almost a century of domination and transition to a circular model. This paper presents a graduate product design course that focuses on closed-loop systems and ways of regenerating value through repairing rather than making something new. Actual Repair is a graduate course, within a trans-disciplinary international MSc program, with a unique triple task approach. For the first task students were expected to find a (set of) broken/damaged product(s), and visibly repair it/them in an aesthetically pleasing way. Then, they organised a Repair Café as a group for the second task. Finally, the third task required designing a system or the touchpoints of a system in which products are repaired. This triple task process resulted in a multifaceted learning experience. At several points during the course, reflective sessions were held to help students articulate the higher-level learnings from their separate projects. Resulting from this research, learning perspectives including circular thinking perspective, seeing the repair possibilities, the stigma of repair, interest in the circular economy, understanding limited resources, exploring community value and exploring alternative user perspectives were presented. This paper contributes to the existing literature by providing a case of incorporating repair into product design education, and by exploring how doing so through three different perspectives triggers deeper learning than a single perspective would have.

Introduction

Although most businesses continue to hold on to the linear system, only a glance at the latest literature would be enough to tell that the world is changing towards a circular one. This transition brings a lot of change with it for product designers and product design education. The change from ownership to usership, the necessity to optimise the resources, create closed loops and achieve zero waste manufacturing requires a variety of design skills (Bocken, de Pauw, Bakker, & van der Grinten, 2016; Ghisellini, Cialani, & Ulgiati, 2016; Ellen MacArthur Foundation, 2012; Webster, 2013; van den Berg & Bakker, 2015). Alternative courses need to be developed to effectively teach the severity of environmental problems, vagaries of consumption and complex theories like circular economy. Some studies address these topics and define the required skills and knowledge for novice product designers (Andrews, 2015; De los Rios & Charnley, 2017; Wever, Charnley, Brass, & Harrison, 2015; Ramirez, 2007). Some educational resources, courses, and projects also exist that aim to incorporate sustainability and circular economy into the product design education (Ellen MacArthur Foundation, 2015; Lofthouse, 2013; Ramirez, 2006; Wever et al., 2015). However, there aren't many courses in product design education that focus on alternative perspectives of intervening with what already exists through repair rather than designing something new. For instance, within architecture, there is an acute awareness that renovation and retrofitting are important parts of making homes and other buildings more sustainable and circular.

It is commonly accepted in the literature that universities play a primary role in the change towards a sustainable system (Fernández-Sánchez, Bernaldo, Castillejo, & Manzanero, 2014; Mochizuki & Fadeeva, 2008, Yasin & Rahman, 2011). Some authors claim that this change requires a complete transformation of the paradigm of education because existing sustainability education is based on the ongoing linear model. The world is dominated by the linear economic model and by default it formalizes the way we teach. For example, sustainability education often encourages "sustainable" consumption and consumption of green products rather than a reduction in consumption (Kopnina, 2017). Green products mainly target minimising the negative impact of the linear economy on the environment. Unfortunately, most of them are designed to be manufactured and used in the linear system. The process starts with the extraction of raw materials, transportation, use of non-renewable resources and continues to produce waste through the disposal. We need to teach our students the reduction in consumption, product longevity, and closed-loop models. Instead of production and consumption of "green" products, we could focus on making the most of what already exists through repair. It is crucial to teach students how to distinguish the difference between doing less bad and doing good to the environment also between greenwashing and circularity. This paper presents a product design course that focuses on an alternative mode of creativity and design through repairing rather than making something new.

Actual Repair Course and Triple Task Approach:

Actual Repair is a graduate course taught in fall of 2018 within a trans-disciplinary international MSc program in Design. It utilises a unique triple task approach that incorporates repair into product design education. This course included three tasks which aim to explore the systems perspective on products considering product repair (Figure 1). The first task is called beautiful visible repair. Students are expected to find a (set of) broken/damaged product(s), and visibly repair it/them in an aesthetically pleasing way. Students explored how a repair can enhance the character and aesthetics of products. They repaired a diverse range of physically damaged products including ceramic plates, a bicycle, and textiles, etc. (Figure 2). The list of the students and their projects can be seen in Table 1.

Student	Project Name
1	Clockwork
2	Red Bicycle
3	Leggings
4	Ceramic Concrete
5	3DP comb
6	Doll Stroller
7	Kintsugi Plates
8	Paper Lampshade
9	Bicycle Lamp
10	Cutlery
11	BMW Cup
12	Headphones
13	Watch Strap
14	Glass Lampshade
15	Motorcycle Part

Table 1. List of the students' beautiful visible repair projects.

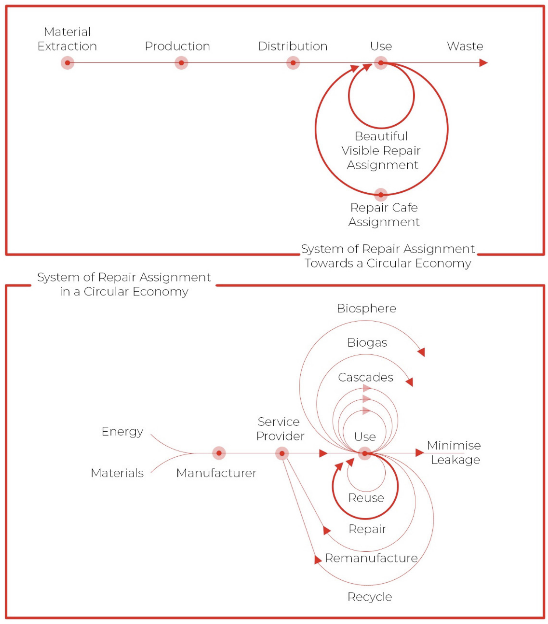

Figure 1. The scope of assignments considered in a linear and circular economy.

This task helped them understand and reflect on their design and repair skills in relation to the challenge area. Based on their experience with the first task students were asked to organise a Repair Café as a group for the second task which enabled them to create and experience a co-design activity. Repair Cafés are events in which people bring damaged consumer

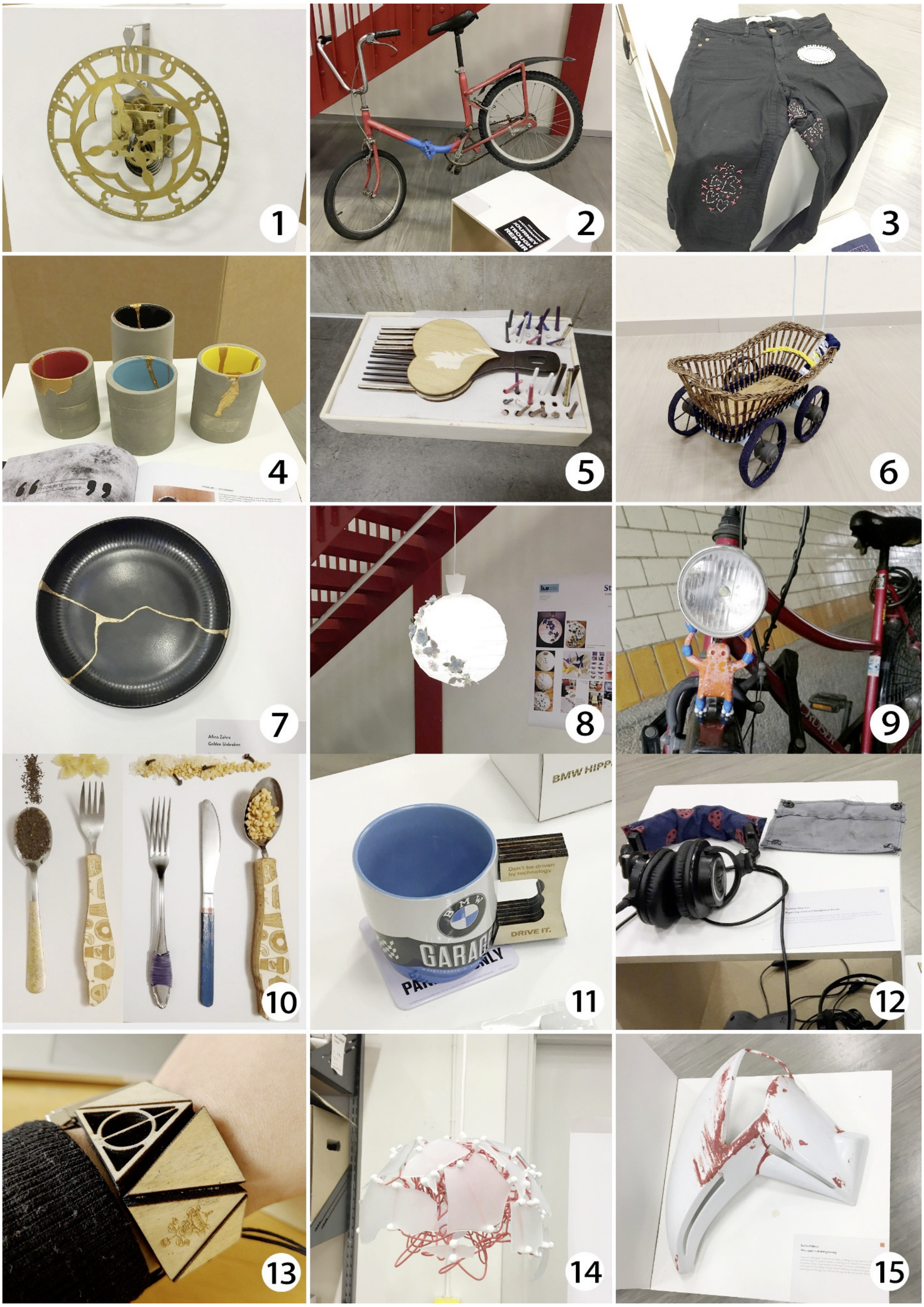

Figure 2. The students have visibly repaired a diverse range of physically damaged products including bicycle, leggings motorcycle part etc.

products and fix them together with volunteer repair specialists (Charter & Keiller, 2016). The aim of this task was to connect with users and to have a better understanding of their perception of the damaged products and visible repair. In the Repair Café, 26 products were repaired. There were both technical and aesthetic repairs. The third task was designing (the touchpoints of) a system in which products are repaired, considering the diverse aspects of a system such as product design, service design, retail design, information design, business models, economic viability and legal frameworks in varying depth. The students worked in three groups and the list of projects that they developed can be seen in Table 2.

Groups	Project Name
1	Stitch & make
2	Utopia
3	Fiber Futures

Table 2. List of the students who worked in three groups for the system of repair assignment and their projects.

The triple task process triggered more learning perspectives than a single perspective would have. For example, some students explored mending textiles during the first assignment. Some of them already knew how to saw and helped others. This assignment enabled them to realise that each of them had skills in certain areas, so they divided repair jobs according to their skills for the second assignment. During the Repair Café, students mending textiles sat together to be able to use the tools together. This gathering resulted in a collaborative, creative environment where they helped each other and created ideas together. This creative experience shaped Group 3's third assignment. They designed Stitch & Make Sewing Workshop to create a similar setting in local communities where people can mend clothes together and learn from each other.

At several points during the course, reflective sessions were held to help students articulate the higher-level learnings from their separate projects, such as a focus group-style session aggregating the insights from the different individual visual repairs (Özkan & Wever, 2019). Finally, students organised an exhibition and presented the combined results of these three tasks at the university.

After the assignment, a focus group session was conducted to understand students' insights into the process. Additionally, students were asked to prepare a project report at the beginning of the project and reflect on their experience and write about their learning experience. Data from the focus group session, students' project reports, presentations, and studio discussions were collected and used to develop the outcomes of this research. The learning perspectives of this research include circular thinking perspective, seeing the repair possibilities, the stigma of repair, interest in the circular economy, understanding limited resources, exploring community value and exploring alternative user perspectives.

Results

In this part, we will explain seven learning perspectives that resulted from the triple task approach and include some of the design outcomes that students have developed.

Circular thinking perspective

Acquiring the circular thinking perspective together with understanding the impacts of the dominant linear growth-based system is a complex task that cannot happen overnight. On the other hand, visible repair forms a challenge to our ways of thinking about things, so that it could be an effective strategy to help students start to grasp the hegemonic effects of conventional production and consumption patterns. The actual repair course extends the focus of conventional product design education from the design and use phases towards the circularity of an object's life. Because of the emphasis on the visibility of the repair, students also questioned some social norms. For example, Student 3 mended her leggings which were ripped inside part of the thighs. She used bright coloured threads and sashiko technique which is a traditional Japanese decorative embroidery (Figure 3). Although she created a design that she liked and wanted to wear, she did not wear them as she was embarrassed and worried about what would other people think.

Figure 3. Student 3 mended the leggings that have the same damage inside of the thighs.

Seeing the repair possibilities:

Seeing repair as a part of the products' life cycle and designing for repair are important abilities that impact the increased utilisation of products accordingly reduction of waste. For some students, this assignment was an opportunity to repair the objects that they have been keeping in their homes and planning to repair (Students 1, 2, 3, 5, 8 and 11). For example, Student 8 stated in her project report that: 'Actually, it was always felt that this project came to me as a chance to do something I have always wanted to do, which is fixing a valuable object that was giving me a burden seeing it ruined and not able to mend it due to lack of time. It was this assignment's main point to find damaged objects. In addition to that, the assignment improved their knowledge about repair and damage. Therefore, they started to see more solutions and possibilities to repair objects. Student 1 showed his/her increased interest by stating that: 'I want to say that I now see more solutions and possibilities to actually sit down and repair objects.' Similarly, Student 14 explained how he saw the broken lampshade as an opportunity to create something beautiful through fixing it (Figure 4). As he stated: "As with Japanese Kintsugi, the repair emphasizes the mends rather than attempting to conceal them. This creates a whole new type of aesthetic value. The fact that the shade broke opened opportunities for aesthetic repair."

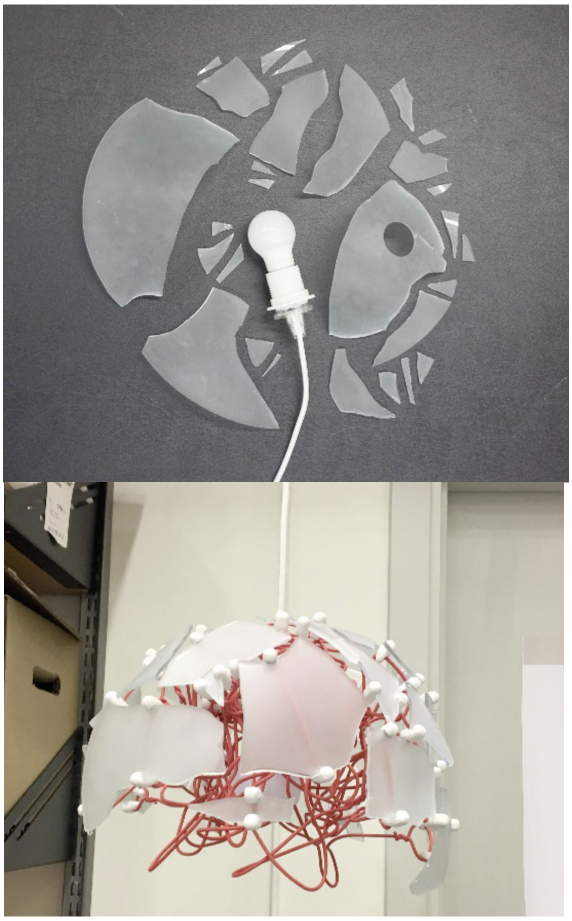

Figure 4. **Student 14 reconstructed the broken glass lampshade and created a new one by using the broken glass pieces and 3D printed parts.**

The stigma of repair

Throughout history, repair has been associated with poverty and hardship, therefore a negative stigma is attached to repair and repaired products (Terzioglu, 2017). Although the socio-economic circumstances have changed especially in today's throwaway society, the stigma still affects people's perception of the repair. We observed that it influenced some students' initial thoughts related to this assignment (Student 1, 11, 12). Student 11 found the repair task confusing and unexciting at first as she stated that "At the beginning of the project I was quite confused and not so excited about it. Because I would not normally go for repairing stuff that got broken if it means having to learn about tools." She also added: "Repairing can be fun …. Sometimes things are not as boring as they look." Some of the students did not see the creative part of the repair activity at the beginning of the project. Itis understandable as a repair is not often assumed as beautiful and as it can be designed.

Interest in the circular economy

Students' comments evolved in time throughout the project showing the increase regarding their interest in environmentalism and circular economy. Some of them aimed to create awareness through their projects. They wanted to inform users and designers about how important repairing is, instead of buying new stuff in terms of eliminating waste and solving environmental problems. For example, Student 4 stated that 'The overly complicated and heavy effort method that I used to repair these cups was necessary to show the importance of repair and raise awareness about the materials and usage in our everyday products.' (Figure 5). He also added 'This design project invites designers as well as consumers to think about the products before disposing of them, explore different ways to repair and appropriate their products before throwing them away.'

Figure 5. Student 4 aimed to inspire people to explore different ways to repair their products before throwing them away.

A similar attempt can be seen in Groups 3's system of repair project. It focuses on the lifecycle of clothes and aims to create awareness about the global textile manufacturing industry. The group searched for different ways of educating people about the reality of the textile manufacturing process. They developed three concepts that focus on different stages of the system (Figure 6). The first one is the Materialism Kit. It gives the user the chance to experience growing cotton at home and then creating a fabric with the cotton that they have cultivated. It is a creative way of emphasizing how much effort, time and resources go into a piece of fabric that customers usually do not think of and take for granted in the current throwaway society. The second one is the Spool Museum. It is a museum concept design that enables visitors to see the material selection stage, manufacturing process, retail stage and post-life of clothes. Their third concept Stitch & Make Sewing Workshop aims to create local communities where people mend textiles together.

Figure 6. Group 3's system of repair project aims to create awareness about the global textile manufacturing industry.

Understanding limited resources

The existing growth-based industrial system is challenged by real or perceived material scarcity and volatility of prices. The world does not have limitless resources; thus, novice designers must grasp its capacity and acquire the ability to use the resources effectively. Students emphasised this topic in their system design projects. For example, Utopia project visualises a community that is based on the principles of the circular economy. The inhabitants of this city have the awareness of the worlds' limited resources and they use various systems to make the most of the value of their products.

Exploring community value

Repair Café organisation has led to a rich way of participatory engagement compared to the traditional repair services where the customer is not involved in the repair process. Students applied the Repair Café model as it is. Initially, they prepared posters and put advertisements on social media to attract people. Participants were asked to bring broken products. Students repaired the objects together with the users. The importance of working in partnership with users lies in learning from users, educating people and creating a community. Through education and awareness, customers become active users who are aware of their rights and confident about finding or advocating for solutions to their issues. Similarly, creating a community could lead to user-led movements or organisations and empower the existing ones, in this case, Repair Cafés.

Exploring alternative user perspectives
Repair Café created a platform for students to engage with users and discuss their products. It ultimately helped them to find solutions and fix the problems. This creates benefits both for users and students. Students had the chance to conduct interviews with some of the participants. They discussed what participants think about damage and repair. Participants told the stories of their objects. Students learned the value of objects to their users and got valuable insights about product design and repair.

Conclusion
This paper contributes to the existing literature by providing a case of incorporating repair into product design education, and by exploring how doing so through three different perspectives enables deeper learning than a single perspective would have. Resulting from this research, learning perspectives and their implications were presented to serve as guidance for educators aspiring to challenge environmental issues. More courses and research are needed to effectively translate the sophisticated theories into pedagogical action, which may, in fact, do more than creating less harm. Conclusions aim to encourage researchers and academics to reconsider the product design education and the needs of product designers in the transition period and a circular economy.

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Demystifying Process-level Scalability Challenges in Fashion Remanufacturing Business Models

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Keywords: Remanufacturing; Upcycling; Fashion; Scalability; Process Interdependence.

Abstract: The purpose of this paper is to investigate how process-level challenges can be solved in order improve scalability of fashion remanufacturing. Fashion remanufacturing has the potential to extend product use life, improve resource and energy efficiencies, deliver lower eco-costs, and at the same time enhance customer value in circular economy. However several challenges currently hinder the industrial scalability of fashion remanufacturing business models. At the process-level these are predominantly related to limited repeatability, lack of standardization, high variability and volume uncertainty. To explore these scalability challenges and prescribe solution, the paper adopts an in-depth case study with a successful Swedish charity-owned remanufacturer. A systematic evaluation reveals clear solutions from a process interdependence perspective (decoupling, formalization and asset specificity) to overcome the scalability challenges related to low sourcing material availability, demands for high skill requirements, and time-consuming processes. First, our case study reveals a formalized approach to determine product-process categories defined by production volume and degree of remanufacturing. Second, by exploring the supply and operational capacity requirements i.e. input material volume, remanufacturing skillset and lead time demand of the 6 different remanufactured product groups mapped along these categories we identify process-level requirements for scalability, and challenges when these are unmet. Decoupling key sub-processes (disassembly and reassembly) reduces the interdependence thus increasing the scope of standardizing the input material for different product groups. In addition, formalized approaches also allow higher routinization of the processes thus generating high specificity of the remanufacturing skillset across different product groups resulting in more process repeatability.

Introduction

Global fashion consumption has nearly doubled since 2000 largely due to the rapid expansion of fast fashion (Pulse of Fashion Industry, 2017). This has resulted in increased fashion waste to about 91 million tons (in 2015), i.e. roughly 17.5 kg per capita (ibid.). A large part is landfilled or incinerated and globally only 20% is collected for reuse or recycling. In this context, remanufacturing in the fashion industry can play a vital role to extend product use life, improve resource and energy efficiencies, and deliver lower eco-costs, as can be observed in other sectors like automotive (Goodall et al., 2014; Vogtlander et al., 2017). In addition, second-hand clothes upgraded through remanufacturing may provide a new look, aesthetics and customer value through such *fashion upgrade* (Pal and Gander, 2018). This has encouraged many fashion designers to undertake remanufacturing.

However several challenges currently hinder the industrial scalability of fashion remanufacturing business models (Pal and Gander, 2018). At the process-level these challenges are predominantly related to limited repeatability, lack of standardization, high variability and volume uncertainty, thus making it difficult to formalize and optimize (Dissanayake and Sinha, 2015; Kurilova-Palisaitiene et al., 2018). Scalability, in this context, refers to the industrial process approach that can be carried out preferably in "factory" environment with certain degrees of reproducability (Goodall et al., 2014). As a consequence, fashion remanufacturing today is practiced mostly in craft or pilot scale, described as upcycling or redesign (Cassidy and Han, 2013; Pal and Gander 2018). Additionally garments are non-modular in product architecture, unlike mobile phones or computers, which makes dis- and re-assembly unproductive, less efficient and time-consuming. This highlights the importance of exploring remanufacturing challenges and solutions in the fashion industry. The purpose of the paper is *to investigate how process-level challenges can be solved in order to improve scalability of fashion remanufacturing*.

Literature background

Fashion remanufacturing

Remanufacturing can be defined as an industrial process to restore the core part of end-of-use products as it passes through several steps, such as inspection, disassembly, refurbishment, cleaning, reassembly, and testing to ensure meeting desired product standards (Goodall et al., 2014; Kurilova-Palisaitiene et al., 2018).

Unlike in other sectors such as automotive and machine tools where remanufacturing is largely related to efficient reclamation of the core parts, predominantly using hybrid manufacturing/remanufacturing, in fashion context it aims at remaking of used clothes through upcycling so that they at least equals to newly manufactured garments in terms of quality. Dissanayake and Sinha (2015) define remanufactured fashion as *"fashion clothing that is constructed by using reclaimed fabrics, which can be either post-industrial or post-consumer waste or a combination of both"*.

However what differentiates remanufactured fashion from upcycling is the focus towards process-level industrialization to reach certain degrees of scalability. Fashion remanufacturing is achieved through efficient reverse logistics and product development. Reverse logistics start with retrieving the discarded garments from various sources, followed by their sorting on the basis of a number of criteria, like fabric type, color, and product category (Dissanayake and Sinha, 2015). Followed by an optional cleaning stage the sorted items are ready for remanufacturing. Dissanayake and Sinha (2015) highlight five-steps underlying the product development process:

1. Trend and material analysis
2. Concept development starting with manual disassembly by unpicking the seam threads or cutting along the seams, followed by design development often using either draping techniques or pattern cutting
3. Sample preparation to develop a collection for potential retail buyers
4. Pattern development and single-ply cutting manually from the flat fabrics
5. Final assembly as an individual/whole garment.

From a decision-making perspective, disassembly and reassembly activities are based on the creative eye of the designer and bounded rationality of the remanufacturer, thus highlighting the presence of rule-of-thumb based heuristics.

Process-level challenges in fashion remanufacturing

It has been highlighted that commercial success of remanufacturing fashion is highly dependent on the following:

- Reducing variability of the quality and quantity of incoming materials and finished products

Remanufacturing largely relies on the collected material from the waste stream. This leads to uncertainty in the quality and quantity of the collected and recovered material. This pinpoints the importance of collaborations to ensure efficient reverse flow of material. During product development this also hinders pattern cutting due to variance in the dimensions of the input fabrics, their types, prints and colors. Repeatability is negligible except that of the design.

- Efficient process planning to reduce unpredictability

Generally disassembly and pattern cutting are manual operations hence costly, unproductive and time-consuming and also increase the material consumption (Dissanayake and Sinha, 2015). Designers' skills and technical capabilities together with tacit knowledge have a crucial role in increasing fashion remanufacturing production efficiency and volume.

Methodology

Given the purpose of the paper, we adopt an in-depth case study approach owing to its exploratory nature to study the scalability challenges.

The case study is conducted with a Swedish fashion remanufacturer (say *Remake*). *Remake* is a part of one of Sweden's largest charity and produces 2200-2500 pieces/year across 25 different products at 3 remanufacturing facilities. It produces fashion items like jackets, shirts, trousers, as well as accessories such as bags and computer cases. These items can be classified as unisex, uni-size and freestyle, as the style, design and the patterns remain the same throughout the year, with slight adjustments being made in the material, fabrics and color palette.

In this research, data was collected primarily through on-site observation of product development and remanufacturing activities for six weeks spent at *Remake* facilities. These observations were documented in a variety of formats, audio (interviews), visual (process maps, photographs) and textual (field notes, *Remake* documents, e.g. product development and constructions diagrams). Narrative interviews were conducted with key personnel, such designers, seamstresses and pattern makers to get snapshots of *Remake*'s processes. Data were aggregated and utilized collectively. For instance, the visual representation of the products/processes provided first-hand information of the remanufacturing processes which then was rechecked through the qualitative information gathered via interviews.

Results and findings

The case study reveals a formalized approach, compared to rule-of-thumb heuristics to organize remanufacturing process at *Remake*. This largely serves as a foundation for understanding how process-level scalability challenges (uncertainty and variability) are addressed.

Product-process categories in fashion remanufacturing

Remake's product categories are defined on the basis of production volume. As in fashion remanufacturing standardization can be difficult to achieve due to lack of repeatability of the incoming material, the production order volumes are considerably small compared to conventional apparel production, yet significantly higher compared to redesign and upcycling pilots. Based on remanufacturing experience, *Remake* has heuristically determined three categories to define yearly production volume for each product; these are:

- *Mass volume*, refers to yearly production $V \geq 100$ items,
- *Standard volume*, if $10 \leq V < 100$, and
- *Limited volume*, if $V < 10$.

Further on-site observation reveals three different remanufacturing process structures at *Remake*, largely determined by the degree of disassembly and reassembly required during remanufacturing.

1. "Sewn from scratch" – Products are first fully-disassembled, i.e. totally opened up and un-seamed and turned to flat fabric. The smaller pieces of fully-disassembled products are sewn together to make wider and longer fabric "snakes" from which an entirely new fashion product is produced by making completely new patterns.
2. "Cut, add and put-together" – Products are semi-disassembled and semi-reassembled. Disassembly is limited to few major or minor cuts at specific predetermined locations. Depending on the design and style of the new product, the old garments which have already been cut into major pieces are stitched together.
3. "Minor-value adding" – Products are not cut or disassembled, instead remanufacturing is conducted only through certain value-adding recoupling activities, e.g. stitching, beading, embroidering and patching.

Typically the number of steps also varies: for full remanufacturing, number of process steps N is ≥ 8, for semi remanufacturing ($5 \leq N < 8$), and for minor remanufacturing ($4 \leq N$).

Evaluating fashion remanufacturing process scalability challenges for different product groups

Mapping *Remake* products onto the product-process categories reveals 6 distinct product groups, as shown in Table 1. Considering that the supply and operational capacity requirements i.e. input material volume, remanufacturing skillset and lead time demands (see Dissanayake and Sinha 2015), are vital to determine the process-level competence of remanufacturing operations, the challenges were noticed to be surfacing out when these requirements were unmet.

- **Input material volume (I_v):** Ease of sourcing indicates the difficulty in accessing the desirable material, mostly second-hand garments for each product group. Depending on factors such as fabric material, size and style, I_v (in kgs per month) varies. Input materials also go back to the sorting plant after each quality check. *Remake* classifies I_v into: *Easy* ($I_v > 100$ kgs), when there is a constant uptake of the input materials for remanufacturing, *Semi Easy* ($10 < I_v < 100$ kgs), when the material is relatively easy to find yet not necessarily appropriate for remanufacturing, and *Hard* ($10 \leq I_v$), when it is hard to find.

- **Lead time demand (LD):** This indicates how time-consuming the processes are for each product group. At *Remake* this is categorized as *High* if LD is more than two days, *Intermediate* if between one and two days, while *Low* if lesser than 24 hours. LD includes non-value adding time (e.g. waiting time between dis- and re-assembly stages) that is typically higher with higher level of disassembly.
- **Skillset requirement (T):** This is normally decided in terms of the experience gained by the workers in terms of weeks of training received. *High skillset requirement* refers to when experienced tailors who have been trained for more than 8 weeks are demanded to do remanufacturing. *Moderate skillset* requirement refers to involvement of tailors who haven't had any experience in sewing in the past, but have been under training for a period of 1-2 months. *Low skillset* requirement indicated that the remanufacturing can be conducted by involving tailors who have been under training for less than a month. To note that not necessarily all the trainees manage to develop same level of skills over a given time, however trainees mostly are proven to gain relatively high level of sewing and cutting skills over a period of 2 months.

Group	Product-process category	I_v	LD	T
1	Limited Volume + "Sewn from scratch"	Easy	**High**	**High**
2	Standard Volume + "Sewn from scratch"	Easy	**High**	Moderate
3	Standard Volume + "Cut, add and put-together"	**Hard**	**High**	Moderate
4	Mass Volume + "Cut, add and put-together"	Easy	Intermediate	Moderate
5	Standard Volume + "Minor-value adding"	Easy	**High**	Low
6	Mass Volume + "Minor-value adding"	Easy	Intermediate	Moderate

Table 1. Mapping the product groups.
*__Bold__ – highlights the key process-level scalability challenges.

It can be concluded that the products (Groups 1 and 2) that are made through full remanufacturing demanded both higher T and LD to remanufacture. These constraints restricted the production volume even though sourcing was not a concern with continuously available materials. The semi remanufactured products (Groups 3 and 4) typically require lower LD and T; thus higher production volume could be attained for such products. However, reassembly in product group 3 require adding 2/3 garment parts onto the base garments, and producing such products require careful mixing and matching of not only style and color but also sizes, and rigorous quality check after every remanufacturing step, that makes LD high. These supply and operational constraints reduce I_v. The products with no disassembly and minor value addition (i.e. Groups 5 and 6) also demand lesser T and LD. However, the patched products (Group 5) require higher LD to manually attach multiple patches on the base denim garment. Compared to denims, group 6 products required lesser patchwork LD due to several factors such as choice of fabric type, design elements and size of selected patches.

Analytical discussion

The study clearly demonstrates that identifying and mapping fashion remanufacturing product-process is instrumental for improving the scalability potential.

Remanufacturing process conditions	Process-level scalability challenges	Scalability solution observed
Sourcing of input material	Low input material volume (as in 3). Process demands aggregated over dis- and re- assembly stages are high to create high filtering/removal (as in 3).	In most cases de/low coupling between disassembly and reassembly places lesser aggregation of stringent requirements on what to source, e.g. forming "snakes" is independent of reassembly type and styles in 1 and 2. Also in no-minor (5, 6), the value-added patchworks etc. are independent of input material type (passing quality checks).
Process lead time demand	Time consuming processes (in 1, 2, 3, 5). Low remanufacturing volume	Improving process-level efficiency by creating formalized rules for disassembly. For full disassembly both standard and non-standard panels are developed (1 and 2), for semi-disassembly cutting is done at set positions and places (3).
Skillset requirement	Low production throughput when skills requirements are high	In most cases workforce skills were improved by creating standard codifications of techniques in order to routinize activities, e.g. in fully-disassembled + fully-reassembled products by forming snakes in standard, repetitive manner. Low skill specificity for different product groups to reduce challenges of dealing with high process variability.

Table 2. Analysis.

Decoupling (of disassembly and reassembly sub-processes) was observed in case of two remanufacturing process structures, either by producing standard "snakes" independent of the type and style of remanufactured products newly developed, or through upcycling activities (e.g. patchworks) independent of the input material type. This reduced the interdependence between the two sub-processes, thus increasing the scope of standardizing the input material for different product groups.

Remanufacturing literature have mostly highlighted rule of thumb-based heuristics in remanufacturing (Gallo et al., 2012), based on the creative eye of the designer and decision-making of the remanufacturers (Dissanayake and Sinha, 2015). But at *Remake*, compared to redesign or upcycling, design concepts and ideas are not generated solely through rule-of-thumb experimentation but more formalized approach is taken towards developing procedures for disassembly and reassembly. In fact once the heuristic product development method has been established, simple "rulebooks" created at *Remake* are used to routinize the process, e.g. to determine the number and combination of different-sized panels for constructing the "snakes" for fully-disassembled products, or for determining specific cutting positions for semi-disassembled products.

Such formalization also generates high specificity of the remanufacturing skillset, but across different product groups due to standardization of the sub-processes, thus allowing more process repeatability.

Conclusions

A systematic evaluation of *Remake*'s products, processes and their key sourcing and operational conditions reveal clear solutions from a process interdependence perspective (decoupling, formalization and asset specificity) to overcome the scalability challenges related to low sourcing material availability, demands for high skill requirements, and time-consuming processes in fashion remanufacturing. Theoretically, this implies that we need a better understanding of the how to create workflow and resource interdependencies in remanufacturing processes, on the top of lean improvements (Kurilova-Palisaitiene et al., 2018), for improving scalability.

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The Circular Economy Analyst – A Tool to Estimate the Environmental Effects of CE Strategies

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Keywords: Circular Economy, Product Carbon Footprint, Life Cycle Assessment, End of Life, Circular Economy Strategies.

Abstract: The aim of a Circular Economy (CE) is that products, components and materials are kept within loops at their highest value for as long as possible. Graphic representations of technical material loops such as the butterfly diagram (Ellen MacArthur Foundation, SUN, & McKinsey Center for Business and Environment, 2015) or the Value Hill (Achterberg, Hinfelaar, & Bocken, 2016), convey this central idea. They also show how CE strategies can be organized hierarchically dependent on their value capture potential. From a resource efficiency perspective, maintenance is preferable to remanufacturing, which is preferable to recycling. The paper describes the methodology of a webtool named CE Analyst, with which users are able to quantitatively estimate the potential changes to a products' environmental footprint of a given "linear" product, when applying one or more CE strategies. The aim is to compare the effectiveness of the different CE strategies in terms of their Product Carbon Footprint and by that give users guidance in the process of designing environmentally sound circular product systems.

Background and Context

The tool described, is part of the training materials developed within the EU-funded project KATCH_e (Knowledge Alliance on Product-Service-Systems towards Circular Economy and Sustainability in Higher Education). It is currently being tested and applied in various trainings. Currently the tool is in the process of being implemented as a webtool, and part of a toolkit. This set of tools offers two more tools named CE Designer and CE Strategist, where the mentioned circular strategies are also cross-referenced. The CE Designer is a semi-quantitative checklist tool which aims to integrate the design implications of different circularity strategies in the product and service development. Similarly, the CE Strategist is a tool which offers guidance and examples in the Business Model Innovation Process. They are already partly available under the URL tools.katche.eu.

Introduction

In a CE as it is broadly understood today, the "inner circles" such as repair, reuse and remanufacturing are emphasised (Kirchherr, Reike, & Hekkert, 2017). The graphic representation of the "Value Hill" (Achterberg et al., 2016) shows a typical products life cycle with the potentials of a CE.

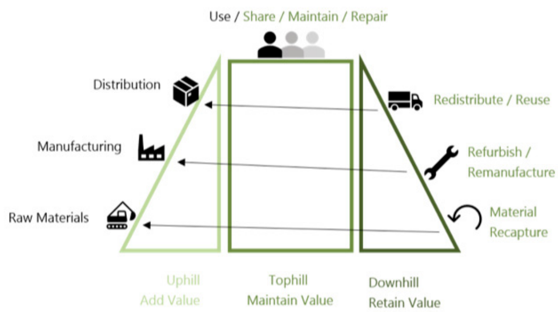

Figure 1. The Value Hill in a Circular Economy © Source: adapted from (Achterberg et al., 2016).

In the pre-use phase on the way uphill value is continually added, through the phases of raw material extraction, production and distribution. In a "linear" economy the built-up value is lost rather quickly. This contrasts a CE where the focus is on the highest possible value capture option. The uphill phase is key to enable these potentials, through a design that enables the value capture in the later stages.

What is described as value in this model can also be seen as the cumulated environmental impacts, that ideally should be saved through longer life times, efficient use and keeping products in the loop on the way downhill. If only the materials of a product are regained through recycling at the end of use, all the efforts from the manufacturing and distribution stage are lost.

However, for particularly raw material-intensive products the environmental benefits of recycling might still be substantial. This depends on the individual environmental profile of a product. The calculation of the Product Carbon Footprint (PCF) shows which life cycle phases are particularly relevant in terms of their environmental effects. The products PCF-profile therefore also informs how much of the products impacts may be shifted, averted or lowered through the application of different CE strategies. This is the understanding the tool builds upon.

Methodology

The eight circular strategies

The CE Analyst tool needs quantitative carbon footprint data of a "linear" product system for the five life cycle phases. Linear, in this context means that none of the CE strategies are yet applied, and products are disposed at their end of life.

Described in the table below are the eight CE strategies that can be modelled with the tool. The strategies are both design and business model centered.

Life Cycle Phase / CE Strategy		Explanation
Uphill	Circular Sourcing	assumes that different material inputs are used and/or a certain fraction of materials are recycled from old products and reused in the production process;
	Maximising Production Efficiency	focuses both on maximising the material and energy efficiency in the production process. (e.g. Industrial Symbiosis, Renewable Energies, waste heat recovery, etc.)
	Product Redesign	assumes that the whole product is redesigned to actively enable end-of-use scenarios and/or prolonging the life-time by designing high-quality products.
Tophill	Life Extension	Spare parts are sold to prolong the use time of a product
	Sequential Use	assumes that one product is used sequentially by multiple users, e.g. through a pay-per-use business model.
	Pooling Use	assumes that one product is used by multiple users at the same time, through a sharing business model (e.g. car pooling).
Downhill	Reuse	assumes that a product has reached its "end of need-phase" and is redistributed to another user without reprocessing or treatment
	Remanu-facturing	assumes that the product is returned to the manufacturer and faulty parts are replaced. The product is returned to the same or a new user as good as new.

Table 1. Overview of the CE strategies applied in the CE Analyst tool.

Defining the linear reference scenario

As a first step the user is required to define the parameters of the linear scenario and put in the life cycle data of the products' PCF for the five life cycle phases: raw material extraction, manufacturing (construction and production), distribution, use and end-of life. These life cycle phases are based on the ISO 14067 – Greenhouse gases - Carbon footprint of products.

Secondly the tool requires the user to put in a description of the functional unit of the product system to allow a comparison with the modelled CE scenario. Particularly important for a viable comparison is the definition of the product life time and the use intensity.

Dependent on the environmental profile of the linear reference product, the tool shows the so-called "maximum circular value capture" (MCVC) of the predefined CE strategies. The MCVC is defined by the share of life cycle phase impacts, which are potentially captured through CE strategies and describes the highest possible environmental improvement from applying the strategy.
For example: The strategy "Pooling Use" potentially reduces the impacts of all life cycle stages, as it captures value at the top of the value hill. It potentially also changes the

impacts in the use phase as these are shared among multiple simultaneous users. The MCVC of pooling is therefore always at 100%.

On the other end of the spectrum, the strategy circular sourcing only potentially reduces the phases of raw materials and end of life. The following table provides an overview of the life cycle phases which are potentially impacted by the strategy.

Life Cycle Phase / Strategy		**Raw Materials**	**Manufacturing**	**Distribution**	**Use**	**End Of Life**
Uphill	Circular Sourcing	x				x
	Maximising Production Efficiency	x	x			x
	Product Redesign	x	x	x	x	x
Tophill	Life Extension	x	x	x		x
	Sequential Use	x	x	x		x
	Pooling Use	x	x	x	x	x
Downhill	Reuse	x	x	x		x
	Remanu-facturing	x	x	x		x

Table 2. CE strategies and their potential influence on life cycle stage impacts.

The MCVC Indicator provides a first orientation of environmental improvement options. By definition, the highest potential is always given with the CE strategies “product redesign” and “pooling use”. However, these obviously may not be applicable for all products.

Modelling the circular scenario

The user can now evaluate the best fitting options for the reviewed product. The selection depends on the products’ suitability for the respective strategies and the MCVC.
To define the CE scenario, the environmental effects are modelled from the inputs of the reference scenario. Each of the strategies relates to different influence parameters. E.g. the strategy “pooling use” affects among others the product use intensity. Reuse aims to prolong the product life time, and so on.

The modelled impacts can be distinguished in four different groups

1. Impacts of a production or product redesign
2. Impacts of a changing product use time
3. Impacts of a changing use intensity
4. Impacts of keeping products in the loop

Table 3 shows a detailed overview, which configurable parameters relate to the individual CE strategies. Dependent on the chosen strategy the user models the parameters, which relate to the inputs from the reference product, e.g. What share of the product – always in terms of its PCF - can typically be reused for a second life cycle? How many users use the product simultaneously in a pooling business model? How much effort is it to redistribute used products to new clients? etc; The user sets each parameter as a ratio that relates to the reference product. The tool provides supportive information in order to help set realistic estimates and encourages the user to document the assumptions behind the variables.

The result page shows a comparison of the linear product system with the modelled circular product system. Additionally, it shows both how the new PCF compares with the linear product system and how much of the MCVC was realised. In methodological terms the system boundaries of the linear product system are adapted according to the parameters set for the circular product system. For example, if a products’ lifetime is prolonged through a repair service, the system boundary of the circular product system is expanded accordingly and the impacts of life cycle stages (except the use stage) are split among the newly defined life time.

The combination of multiple strategies is also possible. Especially combining design-focused uphill strategies, with Business Model-related top- or downhill strategies is encouraged. For example: Modelling the changes of a product redesign (e.g. easy disassembly with a modular structure), so that life extension services become possible later on. To do so, the user is able to save the result of each interim result, as the reference product system for the modelling of the next CE strategy.

Life Cycle Phase / Strategy		Production or product redesign					Product life/ time		/Product use intensity		Keeping products in the loop		
	Configurable Parameters	Raw Materials	Manufacturing	Distribution	Use	End of/Life	Life time extension[1]	Impact on life time due to intensified use	Use intensification due to better access	Use intensification due to simultaneous use	Share of reusable product[2]	Remanufacturing Effort[3]	Redistribution effort[4]
Uphill	Circular Sourcing	x				x							
Uphill	Maximising Production Efficiency	x	x			x							
Uphill	Product Redesign	x	x	x	x	x	x						
Tophill	Life Extension						x				x		x
Tophill	Sequential Use							x	x				
Tophill	Pooling Use							x	x	x			
Downhill	Reuse						x						x
Downhill	Remanu-facturing						x				x	x	x

[1]either through redesign, repair services, reuse or remanufacturing
[2]share of the product (in terms of its PCF) that is reusable in the next life cycle
[3]describes the impacts related to remanufacturing, as a share of the manufacturing process
[4]describes the redistribution effort for a new user, as a ratio of the distribution effort in the first life cycle

Table 3. Configurable parameters for each CE strategy.

Conclusions

The tool presents a method to use existing PCF-data to (1) estimate the maximum potential of different CE strategies, (2) model and combine the effects of their application and (3) enable a comparison of their environmental performance.

The aim is to provide a quick orientation regarding the environmental performance of different CE-inspired product innovations. The tool builds on the existing data of a reference product. Therefore, the results are only as conclusive and significant as the knowledge about the data behind it. Therefore, significant knowledge about the products' PCF is a perquisite for meaningful results.

In some cases, the functional unit might also need to be redefined substantially. E.g. Sharing scenarios must also cover potential rebound effects (e.g. a changing usage behaviour due to ride sharing) which should be included in the interpretation of the results (Coulombel, Boutueil, Liu, Viguié, & Yin, 2018). The tool is designed to provide orientation regarding environmentally sound decision making in product and business model innovation, but not to substitute the need of LCAs.

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PLATE
Product Lifetimes And The Environment

Behavioral Change for Circular Electronics

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Keywords: Consumer Behavior; Behavioral Change; Sustainable Consumption; Nudging.

Abstract: Consumer behavior is a critical factor for sustainable production and consumption. Traditional approaches in promoting sustainable consumer behavior has been dependent on information campaigns and other educational initiatives. But along with knowledge and awareness, psychological and social factors also play a role in human behavior and decision-making – a fact often ignored by such educational campaigns. Several theoretical frameworks, evolving from fields including psychology, economics, and social and behavioral science, have been used to explain pro-environmental behaviors. These theories and related intervention tools can be insightful in understanding the behavioral problems linked with consumption. As governments also start considering behavioral elements in environmental policies and campaigns to increase citizen participation, the right choice of tools and interventions is crucial. The growing discussion on circular economy for consumer products could benefit from the inclusion of behavioral insights. However, there is no 'one-size-fits-all' solution for addressing diverse problems around manufacturing, use and recycling of consumer goods, which the concept of circular economy aims to tackle. Here we review the elements of behavioral change and identify opportunities for behavioral interventions to support a circular system using the case of electrical and electronic products.

Introduction

The growing use of electrical and electronic products (e-products) and the resulting waste (e-waste) has been one of the focus areas in the discussion of resource sustainability mainly due to shortening product lifetimes, the use of critical resources and challenges in resource recovery from e-waste. The concept of the circular economy is considered to be relevant for sustainable use of e-products as well as for better management of e-waste (Parajuly and Wenzel, 2017). Despite the identified potential, there are several technological as well as socio-economic challenges needing to be addressed in order to promote a circular economy in the electronics sector.

In recent years, circular economy has become a popular concept that advocates lifetime extension, reuse and repair of products and components, innovative and resource-efficient business models, and better resource recovery at the product end-of-life. Accordingly, significant effort has been spent on the technological and economic aspects of circular systems. The role of consumers, and the significance of consumer behavior in a circular economy, however, is not equally explored.

In general, it is assumed that people – especially in industrialized countries – are aware of environmental issues and therefore are expected to participate in sustainable consumption practices. Nevertheless, there are gaps between consumers' perception and their actual everyday behaviors. For example, the majority of Europeans are aware of environmental issues linked to our consumption model and the importance of effective use of resources. Many of them claim to participate in product lifetime extension, and to be willing to try reused items or alternative business models such as leasing. The practices however, do not reflect the claims made by the people. When asked, 25% of Europeans say they will lease select e-products but only 1% have ever done so. Similarly, 40% say they would buy used e-products but only 6% have ever bought used items. And while 76% claim to sort their e-waste, only 35% of e-waste is collected in the

European Union (Cerulli-Harms et al., 2018; European Union, 2014). Wrong disposal of e-waste in undesignated bins and stockpiling of used e-products in households has been a major factor contributing to the lower collection and recycling rates (Nowakowski, 2016).

Often, it goes uninvestigated whether and to what degree consumers are going to comply with new policies, technologies, business models and infrastructure that aims at supporting a circular economy. At best, there are information campaigns and it is assumed that as rational beings, people should make right decisions and take actions accordingly. However, people's behaviors are not always in line with their awareness and are also guided by several psychological and social motivations. Assuming consumer compliance as a given and relying solely on their informed decision-making in favor of 'circular' choices could therefore be the weak link of any initiative (policy or otherwise).

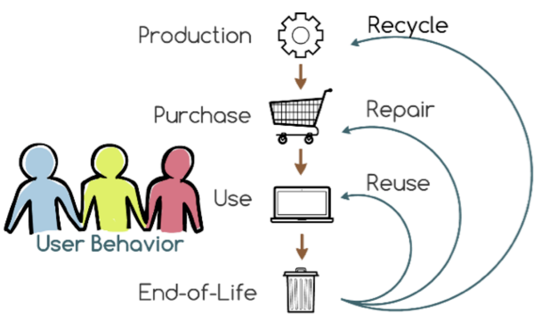

Figure 1. Consumers play an important role in the success of a circular system.

An ideal system for the circular economy should allow all stakeholders, including consumers and businesses, to engage in a fully circular economy through sufficient infrastructure and the right incentives. Stakeholders are often driven by monetary reward and/or legislative obligation but certain transactions in a circular economy rely solely on consumers' behavior. This includes choices such as repairing instead of replacing broken electronics, disposing of end-of-life (EoL) products instead of stockpiling, and recycling e-waste instead of wrongly discarding. Such behaviors have significant impacts on the success of e-waste collection and resource recovery, and in a larger context, of a circular system for e-products.

To this end, the goal of this paper is to shed light on the behavioral aspects of consumption with a focus on circular economy for electronic products. For this, we give an overview of behavioral elements and intervention tools linked to pro-environmental behavior, and explore their potential use in the transition towards a more circular system for e-products and the better management of e-waste.

Drivers of consumer behavior

Human behavior is a result of a complex interplay between external and internal influences and drivers (Martin, Weiler, Reis, Dimmock, & Scherrer, 2017). How a consumer makes decisions depends on external drivers such as economic incentives, infrastructure and technology, convenience, social context, temporal and institutional constraints etc. The study approach of disciplines including applied behavioral analysis and institutional or evolutionary economic focuses on these external factors. The examples of behavioral intervention based on the externalist approach include a combination of economic incentives and regulatory provisions in order to allow the right conditions to promote pro-environmental behavior (Jackson, 2005).

Another 'internalist' approach, popular in social and cognitive psychology disciplines, studies behavior as a result of internal factors such as values, beliefs, norms and attitudes (Jackson, 2005). Behavioral interventions coming from this approach include initiatives such as educational campaigns in order to make information readily available for consumers with the assumption that it will result in pro-environmental attitudes in consumers who will in turn make informed (and thus the right) decisions.

Several theories on pro-environmental behavior are built on these two approaches. Some have also tried to combine internal and external factors proposing integrated models. The norm-activation theory and the value-belief-norm theory are two most popular pro-environmental behavioral theories that link consumer behavior to cognition and moral judgement, and individuals' basic values, respectively. The theory of planned behavior is another popular theory used to explain pro-environmental behavior that does not take into account the moral aspects and suggests the consumer behaviors are shaped by rational decisions that are driven by individuals' intention (Turaga, Howarth, & Borsuk, 2010). These theories have been used in, for example, studying consumer perception towards recycling and reuse of mobile phones (Yla-Mella, Keiski, & Pongracz, 2015), assessing households' willingness to engage in e-waste recycling (Saphores, Ogunseitan, & Shapiro, 2012; Wang, Ren, Dong, Zhang, & Wang, 2019), and understanding the intention-behavior gap in e-waste recycling (Echegaray & Hansstein, 2017).

Despite the substantial literature available on behavioral theories for the management of e-waste, examples of interventions targeting behavioral change are hard to find. And when they exist, the effectiveness of these interventions are not well-documented. In fact, even the studies evaluating the constructs of the popular pro-environmental behavioral theories (moral as well as rational choice) are not conclusive. Besides the conventional public awareness campaign and economic incentives, more recent approaches in promoting pro-environmental behavior include frameworks such as community-based social marketing (McKenzie-Mohr, 2000) and nudging (Thaler & Sunstein, 2008).

Designing a behavioral intervention around one theory may not be sufficient, given that no framework is comprehensive enough to include all attributes linked to human behavior. For example, despite their popularity, rational choice models are criticized for being inadequate, mainly because of the absence of social norms and institutional factors that govern human behavior (Jackson, 2005). There are examples of modification of these theories (Botetzagias, Dima, & Malesios, 2015), calls for an integrative approach (Steg, Bolderdijk, Keizer, & Perlaviciute, 2014), and indications of multiple theories combined being effective (for example, community-based social marketing can work better when applied together with nudging) (Linder, Lindahl, & Borgstrom, 2018). It is also apparent that there is an interplay and overlap among the variables within and across theories. The mantra of social marketing, for example, shares much with the nudging approach (Barr et al., 2013). It is more important to focus on the challenge at hand than which theory to be used.

Prospects for behavioral change

The consumption of e-products, and thus the variety of products used in our daily lives, are only growing. This multiplicity of products offers a challenge in designing behavioral interventions. Different products, depending on their nature, require different strategies in a circular economy and therefore it is important to define the right 'circular' strategy for a given product group and lifecycle stage before designing behavioral interventions. For example, technologically 'matured' household appliances (e.g. a vacuum cleaner or a microwave oven) can be designed to last many years with strong build quality and ease of repair and maintenance. In comparison, IT equipment (such as smartphones) that often have more frequent technological upgrades may be more suited for leasing model allowing users to enjoy the latest technology, whereas producers can use the take-back system to make optimal use of the products returned after the lease period. Behavioral change campaigns should target these specific option for a given product.

Behavioral theories may be used individually or in combination to identify the best-suited strategy targeting the right behavioral variable(s) in a given situation and involving one or more stakeholders. In the case of e-products and e-waste, customized interventions to influence users' decision-making at targeted points during different product lifecycle stages can be more effective than trying to permanently change people's attitude.

Nevertheless, designing, implementing, and monitoring the effectiveness of behavioral change interventions could be challenging for several reasons. The existing examples show that there is a gap between the theoretical understanding of consumer behavior (coming mostly from the discipline of social sciences) and the design of circular business models and infrastructure (mainly depending on the techno-economic aspects of consumption). This gap, if not addressed properly, may lead to consumer behaviors not being aligned with the goals of a circular strategy. While it is important to understand the social and psychological aspects of consumer behavior, it is equally important to combine behavioral insights with the knowledge of product lifecycle in order to design effective behavioral intervention strategies.

Another major issue is the lack of ownership of the task. Often policies and governments are considered to be responsible for encouraging people to engage in behaviors to support any environmental initiative. However, behavioral interventions are not exclusively for policy makers. Other stakeholders in the product lifecycle can also benefit from behavioral insights to achieve circular goals. For example, producers and retailers can use choice architecture, a primary nudging tool, to promote 'greener' products and more circular business models such as leasing, and to promote take-back of used e-products that can potentially be reused. Behavioral insights can also be used by local authorities – cities and municipalities – who usually facilitate the collection of e-waste along with other waste streams. Choice architecture can be a part of designing collection infrastructure and awareness campaign in order to improve e-waste collection and thus to facilitate better resource recovery from end-of-life products.

Behavioral interventions for circular electronics may not always be straightforward and cheap. Here is one example. Introducing labels (the likes of EU Energy Label) for the 'circularity' of a product can help consumers to choose more circular products. However, it is a complex challenge to simplify the lifecycle impact assessment in a single label for the diverse categories of electronic products and their different possible end-of-life management scenarios. Similarly, e-waste collection can be made more effective by introducing separate bins at households for products from different categories and at different state in terms of functionality (working, needing repair or absolute) to facilitate reuse and recycling. However, such a provision may be much more expensive given the lower frequency of e-waste generation (compared to other household waste). In addition, consumers will be reluctant to have another waste bin (on the top of bins for organic, recyclables, paper, etc.) at households due to lack of space or aesthetic issues.

Final Remarks

A growing body of research suggests a promising prospect for utilizing behavioral insights in supporting the transition towards a more circular economy. While some of the approaches seek to entirely change consumer behavior, others focus on creating an environment in which an individual will choose the best of the available options. The efficacy of any intervention depends on the target behavior and not necessarily on the approach of the theory or the intervention tool itself. Streamlining 'circular' end-of-life options including lifetime extension and collection for recycling will require cooperation from everyday consumers. For this, designers of the policies, infrastructure and technology should consider integrating behavioral insights to help the consumers act as expected by the design.

More interdisciplinary research involving social scientists and technology designers is needed to explore the potential for behavioral change for circular electronics. Studies need to focus more on specific case of purchase, use, and end-of-life management of electronics than evaluating generalized theories on promoting pro-environmental behaviors.

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Closed for Repair: Design Affordances for Product Disassembly

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Keywords: Repair; Disassembly; Product Design; Fastener Types; Obsolescence.

Abstract: A common understanding is that modern products are becoming increasingly difficult to repair. While there are many broad contributing and systemic reasons for this, it is equally important to investigate actual products and how they are designed for disassembly. This research looks at consumer electrical and electronic devices and identifies product design features that “afford” disassembly - thereby enabling or discouraging self-repair. An affordance for disassembly offers a user a perceivable means to commence a disassembly process, removing external housings, covers and primary sub-assemblies, in order to gain access to internal repairable components. This research involves, identifying disassembly features of a selection of consumer electronic and technology devices from the 1950s through to the 2000s, documented product teardowns of domestic kitchen appliances undertaken by design students, and a survey of users experience at identifying fastener types.

Importance of disassembly

Product repair has an important role to play towards achieving a circular economy for electronics. Repair has many beneficial social and environmental consequences (EPA, 2018). Repair, and related activities of maintenance and refurbishment, reduces waste, extends the functional lifespan and retains product value (WEF, 2019). Numerous factors contribute to determine repairability. From specific product features, availability of parts, cost of repair (Cooper, 1994; McCollough, 2010) and to broader societal and economic circumstances. Psychological obsolescence (Packard cited in Cooper 2010) also has an important role to play in shaping perceptions about repairability and decisions to replace rather than repair. This has led to the belief that modern products are increasingly difficult, and less desirable to repair. Designers, manufacturers, recyclers, consumers, policymakers and others all have a role to play to facilitate product repair. (WEF, 2019).

This research focuses upon one specific dimension concerning repair – product disassembly. It asks how and why products are becoming increasingly difficult to disassemble and what design features enable or discourage repair? For a product to be repairable it needs to be disassembled in a non-destructive way – so it can be reassembled following a maintenance or repair procedure, without damage.

Consumer electronics and technology devices

Consumer electrical and electronic products, notably mobile phones, laptops, electronic gadgets and small domestic appliances, are strong candidates to study disassembly as they illustrate the magnitude of our throwaway society and short product lifespans (Park, 2010; Slade, 2007). The production and consumption of these devices continues to escalate, while operational lifespans are increasingly shortened and e-waste continues to be one of the fastest growing waste streams (Baldé et al., 2017). Moreover, consumer electrical and electronic products are increasingly discarded rather than repaired (Slade 2007).

Product design features

Product design is key in determining the ease of disassembly. If a product enables logical or easy disassembly it can reduce a significant barrier to repair (Rivera & Lallmahomed, 2015). Equally, products designed for disassembly reduce the time and, accordingly, the cost associated with repair activities. Design for disassembly also offers benefits for end of life for the separation of parts and material recovery. However, unlike a complete disassembly required for recycling, it is often unnecessary for a product repair. Instead, selective or partial disassembly is more likely to be performed for any attempted repair once the problem for its failure has been diagnosed. If faults are traceable, failed parts reachable via a simple and straightforward process then we can say that the product is repairable enough (Sabbaghia, et a., 2016)

Barriers to repair

If repair is indeed declining, then it is useful to first look more broadly at business and economic contributing factors. “Right to repair” environmental and consumer advocates in the United states and Europe, claim that some businesses seek to profit through making products difficult or uneconomic to repair (Matchar, 2016), so they will be replaced. Some businesses seek to prevent owners, third-party suppliers and independent servicing businesses being able to maintain, repair and refurbish their products. These barriers to repair can be further enhanced by restricting or controlling access to spare parts, and the unavailability of repair information and service manuals (Sabbaghia et al., 2016).

Increasingly, as products contain embedded micro-electronics or are controlled by software systems, repair opportunities can be further complicated. For example, repairability can be restricted through measures such as Digital Rights Management (DRM) copyright and encrypted security systems to lock-out self-repairer’s and third-party repairers. Such measures prevent attempts at fault finding, servicing, upgrading, modifying and/or repairing equipment (Repair to Repair, 2019).

Attitudes and behaviour

Consumer attitudes and the way people think about product repairability can be a self-imposed barrier to repair. Repairability may be a desirable feature for consumers when purchasing a product, but it is often not made explicit or clearly understood (Sabbaghia et al., 2016) as to what is feasible. Many working or repairable products are discarded because they are perceived to be ‘irremediably’ broken. A UK survey of vacuum cleaner users revealed a reluctance to carry out maintenance or repair. (Salvia et al., 2015). This reluctance is influenced by perceptions of the costs associated with repair. The cost of spare parts and specialist repair services have been found to be a key consideration for consumers in choosing the option to replace instead of repair (Cooper 2004). The higher the repair price compared to the replacement price, the less likely the consumer is to repair a product (McCollough (2007). Consumers need to be confident that repairs will be performed properly and at a fair price. Self-repair may be an option to save costs, but the repairer will also need to weigh-up the cost and availability of spare parts, tools, their repair skills and the perceived easiness of product disassembly. Success or otherwise will remain uncertain as the repair process requires commitment to investigate, diagnosis and a repair strategy. The first stage of this process commences with disassembly. Preventative product design features can be the first line of defence as a barrier to repair. For example, design features that discourage or prevent disassembly include, security (proprietary tool) fasteners, friction welded parts, sacrificial snap-fits, hidden fixings and adhesive tape bonding.

Assessing disassembly

Various methods now exist to assess repairability through a range of qualitative to quantitative evaluation methods. A qualitative approach to assessing repair can determine if certain criteria have been met – the provision of repair manuals and product information, product design features and service availability. This approach is used by various eco-labelling schemes, such as Blue Angel, Nordic Label and the European eco-label. (Bracquené et al., 2018). Meanwhile, a popular example of a semi-quantitative method is iFixit’s repairability scores for laptops, smartphones and tablets. They use a ten points scale to rate devices using a combination of qualitative criteria. Points are awarded for disassembly, availability of servicing information, upgradability, use of non-proprietary tools for servicing, and component modularity (iFixit 2009a). Quantitative methods, such as the Ease of Disassembly method (eDIM) calculate the amount of time required to disassemble and then reassemble a product (Peeters et al., 2018). Re-assembly time is also included into the metric as it is an important part of the repair process. As fasteners play a key role in determining disassembly, another quantitative method, the U-effort index models the effort required for separating components or subassemblies from each other by removing fasteners or by detaching parts with integral attachments (Sodhi et al., 2004) and adhesives.

Methodology

A premise of this research is that for a product to be repairable it first needs to be disassembled. This needs to be undertaken in a non-destructive way for it to be reassembled without damage - following a maintenance or repair procedure. This can be described as a product's "affordance" for disassembly. That is, its propensity to be disassembled and reassembled. In design, an affordance can be described as the*, "action possibilities of a user when the user interacts with an artefact. They (*affordances) *can be "directly", perceived based on the structural features of the artefact"* (Kannengiesser & Gero, 2010, p50). In this paper, a mix of research methods were employed to discover product design features that can enable or discourage product repair.

Timeline of product samples

Investigating how products have changed in construction and function over time, can offer some insight about how perceptions of repairability may be changing. A sample of products from a design collection held at the University of New South Wales, Australia. were assessed for their affordance to be disassembled. A selection of small consumer technology devices from the 1950s through to the 2000s were examined and photographed to identify disassembly design features.

Product teardowns

A teardown is an ideal way to understand the "anatomy" of a product. It enables part identification and an assessment of product construction, fastenings, materials, function and components. Moreover, it provides an insight into a product's repairability, refurbishment and end-of-life recyclability. A teardown exercise was undertaken with a selection of small kitchen appliances provided by Breville, Australia. Undergraduate design students were required to systematically disassemble and document an allocated product using a process devised by iFixit (2019b). They were asked to identify and record all significant components and attachments (Figures 1, 2 & 3). Results were then uploaded to iFixit for online publication iFixit (2019c).

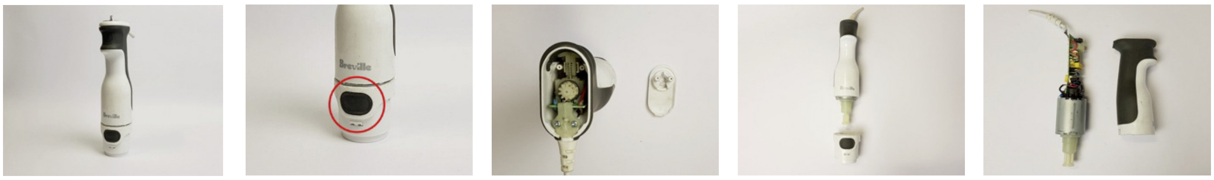

Figure 1. Breville immersion blender teardown.

Figure 2. Breville coffee grinder teardown.

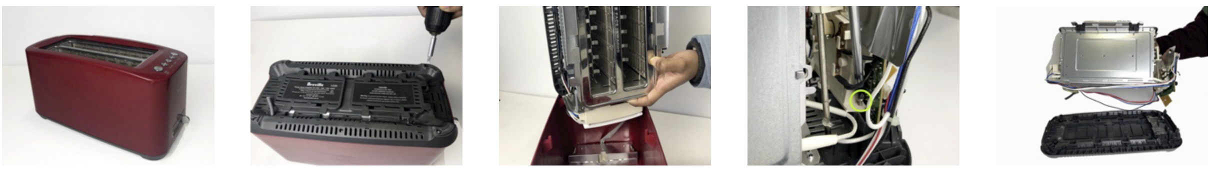

Figure 3. Breville toaster teardown.

Fastener survey

Fasteners, if present, are often encountered at the first stage of any attempted product disassembly process. The type of fastener used can influence perceptions of repairability, or more directly determine actions and capabilities by the would-be repairer - to contemplate and commence a disassembly project. A survey of 66 respondents were asked to identify various fastener types they had encountered during previous product repair experiences (Figure 4).

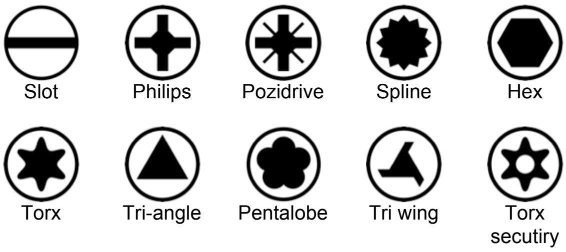

Figure 4. Survey screw fastener heads.

Discussion

Changing products

As products change over time, so does the level of "convenience" for self-repair (Mashhadi et al., 2016). This "convenience" can be expressed through product design features (affordances) for disassembly. Of the products sampled for this research, it was found that older products offered more direct access to internal components than many equivalent contemporary products. For example, a 1950s Braun slide projector and a 1960s National Panasonic radio offer direct, no-tool access to internal components (Figure 5 & 6). This is a necessity affordance for the replacement of consumable items, such as bulbs and batteries, and for periodic maintenance - cleaning and recalibration. If an actual repair is required, then disassembly is relatively intuitive and straightforward with commonly available tools.

Figure 5. 1950s Braun slide projector.

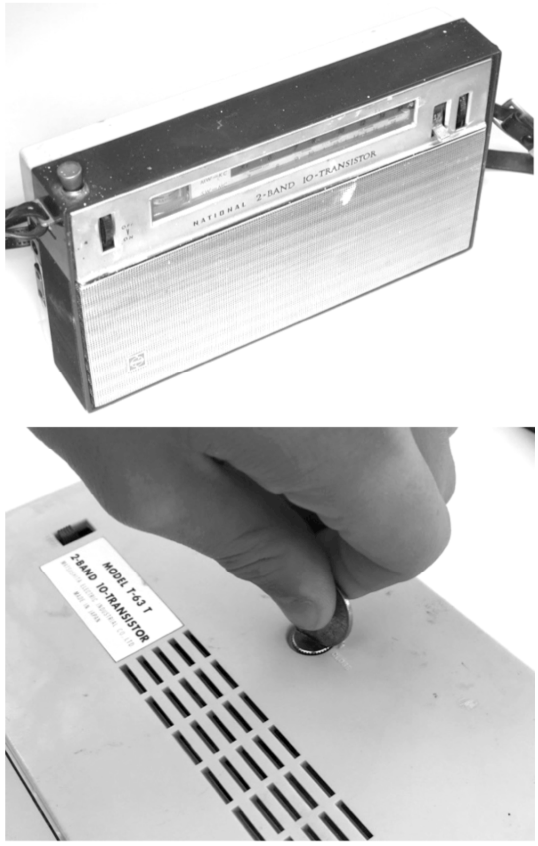

Figure 6. 1960s National Panasonic radio. Single slot head fastener, no tool is required for primary disassembly.

Declining need for maintenance

The requirement for periodic maintenance has diminished for many categories of contemporary products investigated in this study. Before the advent of microelectronics and purely "solid state" and digital devices, electro-mechanical devices required periodic maintenance to be recalibrated, tune or replace consumable components. For example, typewriters required lubrication and replacement of ink ribbons, pre-transistor radios required replacement vacuum tubes (valves), and portable electrical items require replacement batteries or possibly belts and fuses. However, as these devices have become progressively displaced by solid-state digital equivalents or become obsolete altogether, the requirements for maintenance has diminished in proportion to the decline of their mechanical complexity. An added benefit by removing maintenance or ease-of-repair disassembly features is that simplified product construction can reduce the number of parts and can save manufacturing and prime purchasing costs (Sauerwein et al., 2019). The consequences, intended or otherwise by manufacturers, is that if disassembly is required it then becomes more difficult or in some instances impossible without causing further damage through destructive disassembly methods. As was discovered during the student product teardown activity. Certain products, notably a stick blender, could only be dismantled by using destructive methods.

Batteries and Repair

Preventative disassembly features have emerged as important issue when it comes to battery replacement for contemporary mobile technology devises (iFixit, 2019a; Park, 2018). Until the advent of embedded "sealed for life" products containing rechargeable Lithium and nickel-metal hydride (NiMH) cells, battery replacement was a common necessity for many electrical products. For example, products such as a Garmin GPS III and Sony CD Walkman (circa 1990s) afford the user a simple means for battery access for routine replacement. Many variants of earlier generations of mobile phones (for example the Nokia 3310 series) offered partial no tool disassembly with "click-on/off" covers - even though the need for battery access was a less frequent necessity. Since the mid-2000s onwards, the design trend for similar products has often been to eliminate internal user access altogether - despite the need for periodic battery replacement or any other parts. In one notable instance concerning the Apple iPhone, since 2009 Apple has actively discouraged users attempting a disassembly for battery replacement and other commonly required repairs. It has achieved this through the use of a highly specialised type of fastener, the Pentalobe five-point-screw head, and aggressive adhesive tapes. Although Apple is not alone when it comes to the use of specialist security fasteners. It was discovered that for other earlier generations of mobile technology products and more recent small kitchen appliances have also adopted similar practices. However, this was not to prevent access to batteries, but rather to deny access users to delicate or high-voltage electronics.

Screw fasteners

As has already been identified screw fixings are often the first line of defence in determining a user's prospects for disassembly. The shape of a screw head is a significant contributing factor to disassembly effort and time (Sodhi et al., 2004). Respondents to a fastener survey, most of whom claimed some knowledge and skills of product repair, reported that familiarity the most common screw head types (Philips and Hex), and somewhat familiarity with more technical fasteners (TORX and Spline). This survey found that 80% of respondents agreed that if encountered, a Pentalobe screw head it would likely prevent progress while attempting to disassemble a product. Less than 4% of respondents recognised the shape of this head or associated it with Apple products (Table 1).

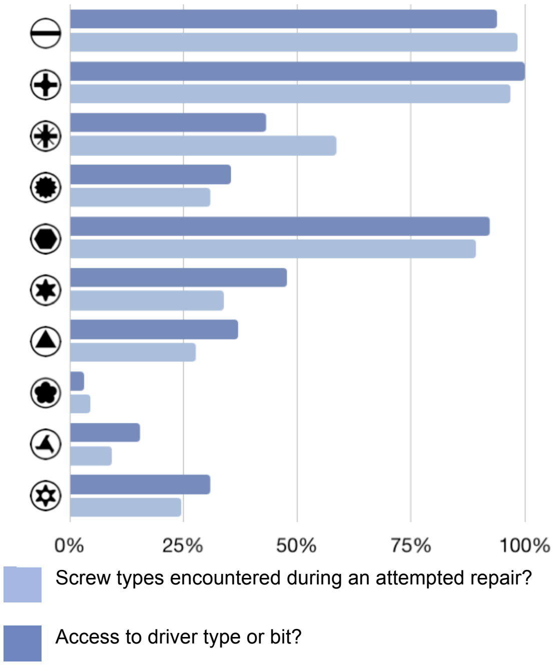

Table 1. Identifying and encountering fastener head types.

Conclusion

This research attempts to highlight the importance of external product features as a first line of defence that can afford product disassembly. User perceptions of how easily a product can be disassembled greatly improves the opportunities for a user self-repair. What opens and shuts (battery compartments), unwinds and tightens (screw fastenings) are key indicators for ease of disassembly. The way products are designed and configured enables or prevents nonprofessional individual consumers from attempting a disassembly for self-repair. No tool disassembly features and availability of 'universal' or generally available non-proprietary tools for common fastener types offer an affordance for disassembly and promote positive attitudes and behaviours towards repair. Unlike many electro-mechanical products of the past, many contemporary devices are perceived to be "sealed for life". They are often not designed for maintenance or repair. Making a product difficult to disassemble and uneconomic to repair may save costs for producers and create demand, but it contributes to premature obsolescence and e-waste. Disassembly empowers us and our ownership of stuff. This is summed up by the refrain 'If you can't open it you don't own it' (Jalopy, 2005).

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Informal E-Waste Recycling: Seelampur, in North-East Delhi

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Keywords: E-waste; Informal Recycling; India; Recycling; Seelampur.

Abstract: An unintended consequence of rapid innovation, lowering costs and the greater availability of electronic products and digital technologies is that e-waste is now the fastest-growing waste stream in the world. Much of this e-waste is processed in developing economies (WEF 2019).
India generates between 1.7 million to three million tonnes of e-waste annually (Blade, et al., 2015) and approximately 90% (Awasthi, 2017) of this is processed by a widely distributed network of informal sector workers who collect, dismantle and recycle this waste. They operate outside of any regulated system or formal organisational structures (Khanna, Park, et al., 2018). Seelampur, in north-east Delhi, is known as a significant destination for e-waste dismantling and recycling. While the actual buying and selling of e-waste takes place under the cover of darkness, with suppliers and buyers arriving from all over India, dismantling takes place visible to passers-by during daylight hours. In narrow laneways, open to the street workshops units receive, sort and dismantle e-waste.
This study involved visits to e-waste dismantlers in Seelampur, north east Delhi. The reading of this presentation is to be viewed as field reportage, primary source information gathering. It contributes to related research undertaken at UNSW, Australia into e-waste, and adds context to research on product lifetimes.
Recycling in Seelampur, Delhi illustrates a paradox of e-waste recovery and processing. The collection and recycling of e-waste in many advanced industrial economies is regulated, but recovery rates often remain quite poor. In India e-waste collection and recycling is mostly informal and unregulated, but little is wasted. It appears chaotic and disorganised, but it is remarkably efficient. Informal sector collectors and recyclers are very resourceful at being able to extract value at every stage of the recycling process. Unfortunately, workers often endure hazardous working conditions of long hours in cramped workshops handling hazardous materials. Many workers come to Seelampur in search of work. It is reported that, casual daily workers earn around $5 USD per day (Wani 2017). Poor working conditions and hazardous material processing methods remain a primary concern to human health and the environment.

Introduction

More than 95% of India's e-waste is processed by a widely distributed network of informal workers of waste pickers. They are often referred to as "kabadiwalas" or "raddiwalas" who collect, dismantle and recycle it and operate illegally outside of any regulated or formal organisational system. Little has changed since India introduced e-waste management legislation in 2016.

Seelampur is the largest e-waste dismantling market in India. Each day e-waste is dumped by the truckload for thousands of workers using crude methods to extract reusable components and valuable metals. Workers come to Seelampur desperate for work. We learnt that workers can earn between Rs. 200 - 800/day ($4-$16 AUD). Women and children are paid the least. Income is linked to how much they dismantle and the quality of what is extracted. They work for between 8 to 10 hours days. Respiratory problems are reportedly common working in these smoke-filled conditions. The waterways in Seelampur are in very poor condition. They are used as a dumping ground for all possible waste materials. Children were sighted playing in the waste. Open burning of waste also takes place alongside drains. Fire is also often used to reduce waste accumulation, despite its contribution to Delhi air quality problems.

Figure 1. Obsolete computer equipment in Seelampur. Photo: Alankrita Soni.

Figure 2. Dismantling e-waste. Photo: Miles Park.

Figure 3. Dismantling computer hard drives. Photo: Miles Park.

Figure 4. Open burning to recover metals. Photo: Alankrita Soni.

Figure 5. Women extracting copper from electrical cables. Photo: Alankrita Soni.

Figure 6. Seelampur (nullah) drain choked with solid waste from nearby residential areas, sewage and discarded e-waste. Photo : Alankrita Soni.

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Special thanks to: Alankrita Soni in Delhi for her contributions and photography, and for arranging my transport on the back of Kuldeep's Royal Enfield motorbike – an efficient means of transport to reach deep into the narrow alleys in Seelampur.

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Environmental Impacts of Smart Bulbs: A Discussion Paper Reviewing the Current Issues and Research

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Keywords: Lighting; Smart Bulb; Design; Digital Obsolescence; Life Cycle.

Abstract: The evolution of the light bulb over the last 40 years has seen some radical design and technology changes in the pursuit of efficiency. These changes have also delivered some unexpected negative environmental impacts, for example, so-called eco-friendly bulbs that caused mercury pollution. New lamp designs and technologies such as the Smart bulb (LED bulb wirelessly controlled via an app) could create a similar predicament; it was predicted they would lead to significant energy savings; however, recent real-world testing has shown that Smart bulbs are significantly less efficient than current non-smart bulbs. Some Smart bulbs are even less efficient than incandescent bulbs, yet they all embody significantly greater resources and toxicity potentials than incandescent bulbs.

This literature study and discussion paper brings together existing but previously unconnected issues and research in order to gain a clearer picture of the current environmental impacts of Smart bulbs. All environmental potentials at each life cycle stage will be investigated such as energy consumption, functional and digital obsolescence, function creep and increasing e-waste.

The aim of this paper is to provide the foundations for further research into design solutions that improve of the environmental impacts of Smart bulbs in the future.

Introduction

Electricity generation accounts for about one quarter of all anthropogenic greenhouse gas emissions (IPCC, 2014) with lighting accounting for 19% of global electricity consumption. (IEA, 2014), so the design decisions made by the lighting industry can have significant environmental impacts through in-use energy consumption.

There are over 18 billion A-type lamp fittings currently installed worldwide (Smallwood, 2016). The average Australian house has 48 lamp sockets (Energy Rating, 2017), the average American home has approximately 50 lamps sockets (EPA, 2017), and 46% of all U.S. lighting installations are A-type lamps (DOE 2016).

The Smart bulb market is predicted to grow forty-fold in just 10 years, so the design decisions made now for Smart bulbs will have significant environmental impacts in the future.

Due to the sheer scale of the market, the embodied energy, resources and toxicities of the bulbs that are design and manufactured for these fittings in the future could also have significant environmental potentials.

The International Energy Agency (IES) are predicting a forty-fold increase in the number of installed Smart bulbs from 2015 to 2025 (4E, 2016a, p. 25), bringing potentially even greater environmental benefits through predicted energy savings, up to 78% reduction assuming 100% penetration (DOE, 2016).

However, this rapid expansion also has the potential for negative environmental outcomes, such as increased resource depletion and toxicity potentials, efficiencies even lower than incandescent lamps (4E 2016b, p. iv – v), and upstream energy consumption (4E 2019 p.4).

Development of the Light Bulb

The tungsten filament light bulb was a magnificent example of design and manufacturing efficiency, weighing only 26 grams with around 10 simple parts and no electronics.

After remaining relatively unchanged for the first 100 years, light bulb experienced its first true disruption about 40 years ago in the form of the energy efficient CFL bulb, which (in hindsight) brought with it some negative environmental impacts, such as mercury pollution (Aucott, 2003) and resource depletion (Lim, Kang, Ogunseitan & Schoenung, 2013).

Many of these impacts could have been avoided or minimised if more thought had been

given to issues such as LCA during the development and design process and if a more honest approach was taken when presenting the real-world benefits and harms.
We are now in the process of the second disruption, the LED bulb, which also brings higher resource depletion and toxicity potentials than the incandescent bulb (Lim et al, 2013) that could still be avoided or minimised through design improvements.
We are about to embark on the third (and possibly most significant) disruption, the Smart bulb, which has perhaps the greatest environmental potentials, both positive and negative (4E, 2016b).

Smart bulbs

The Smart bulb is a term that that can be used to describe a range of features, for the purposes of this research we will use the definition provided by the US DOE for their Energy Star Program in the report "Residential Connected Lighting Market" (Smallwood, 2016);

- Simple Dimming
- Basic Tunable White
- Complex Tunable White
- Colour Tunable

A Navigant Research report called "IoT for Lighting" found the global market for Smart Bulbs is projected to grow almost ten-fold from $651.1 million in 2017 to $4.5 billion in 2026 (Navigant Research, 2017). Over 30 million Smart bulb sales are forecast in 2021 (Smallwood, 2016).

Life cycle impacts

In order to establish a clear understanding of the environmental impacts of different bulb technologies, all stages of the life cycle must be considered, including Production and End of Life (EoL), not just the use stage.

Technology	Production	Use	EoL
Incandescent	Low	High	Low
CFL	Med	Med	High
LED	Med	Low	Med
Smart Bulb	High	High	Med

Table 1. Comparison of environmental impacts of different bulb technologies at different stages of lifecycle.

Incandescent lamp - made from glass, steel and tungsten filament, inefficient, short life, recyclable.
CLF - increasing use of toxic substances (mercury and lead) – more efficient, longer life, hazardous waste at EoL (end of life).
LED - semiconductor production - high embodied energy / waste, very efficient, long life, med E-waste at EoL.
Smart bulb - semiconductor production and wireless comms – high embodied energy, low efficiency, high E-waste at EoL.

Life Cycle Assessments (LCAs) are an effective way to investigate and compare the environmental impacts of different products, however I have been unable to locate any thorough LCAs that have been carried out on Smart bulbs.

Energy Consumption

This issue has number of influencing factors beyond the normal metric of lumens per watt (lm/W), many of which are complex and hard to quantify. Significant energy savings are projected by the US DOE (DOE 2017) but these are based on highly optimistic assumptions, i.e. non-smart bulbs are left on for more than 3 times the time they are required, and no Smart bulbs will be left on unnecessarily.
The real-world energy consumptions tested by Energy Efficient End-Use Equipment (4E, 2016b) tell a very different story, with real-world efficiencies that are a fraction of the equivalent non-smart bulbs.
However, these real-world efficiencies do not take into account the upstream power consumption (the power consumed by data of Smart bulbs) which could be as much as the power consumed by the bulbs themselves (4E, 2019, p. 4).

Projected energy consumption: The US DOE report "Adoption of Light-Emitting Diodes in Common Lighting Applications" estimates if 100% of A-type bulbs were replaced with Smart bulbs it would achieve energy savings of 71% (DOE 2017), through the following mechanisms;

- Easy integration with (or built-in) sensors such presence detection and daylight harvesting, ensuring the light is not on (or dimmed) when there is no one in the room, or there is plenty of daylight in the room
- easy integration with timers and scheduling, so lights are automatically

after a certain time at night, even if people have forgotten to turn them off
- the ability to monitor and track power consumption, so users can work out the most effective ways to reduce power consumption

Real-world energy consumption: In 2016 the Solid State Lighting Annex of the 13 country forum Energy Efficient End-Use Equipment (4E, 2016b) published the most detail report to date on the power consumption of Smart Bulbs called "Smart Lighting – New Features Impacting Energy Consumption."
The study looked at 32 different models of smart bulb, across 4 different countries and 5 different laboratories, to "assess the 'smartness' of these lamps in terms of the energy impact utilising the 'smart' functions." The lamps chosen represented a broad selection of smart bulbs on the market, covering a wide range of features and using all the current communications options such as WiFi, LiFi, Bluetooth, Zigbee, Z-wave and 6LoWPAN.
27 different models of white smart bulbs (non-colour changing) were studied.
The report found that the standby power drain of smart lamps "can drastically increase the lamp's total energy use, and depending on the daily hours of operation, the standby energy consumption can even be larger than the energy used for providing lighting". It found that "when the lamp is used one hour per day, the *overall efficacy* varied from 9 to 51 lm/W (average 30 lm/W) where a few smart lamps had an overall efficacy below that of incandescent lamps."
5 models of models of decorative smart bulbs (colour-changing) were studied for daily power consumption, and found that the average ON efficiency was only 14 lm/W and the average overall efficiency (standby + ON, assuming 1 hour per day use) was just 3.7 lm/W, a big step backwards in efficiency.
The Residential Lighting Report, prepared by Energy Efficient Strategies (E3, 2016) found that 63% of all lamps have an average daily usage of less than 1 hour, confirming that the results from the 4E report above are applicable to the real-world use of Smart bulbs.
Most Smart bulbs also require a powered hub in the vicinity in order facilitate connection and these hubs will also require continuous power. As the smart bulb market grows, the standby and gateway power consumption will become a significant. An almost 40-fold increase to 3.25TWh is predicted in standby energy consumption for Smart bulbs including gateways, from 2015 to 2025 (4E, 2016a, p. 26).

Upstream Power Consumption: Smart bulbs bring with them a whole new form of energy consumption the lighting which is less visible and harder to measure. Upstream power consumption is the power consumed remotely through the collecting, processing, storing and serving of the data associated with Smart bulbs. There is no research on the upstream power consumption of Smart bulbs specifically, however there is research on IoT connected devices in general.
In 2019, approximately half of the total energy consumed by IoT connected devices will be upstream of the devices, effectively a hidden consumption (4E, 2019 p. 4). If this ratio of upstream/downstream consumption is applied to Smart bulbs then the total power consumption in real-world use would almost double.
This is an important factor that has not been considered previously in any Smart bulb energy consumption studies and needs more attention.

Obsolescence

Obsolescence is an important issue in a product field that bases its environmental credentials upon the assumption long lifespans. However, there are a number of reasons why the commonly held assumption that LED and Smart bulbs will be useful and used for the entirety of the lamps predicted life.
"Making things last: digital obsolescence and its resistance by DIY culture" by Roedl explores the complexities of technological and digital obsolescence and what some of the solutions or remedies may be. He states obsolescence can occur via a range of mechanisms, and often these mechanisms are intertwined in complex ways (Roedl, 2016);

- Obsolescence of quality; e.g. when the bulb fails or degrades sooner than was expected.
- Obsolescence of function; e.g. when the function of a new bulb surpasses that of the prior bulb.
- Obsolescence of desirability; e.g. when symbolic function of a new bulb renders the
- prior bulb less fashionable.
- Digital Obsolescence; e.g. when a Smart bulb that no longer functions

because the app for controlling it is incompatible with an operating system update.

- Legal or contractual obsolescence; e.g. the banning of incandescent bulbs.

Digital obsolescence: Perhaps the biggest challenge facing the industry with the rise of the Smart bulb is digital obsolescence.
If a control protocol or app was to become unsupported or the cloud service for a particular device was to cease, as was the case with the Smart home hub Revolv (Finley, 2016), potentially millions of otherwise perfectly good bulbs could be disposed of. Alternatively, firmware upgrades could cause catastrophic failures, as was the case for LS6i smart locks (Carman, 2017).
Another form of digital obsolescence will be brought about when the security of a connected lighting product or system is compromised. We are already seeing the first incidents of hacking and malware vulnerabilities of Smart bulbs.
In 2015 two computer science students, using equipment bought on eBay were able to hack into Phillips Hue bulbs from a distance of 100m to "create strobes of light at frequency ranges that are known to induce seizures in people suffering from photosensitive epilepsy" (Ronen & Shamir, 2015).
In 2017 all three of the major IoT bulbs on the market (Philips Hue, Osram Lightify, and GE Link) were shown to be vulnerable to "wardriving" (the act of searching for and connecting to vulnerable Wi-Fi networks) (Morgner Mattejat, Benenson, Muller, Armknecht, 2017).
When the security of a connected lighting product or system is found to have been compromised, this could also result in the disposal of millions of otherwise functional Smart bulbs.

Function creep

As bulb lifetimes have extended (compared to 1000-hour incandescent bulbs), manufacturers are facing the prospect of dwindling sales as the market is saturated with long-life bulbs. Manufacturers are looking to add more features to their bulbs in order to maintain sales. Eric Swenson, from the Nichia America Corporation, stated in his submission to the 2019 DOE R&D Workshop, Fort Worth, Dallas called "Raising the Bar -Efficacy was so 2015", (Swenson, 2019) "To expand the market, we must keep fine tuning! By adding new features, the Lighting market will continue to grow."

The 4E report discussed above (4E, 2016b) also looked at the fact that there are more and more functions being added to smart bulbs, making the estimation of power consumption even more complex and difficult. Some examples of smart lighting functions are;

- Illumination of the room in any colour of light available on the visible spectrum
- Presence detector switches the luminaire on when someone enters the room
- Sensor that measures temperature and humidity and communicates that information to air conditioning and thermostats
- Geofencing - can automatically turn the lights to your pre-determined settings by detecting your proximity via your phone
- Burglar alarm
- Smoke alarm
- Baby monitor
- App which receives voice commands regarding other gadgets under its control
- WiFi boosting
- Visible light communication (LiFi)
- Cameras

As more functions are added, this leads to greater levels of embodied energy, resources, and toxicity, more complex manufacturing, problematic dis-assembly and recycling, and greater levels of e-waste. The more complexity and features that are built into a smart bulb, the more likely failure or digital obsolescence becomes, further exacerbating the life cycle issues.

E-waste

The United Nations University (UNU), International Telecommunication Union (ITU) & International Solid Waste Association (ISWA) commissioned the 116-page report on E-waste called "The Global E-waste Monitor – 2017". The report finds that 44.7 million metric tonnes (Mt) of e-waste were generated in 2016, 0.7Mt of which was made up of lamps, and this is projected to grow to 52.2 Mt by 2021. Of all the e-waste generated, only 20% is recycled through appropriate channels (Baldé, 2017).

Conclusions

A number of areas have been identified as requiring further research in order to improve of the environmental impacts of Smart bulbs;

1. Life Cycle Assessments will need to be carried out on a range of Smart bulbs and gateways in order to get a clearer picture of the environmental impacts at all life cycle stages.
2. Any possible power consumption reductions due to improved control and monitoring created by Smart bulbs needs to be investigated further, with power consumption projections based on user interaction studies rather than best-case assumptions.
3. Standby and gateway power consumption data will need to be updated, as this is expected to have improved since the 4E study was undertaken in 2016.
4. Upstream power consumption will need to be addressed as it relates to Smart bulbs, although this will have to rely on a number of assumptions due to the complexity and diffuse nature of upstream power consumption.
5. More work is required in the area of obsolescence as it relates to smart bulbs, particularly functional and digital obsolescence.
6. The issues of function creep and E-waste will also require further research as they relate specifically to Smart bulbs.

This further research could then be integrated into a practice-based design process in order to develop functional and feasible solutions that make the most of the opportunities and solve the challenges currently presented by Smart Bulbs.

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Software Applications Adopting Computer Vision for Repair, Reuse and Recycling

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Keywords: Repair; Reuse; Recycling; Waste Electrical and Electronic Equipment (WEEE); Computer Vision.

Abstract: The increasing complexity and variation combined with the fast growing amount of Waste Electrical and Electronic Equipment (WEEE) entails both challenges and opportunities for reuse, repair and recycling centers in a circular economy. Recently developed computer vision systems have the potential to offer solutions to these challenges by automatically recognizing the specific product model, which entails the opportunity to facilitate the retrieval of product information and reuse, repair and recycling instructions. As a first step in the development of an application with such functionalities, the encountered challenges and opportunities, as well as the desired functionalities for such an application are investigated by means of a literature study, plant visits and discussions with several actors of this sector. Based on this analysis, an architecture has been developed for the envisaged application of which several components have already been successfully tested.

Introduction

The Circular Economy paradigm poses major challenges, as well as opportunities, as highlighted in the ambitious Circular Economy Package adopted by the European Commission (European Environment Agency, 2015a). The strategies proposed in this package envisage an additional 600 million tons of waste to be annually reused, repaired, remanufactured and recycled, yielding net annual savings for European businesses of up to €600 billion, equivalent to 8% of the annual turnover, and a reduction in global greenhouse gas emissions by 2-4% (European Environment Agency, 2015b). In order to reach these eco-efficiency targets, radical innovations are required for the treatment of high-value/high-impact waste streams, such as Waste Electric and Electronic Equipment (WEEE). WEEE, also referred to as “e-waste”, currently is the fastest growing waste stream in the EU, growing at annual rate of 3-5% (Eurostat, 2019a). Whereas there is a high variation among member states in Europe, reuse and repair efficiencies are overall still characterized by relatively low efficiencies in Europe (Eurostat, 2019b).

One of the major reasons for this is that information associated with products is gradually lost after the point of sale (Thomas, Neckel, & Wagner, 1999). Close cooperation of the authors with large OEMs in prior research, such as Philips, also demonstrated that even when the product model is correctly identified it is either not possible or very difficult to retrieve relevant information for reuse, repair and recycling, such as technical drawings, manuals, disassembly instructions, component lists, failure diagnostics, material types used, etc. The reason for this being that all information was mostly not systematically stored in a well-structured manner for this purpose.

Consequently, operators in reuse, repair and recycling companies are either deemed to (1) treat all products of a specific category in the same manner, or to (2) become specialists with the required knowledge on properties and differences of different product brands and models or to (3) browse the internet for information and instructions. While recycling centers mainly opt to treat all products of a product category in a similar manner or to make only minor differentiations among generic product features, organizations focusing on reuse and repair were found to often rely on people with adequate knowledge and experience, freely available product information and reuse and repair instructions on various websites, such as www.ifixit.com.

However, recently developed computer vision architectures can offer solutions to automatically identify the design or model of products. Therefore, the University of Leuven – KU Leuven recently started working on the

development of an application to allow the exploration, combination and demonstration of the applicability of computer vision systems for the sector of reuse, repair and recycling. This research is part of the Smart Re project funded by the Flemish waste agency OVAM under the 'Vlaanderen Circulair' project call for circular cities and entrepreneurship.
For this the ongoing research investigates the applicability and the integration of prior developed computer vision algorithms to identify products and product features using a computer or tablet with an external or integrated (web)cam. Initial focus is on the detection and identification of barcodes and the brand and model number mentioned on the product labels. Asides from identifying the product model it is of equal importance to also make useful information available for reuse, repair of recycling operations. For this purpose, existing algorithms and database structures are explored to easily retrieve product information from different sources. It is the objective that the developed software, user interfaces and databases will be integrated in an application which will be tested and evaluated in close cooperation with the network of reuse and repair centers of Flanders 'De Kringwinkels' and by Belgian's largest recycling company Galloo.
In the initial phase of development of this application it is of importance to obtain a good overview of, on the one hand, the opportunities and challenges and, on the other hand, the desired functionalities of this application. In addition, to define priorities in the development of the envisaged application it is important to investigate which components, such as computer vision algorithms, are already available and to understand the required efforts to integrate these components in the envisaged application. For this reason, multiple plant visits and discussions with different actors of the reuse, repair and recycling sector have been performed. In addition, initial experiments have been carried out to evaluate the applicability of different computer vision algorithms for the envisaged application, on which is reported in this article.

Challenges and opportunities

During various discussions with reuse, repair and recycling centers, the following challenges and opportunities of relevance for the envisaged developments were identified:

- The increasing turnover of staff in reuse, repair and recycling centers increases also the urge to properly document acquired knowledge to prevent knowledge to be lost every time someone leaves the organization.
- A significant share of the people working in reuse and repair centers are employed by the social service department of the Flemish government. As a result, there is an increasing importance for tools to education of these employees.
- There is an increasing difference in capabilities of the employees of reuse, repair and recycling centers in consequence of legislative and social evolution both on regional and international level, as well as the refugee crisis that Europe is currently facing. Consequently, it is of importance to find means to improve the cooperation amongst these employees to simulate the sharing of knowledge regardless of cultural and language barriers, for example between a well-educated refugee and a lower educated employee.
- New legislation for protected working environments increases the need to find tools to adapt the work to the individual needs or limitations of the employees, as the inverse is often not feasible (Flemish Department of Work and Social Economy, 2013).
- The increasing complexity of the testing for reuse and the repair of more recent electric and electronic equipment has forced reuse and repair centers to specialize. However, due to the further increasing complexity of these products, several reuse and repair centers are currently considering to limit their scope or to entirely stop their activities. The main reasons mentioned is that either it is not possible to find employees with the required knowledge and experience or that it is no longer possible to train them their selves.
- The current demand already exceeds the offer of second hand or repaired electric and electronic equipment. With the systematically increasing collection targets, this offer and demand could come in better balanced. However, the increasing concern on data security is expected to have a negative effect on the number of IT-

products that will offered to reuse and repair centers. Therefore, there is a need to integrate the required procedures and checks to assure correct data wiping.

- A further evolution in customer behavior is expected, which will force reuse and repair centers to adapt their communication and sales strategies. Several of the interviewed reuse and repair centers already operate an online sales channel. However, the detail of information on these sales channels is today still rather limited and will need to be further improved to meet customer expectations.
- During both discussions with recycling centers and experiments carried out by the authors it was pointed out that a significant share of the waste stream of WEEE were relatively recent products. For example, in an experiment carried out in 2016 at Galloo in Belgium 288 Hard Disk Drives (HDD) from laptops and 94 HDDs from desktop PCs were collected. For all these HDDs the year of production was retrieved from the label. This experiment showed that more than 15% of the laptop and desktop computers encountered in the WEEE were less than 5 year old, as shown in Figure 1. Prior research also confirmed these findings for whitegoods and demonstrated that 10% of all discarded washing machines were less than 5 year old (Prakash, Dehoust, Gsell, & Schleicher, 2016). This indicates that still a substantial number of products in the WEEE that is currently send for material recycling can either be reused or repaired, or could be disassembled for components that could be used for others repairs.

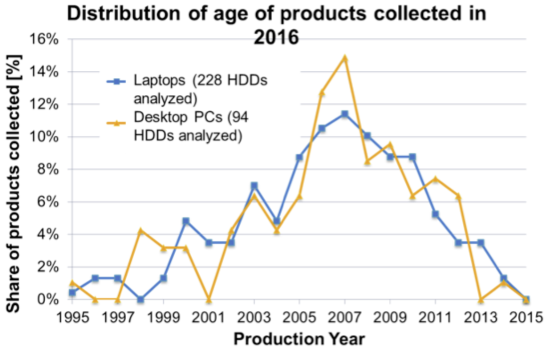

Figure 1. Year of production of HDDs from laptops and desktop computers in WEEE.

Desired functionalities

Since reuse and repair centers face different challenges, they also have, sometimes the same, but also very different advantages of tools for the efficient retrieval of product information and instructions.

For reuse centers, the following opportunities and, hence, the desired functionalities of the envisaged application were identified: (1) making manuals and checklists available for the testing of the correct functioning of the product, (2) making the original sales price and past sales experiences for similar or the same second hand products available, for example past sales price and shell time, to allow a more correct price setting and (3) make correct product information available to correctly identify the customer. For example, the energy class of the second hand product is considered to be important information to inform customers on the intensity with which a second hand product can be used without being economically disadvantageous compared to a similar new product.

For repair centers the desired functionalities also comprise these of a reuse center when the repair is not commissioned by the owner of the product, but repaired products are sold to a new customer. In addition, an application can support the different steps in a repair process by: (1) supporting the preparation of a quotation, for example by making estimations on the expected time required for repair and cost of spare parts for prior repairs of similar or the same product. (2) The identification of the failure can also be facilitated by either or both making failure diagnostics or failure probabilities available for the person performing the repair. (3) After failure diagnostics it is of importance to have the correct repair instructions at hand to guide the required handlings, such as disassembly, cleaning and reassembling. (4) Spare parts are commonly searched online. However, finding the suited spare parts, verifying that it is the correct spare part and comparing different options and prices, can be time consuming. Therefore, it is of value to facilitate the linking of a product model with suited spare parts.

For recycling centers the main value is considered to be (1) in supporting the identification of products that can be either reused entirely or of specific components that could be reused or used for repair or upgrading, for example RAM memory and HDDs could be recovered to upgrade the working memory and

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Figure 2. Results of analysis by Tesseract OCR software of a label from a Philips LCD TV.

the data storage of older computers. Another possible use is (2) the support of dismantling activities, in which product specific instructions could be provided to vary the depth of disassembly depending on the ease of disassembly and value to be recovered. In addition, (3) information on the type of materials used, such as the type of plastics used for the housing components, could also be of value to support the sorting and, subsequent, recycling of the dismantled components.
Asides from supporting the process of reuse, repair and recycling it is always also of importance to support the reporting both internally and externally, for example for compliance with national legislation. For internal reporting, many opportunities exist to stimulate the employees either financially or by better quantification on how they contribute to both economic and environmental targets.

Initial computer vision experiments

Whereas many opportunities lie in making more (correct) product information and instructions available, the first challenges is the correct identification of the product make or model. To speed up the identification of the correct product model the applicability of computer vision techniques is investigated. However, it should be considered that the efficiency and accuracy of any computer vision techniques strongly depends on the quality of the provided image. Therefore, it is of importance to define a suited camera setup. For this two options are considered; either a mobile setup in which the operators moves a camera close to the label of a product and takes an image after verifying the quality of the image or a fixed setup in which an image is gathered from the entire product. In both cases a proper control of the lighting has proven to be of importance, which in case of a mobile setup can be significantly improved by applying a ring light around the camera. For a mobile setup additional advantages are the use of a blue screen which allows to easily crop the product from the full image. In addition, a 3d camera is considered to have significant potential as the geometric shape could also be used to define the product model.
After gathering a qualitative image, the first most evident step is to perform barcode detection, as this is a fast and reliable way to determine the product model. Various software solutions are commercially available to perform barcode detection, as well as open source solutions, such as Zbar (Brown, 2011). Initial experiments with this open source software demonstrated that when a barcode is visible the location, type and content of the barcode can easily be determined for EAN-13 or EAN- 8 barcode (European Article Number of International Article Number), UPC-A or -E (Universal Product Code), Code 128 or 39 and QR Code. However, the speed of detection and success rate for correct identification strongly depends on how the barcode is supplied, as the efficiency is much higher when only a cropped image of the barcode is supplied then when an image containing also other information, such as text, is passed on to the barcode detector.
Initial experiments also demonstrated that there is not always a barcode present or that in some cases the barcode is damaged to the extent that it cannot be decoded. In addition, information from the barcode does not always enables to make a direct link to the product model, as barcodes are also commonly used for service tags, labels of software licenses, etc.

Therefore, it is also valuable to perform Optical Character Recognition (OCR) to read the text from barcodes, which in most cases also contains the product model. Also for OCR, many solutions are available both as commercial software, such as Apose, Asprise, hecksum, Atalasoft, Glyphreader, Abbyy, and as open source software such as Tesseract (Google Open Source, n.d.). In cooperation with industrial partners both the commercial and open source software were compared and substantial differences were found. When the text was correctly cropped and passed on to Tesserect, the results were comparable to those of the best working commercial OCR software. As shown in **Figure *2***, it is technically feasible to extract useful information with the Tesseract OCR software. However, extracting the model number is not always evident, as the model number is not always preceded by 'MODEL NO'. Therefore, it is important to apply different filters to exclude words that don't provide useful information, such as '50/60Hz' and 'WARNING'. In addition, in several cases it was found that some letters were wrongly read, such as a "0" as an "O", which will need either a corrections or a variation of the read model number prior to finding a match.

Based on these findings, the architecture shown in **Figure *3*** is proposed. In this architecture the user has a mobile application with which an image of the label is captured, the mobile application will downscale the image resolution and send it to the server. On the server, deep learning computer vision software will be used to segment the labels into images that only contain text or only a barcode, which will be passed to either Tesseract or Zbar. The results from these algorithms will be filtered and afterwards used to find a best match in the database. If the match has a high confidence, the information that has been stored for the identified product model will be passed on to the operator and the operator will be provided the option to correct or add information for the specific product.

Conclusions and future work

In the presented research several challenges faced by reuse, repair and recycling centers have been identified, as well as opportunities on how a software application could support these activities by identifying the product model using state-of-the-art computer vision technologies to retrieve information in a database. A generic architecture for this software has been identified based on initial experiments with open source software for barcode reading and Optical Character Recognition (OCR), which demonstrated great potential of the envisaged application.

In future research, large datasets of images from product labels will be gathered to in first instance train deep learning computer vision software to detect both the location of barcodes and text in an image to segment the image and

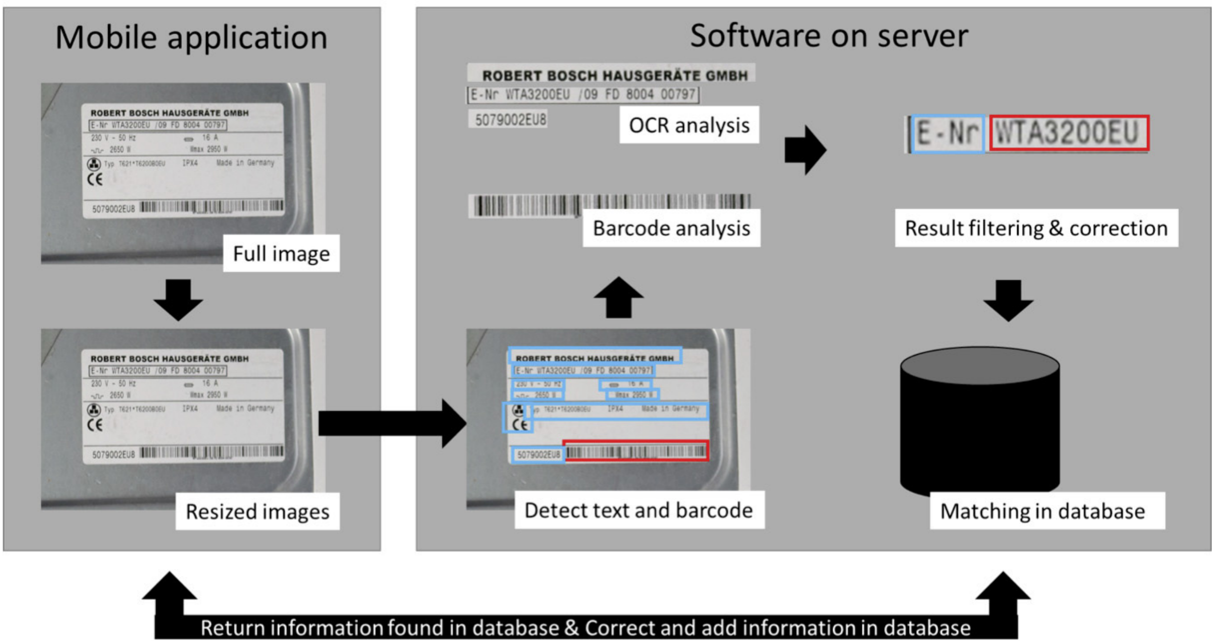

Figure 3. Simplified and initial architecture for reuse, repair and recycling application using computer vision.

improve the efficiency of barcode detection and OCR. Thereafter, the required filters will be developed based on this large set of product labels and software for finding a match in a database will be developed. Finally, experiments will be carried out in close cooperation with reuse, repair and recycling centers to evaluate the robustness of the developed software and to determine which information and instructions have the highest value to be saved and retrieved by the developed application.

Acknowledgments

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Product Lifetimes And The Environment

Analyzing Circular Economy Aspects in ISO Type I Ecolabelling Criteria

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Keywords: Ecolabel; Circular Economy; Durability; Reparability; Upgradability; Reusability.

Abstract: In recent years, a trend that moves towards the concept and development of circular economy models has appeared, focusing on ensuring that the values of products, materials and resources remains in the economy for as long as possible and also on minimising waste generation. This means optimising resource yields by circulating products, components and materials for the best utility at all times. For this purpose, the European Commission introduced a series of measures that cover the whole life cycle of products and materials to increase the value of products by promoting their longer use so as to minimise the amount of waste by designing for repair, remanufacturing, durability, refurbishing or recycling, among others. ISO-type I environmental programmes play an important role in this context as they are intended to educate and raise consumer awareness of the impacts of a product by identifying its best environmental performance during its life cycle. This encourages both producers and providers to offer environmentally friendlier choices and, in turn, compatible with the circular economy concept. With this approach, this preliminary study analyses how circular economy aspects are promoted by different ISO-type I environmental programmes. To do so, the ecolabel criteria proposed for each product category in different ISO-type I environmental programmes were reviewed to identify which circular aspects related to the life extension are already considered and in which terms. It was also determined how specific circular aspects can be further strengthened in some product groups that do not currently integrate them.

Introduction

The Circular Economy concept is focused on ensuring that the values of products, materials and resources remained in economy for as long as possible by circulating products, components and materials for their best utility at all times. With this approach, a series of measures that cover the whole life cycle of products and materials have been introduced (COM 614, 2015; COM 33, 2017). They are focused on minimising the amount of generated waste by applying product design strategies that facilitates its repair, remanufacturing, longer durability, refurbishing or recycling. These strategies has also been prioritised by the Directive 2008/98/EC, which presents a waste management hierarchy prioritising "reuse" over other waste management approaches such as recycling or other recovery alternatives.

The demand of these products depends on their recognition by consumers, who should be able to identify them and understand the requirements that they incorporate. With this approach, ISO-type I environmental programmes (ISO 14024, 2018) identify products or services proven environmentally preferable by satisfying specific environmental criteria through the use of a logo indicating the corresponding ISO-type program. The objective of this ISO-type I environmental label is to contribute to a reduction in the environmental impacts associated with products by guiding consumer choices towards product and service options that have a better environmental performance, encouraging both producers and providers to offer environmentally friendlier choices.

The study of the relationship between ecolabel criteria and circular aspects is incipient in the literature. Suikkanen and Nissinen (2017) analyzed some ISO-type I environmental programmes (Nordic Swan Ecolabel and the EU Ecolabel) to determine how the product ecolabel criteria promote the extended product service. With this approach, this study analyses circular aspects integrated in different ecolabel criteria from different ISO-type I environmental programmes in order to identify which circular aspects are already considered and in which terms.

Methodology

Considering that the study aims at analysing how circular aspects are promoted by different ISO-type I environmental programmes, Figure 1 shows the methodology followed to achieve this objective.

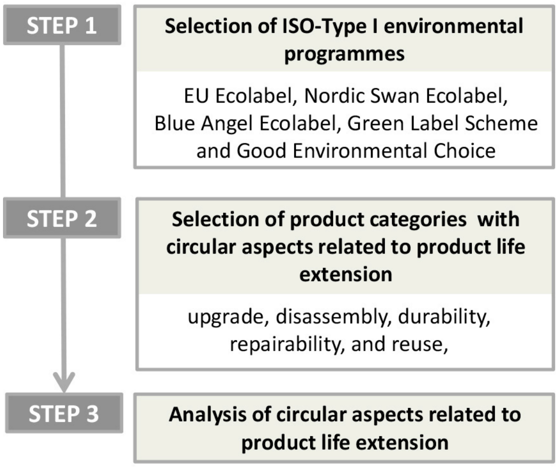

Figure 1. Methodology.

The starting point of the study (step 1) was the selection of different ISO-type I environmental programmes. Secondly (step 2), the ecolabel criteria for different product categories of each ISO-Type I program was analysed in order to select those including criteria related to circular aspects. The next step (step 3) addressed a content analysis, for each selected product category, of the ecolabel criteria directly related to circular aspects with focus on product life extension: upgrade, disassembly, durability, repairability and reuse (COM 773, 2016; COM 614, 2015; COM 33, 2017). Finally, the study results (step 4) show an analysis of the product categories and the ISO-type I environmental programmes that incorporate these specific circular aspects related to life extension.

This information will be useful for proposing guidelines about how to integrate circular aspects related to life extension into the product categories that do not currently consider them.

Results

This section shows the results obtained after applying the described above methodology.

Step 1. Selection of ISO-Type I environmental programmes

Different ISO-type I environmental programmes were selected. The guideline for this selection was to cover a worldwide geographic perspective and that ecolabel criteria were freely available in English, through Global Ecolabelling Network (GEN, 2019). The following five ISO-type I environmental programmes were selected: EU Ecolabel (European Union), Nordic Swan Ecolabel (Nordic countries), The Blue Angel EcoLabel (Germany), Green Label Scheme (Hong Kong) and Good Environmental Choice Australia-GECA (Australia).

Figure 2 shows the logo of the ISO-type I environmental programmes reviewed.

Figure 2. Logos of the ISO-type I programmes reviewed.

Step 2. Selection of product categories with circular aspects related to product life extension

After the review of the ecolabel criteria from the different product categories belonging to the five ISO-Type I environmental programmes described above, criteria from 81 product categories were analysed at this preliminary stage of the study. The distribution among the five ISO-Type I environmental programmes is shown in Figure 3.

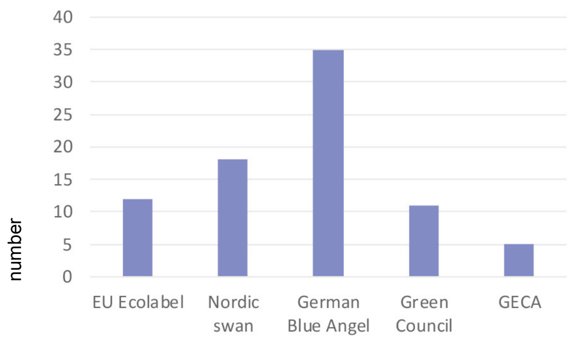

Figure 3. Number of product categories analysed from each ISO-Type I environmental program.

The analysed product categories were aggregated into the 36 product groups reported in Table 1, in order to homogenize nomenclature and simplify the presentation of results.

Step 3. Analysis of circular aspects related to product life extension included in the ecolabel criteria

A total of 26 circular aspects related to life extension were identified in the criteria defined for these 81 product categories analysed.

These circular aspects were also aggregated according to their content into the following groups:

- Upgradability. It contains aspects related to the requirement of ensuring upgradeability or reconditioning of the product, the capability of products to integrate components easily accessible and exchangeable using universal tools, etc.
- Disassembly. It contains aspects related to the capability of the product to be disassembled, including requirements for joints between materials, components or parts, etc.
- Durability. It contains aspects related to requirements such as colour retention, resistance, etc., the commercial guarantee to ensure that the product will function for a certain number of years, as well as provision of spare parts. Other aspects are related to the minimum number of hours of operation or to the incorporation of mechanisms to facilitate the dosage of the product.
- Reparability. It contains aspects related to the design for repair by designing components easily accessible and exchangeable using universal tools.
- Reusability. It contains aspects related to the reuse of components by refilling their content or by establishing a minimum of reused materials into its design.

Table 1 shows the extent to which each ISO-Type I environmental program include the described life extension aspects in the 81 product categories reviewed.

	ISO-TYPE I PROGRAM					ASPECT				
Product Group	ECOLABEL	NORDIC SWAN	BLUE ANGEL	GREEN COUNCIL	GECA	Disassembly	Durability	Repairability	Reusability	Upgradability
Furniture (general)	o	o	o		o	•	•			
Office furniture		o	o				•			
Bedroom furniture, including bed matresses	o		o		o	•	•			
Kitchen furniture, including cooker hoods			o			•	•			•
Living room furniture			o				•			
Carpeting Modular				o	o	•	•		•	
Saunas			o				•			
Windows & exterior doors		o					•			
Building chemicals		o					•			
Chemical building products		o								•
Indoor and outdoor paints and varnishes	o	o				•	•		•	
Floor coverings		o			o	•				
Panel boards and slatted frames			o		o	•	•			
Flushing toilets and urinals	o						•	•		
Sanitary tap water	o						•	•		
Heat pumps	o						•			
Imaging equipment	o	o				•	•		•	
Televisions and projectors	o	o	o			•	•	•	•	
Personal computers, notebook & tablets	o	o	o	o		•	•	•		•
Monitors and screens			o	o		•	•			•
Copying, printers & fax machines			o	o		•	•		•	
Ink and Toner Cartridges		o		o		•			•	
Phones & telephoe systems			o			•	•	•		•
Lamps (fluorescent & LED)				o		•	•			
Pen				o		•			•	
Small EEE (coffe machine, hair dryers, kettles, toaster etc.)			o	o		•	•	•		
White large EEE		o		o			•			•
Stationary air conditioners			o			•	•	•		
Disposable for foods		o				•				
Compost bins		o					•			
Shampoos, shower gels and cosmetic products	o	o	o				•	•		
Purpose cleaners, glass, laundry... cleaners			o				•			
Textiles (clothes and towels)	o		o				•			
Footwear products	o		o				•			
Toys		o	o				•			•
Playground equipment		o				•			•	

Table 1. Relationship among product groups reviewed with ISO-Type I environmental program and life extension aspect.

Conclusions

This preliminary results show that durability aspects are already being included in the ecolabel criteria defined for most of the product categories belonging to the ISO-Type I environmental programmes, mainly for EU Ecolabel, Nordic Swan and German Blue Angel. However, for GECA and Green Council program, disassembly aspects are more generally included. It has to be taken into account that disassembly aspects integrate all requirements related to tools, joints and design considerations needed to facilitate the dismantling of the product, influencing as well into their reparability, reusability and upgradability.

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European Ecolabel Scheme (2019) http://ec.europa.eu/environment/ecolabel/the-ecolabel-scheme.html

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Time in Market: Using Data Mining Technologies to Measure Product Life Cycles

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Keywords: Data Mining; Web Crawling; Time in Market; Obsolescence; Smartphones.

Abstract: Time in Market (TIM) is a metric to describe the time period of a product from its market entry to its decline and disappearance from the market. The concept is often used implicit to describe the acceleration of product life cycles, innovation cycles and is an essential part of the product life cycle concept. It can be assumed that time in markets is an important indicator for manufacturers and marketers to plan and evaluate their market success. Moreover, time in markets are necessary to measure the speed of product life cycles and their implication for the general development of product lifetime. This article's major contributions are to presenting (1) time in markets as a highly relevant concept for the assessment of product life cycles, although the indicator has received little attention so far, (2) explaining an automated internet-based data mining approach to gather semi-structured product data from 5 German internet shops for electronic consumer goods and (3) presenting initial insights for a period of a half to one year on market data for smartphones. It will turn out that longer periods of time are needed to obtain significant data on time in markets, nevertheless initial results show a high product rollover rate of 40-45% within one year and present a time in market below 100 days for at least 16% of the captured products. Due to the current state of work, this article is addressed to researchers already engaged in data mining or interested in the application of it.

What is TIM good for?

Time in Market (TIM) as a product metric is considered to measure the time period of products entry into a market and its eventual withdrawal.

Did you know that there are at least over 500 different types of toasters, more than 800 water boilers and over 1.600 smartphones being traded in Germany within one year (data by the author)? In today's era of mass consumption and customization there are hundreds, if not thousands, of new electronic consumer products introduced every week worldwide (Cox/Alm 1998). It's astonishing how shop operators, consumers and market authorities can deal with all this complexity (Schwartz 2009, Schneider et al 2007). Especially modern online distribution systems enable a world of abundance with unlimited shelf spaces and an enormous choice of products. (Anderson 2008: 143ff). "Yet abundance is the driving force in all economic growth and change" (Gilder 2006: 6).

Little empirical evidence of shortening of product life cycles

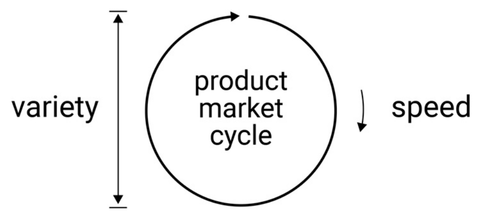

Figure 1. Product variety and life cycle speed in the market.

There have been many discussions on premature obsolescence and accelerated product life cycles, but not much research on the actual speed of the market cycle and variety of products in the market (Figure 1).
Bayus was one of the first to critically pointed out that while there is a lively discussion about the shorting of product life cycles, nobody cares about the empirical evidence (Bayus, B., 1998). Even reference books on product life cycle management, which suggest holistic approaches, ignore TIM as a metric and objective of the product life cycle (Stark, J., 2015).

The more products, the more obsolescence

This is striking given the fact that shorter TIM and an ever-increasing variety of products can be seen as a main driver for obsolescence. According to the linear assumption and thesis: the higher the variety of products in the market (e.g. by product proliferation, mass customization) and the shorter their timespan in the market, the higher the absolute number of products that will become obsolete at some point in time (Trentmann 2017: 672 ff., Slade 2006:29-55, Packard 1960:29-40). In short, the more products, the more obsolescence. The main advantages of the TIM indicator i.a.:

- *Business relevance:* TIM is an important factor and objective for the success of companies in an increasingly competitive consumer electronic market, especially when general product life cycles are shortening (Cooper 2005:19-20, Brown/Lattin 1994).

- *Optimized product strategies:* Better insights on TIM can mitigate the risk of misplanning, overproduction that cause negative environmental effects and business damage.

- *Accessibility:* In many cases semi-structured product data can be openly accessed and automatically processed afterwards.

Operationalization of TIM

According to a general market-oriented concept of product life cycles, there are different stages a product goes through from its initial launch until completion of the life cycle at the point the product becomes obsolete (Kotler/Armstrong 2012:273). Figure 2 shows an adapted and simplified product life cycle to give a better understanding on the difficulties to measure TIM.

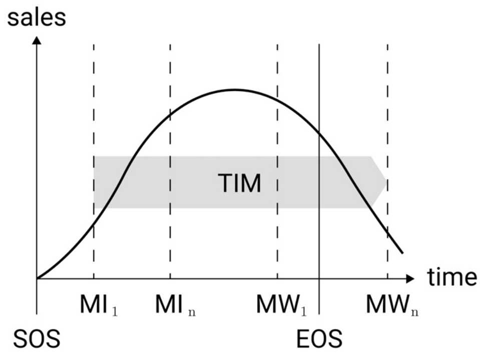

Figure 2. TIM within the product life cycle and cumulated sales rate.

The key parameters shown in figure 2 are:

- *Start of sales (SOS):* The manufacturer or market representative start sales, directly to customers, to trade intermediaries or to trading companies.

- *Market introduction (MI):* The products become available in the market through different vendors at different point of times (MI_{1-n}). The cumulated sales rate typically goes up.

- *End of sale (EOS):* At some point in time the manufacturer discontinues the production and distribution of the product.

- *Market withdrawal (MW):* Manifold reasons induce vendors to withdraw the products from their marketplace at different point of times (MW_{1-n}). The cumulated sales rate typically declines.

Differentiation at multiple scales

The model outlined above is to be understood as an idealized superposition of several microcycles on different levels. On the one side, there is a complex differentiation of vendors on the market stretching from retailers to second hand re-commerce marketplaces. On the other side, there is a complex differentiation at the product level. A smartphone of the type iPhone 8 Plus from the manufacturer Apple is offered in at least 14 corresponding configurations due to different colors and size of the internal memory. The same problem of distinction occurs with different colors of toasters, notebook keyboards in different languages or televisions display size.

Regarding the bulk of product variety and single product market cycles it seems rational to itemize the observable data along the taxonomy presented in figure 3.

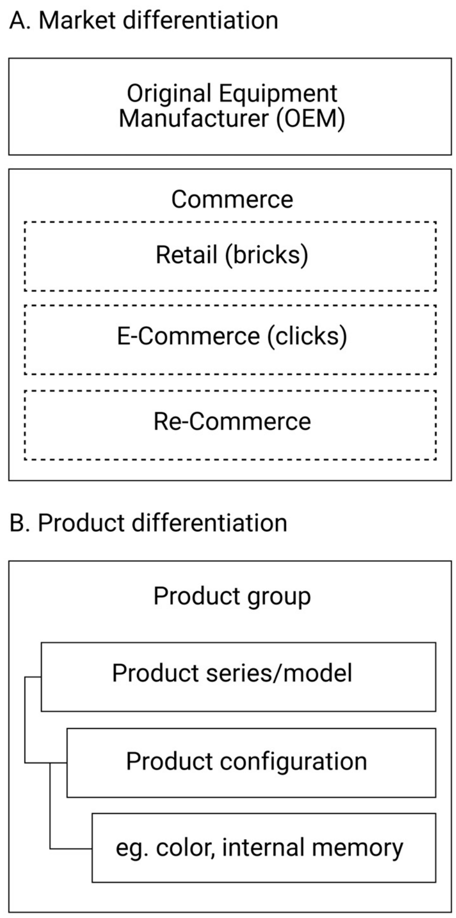

Figure 3. Market and product specific taxonomy.

The taxonomy proposed in figure 3 offers a basic ontology to describe market and product specific TIM. The e-commerce sector at the market level (A) is assumed to achieve a longer timespan in the markets as they don't have the same scarcity of physical shelf space such as retailers in physical stores. Moreover, re-commerce providers probably realize expectably longer timespans in markets due their business model. Inevitably, for further analytics it becomes necessary to distinguish between different product levels (B). As already mentioned, products are often manufactured in series or models and have different configurations. A smartphone model of the type of an Apple iPhone 8 with 64 gigabyte internal memory can have a longer TIM than its smaller equivalent with only 32 gigabyte memory. Where possible, it is necessary to analyze TIM at different product levels to enable detailed analysis of the results.

Data mining approach

Inevitably, an article of this scope cannot cover every technical detail. For this reason, the following section will focus on the concept of data mining and major challenges of web crawling to give even non-experts an insight in this complex field. For a broad overview the author recommends Fan and Bifet (Fan/Bifet 2014) and for a detailed study of the general concept and application Sumathi and Sivandam (Sumathi/Sivanandam 2006).

Definitions and key concepts

Data mining refers here to the process of acquiring and analyzing large amounts of data in order to discover patterns and other information (Sumathi/Sivanandam 2006).

Web crawler are software applications commonly known as bot, web spider, web scraping or data harvesting. They can browse hyperlinks, collect pages from online resources and extract the relevant information (Patil/Patil, 2016, Castrillo-Fernández 2015).

Technical requirements

The basic task was to setup a system that automatically extracts, preprocess and stores online product data from different product categories of selected German e-commerce and retail shops on a weekly basis. In addition, the system must be able to match products from one shop to another. The implementation process and a simplified recursive workflow are shown in figure 4 and explained below.

Step 1: Selection

The online shops in Table 1 were selected because of the provider's market share in the consumer electronics sector and the possibility to automatically retrieve data. The latter point is important because some online shops limit access to websites through legal and technical restrictions. In order to avoid double counting of single shops, aggregators such as amazon.de, google.de, or idealo.de where excluded from the selection.

Shopname	Market place	Period since
saturn.de	bricks & clicks	2018-06
mediamarkt.de	bricks & clicks	2018-06
medimax.de	bricks & clicks	2018-09
euronics.de	bricks & clicks	2018-09
conrad.de	bricks & clicks	2019-02

Table 1. Selected online shops.

The five selected shops accounted in the year 2017 at least for 50-60% of the net sales of the leading companies in the German consumer electronics retailing sector (Estimation based on LZ 2018). Thus, the presented data can be considered as relatively representative for the predefined marketplace (see figure 3).

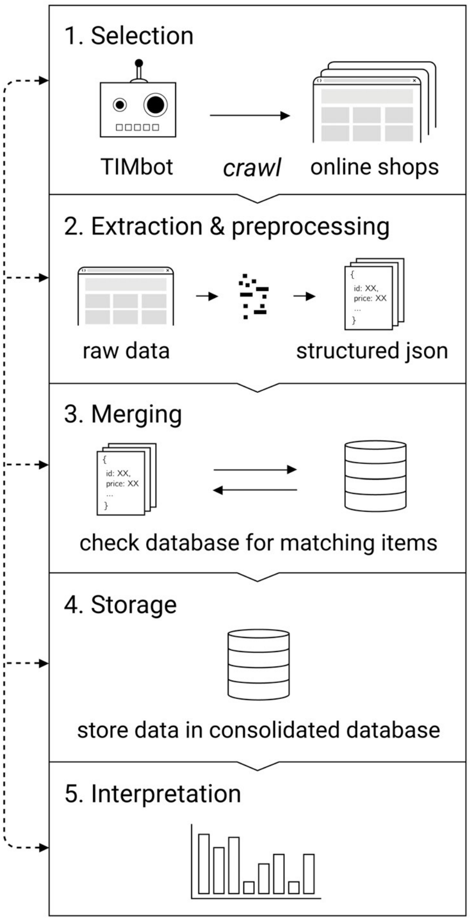

Figure 4. Simplified workflow of the data mining and webcrawling process.

The general process of webcrawling is realized through various libraries, frameworks and software written with the programming language Python (Python 2019). Due to the different technical setups and structure of the shop websites various crawling approaches are used. All together they build a software system that will be named in the following as *TIMbot*.

Step 2: Data extraction and preprocessing
TIMbot is crawling predefined product categories by the shops internet address (URL) and extracts the raw semi-structured data from the HTML structure or via occupying the database interface (API). The data will be filtered through predefined patterns that select target information such as the name, brand, product link and additional product information. The most important information is the European Article Number (EAN) which identifies each product and its different configurations by a unique number. The preprocessed data is then stored as structured data string in a json-File.

Step 3: Merging
All product data will be stored in a consolidated database. In order to generate time series from one week to another the product data from the json-File will run through a specific merger script (*Merger*), to check first if the EAN is already present in the database. If not, TIMbot will entry a completely new product in the database. If the product already exists, only some information such as price and page rank will be stored as a separate new data point (*event*).

Step 4: Storage
The data will be stored in a MySQL-Database system which provides a highly reliable and almost unlimited dataspace. MySQL is widespread, recommended for structured data and well documented. So far, the database contains over 40.000 unique product items and captures over 2 million corresponding datapoints (*events*) as time series.

Step 5: Interpretation
The Database can be accessed by a variety of different analysis and statistic programs such as MS Excel, Tableau or Stata.

Initial insights into the smartphone market

The following statistics focuses on the product group of smartphones and a limited time period from July 2018 to June 2019. Due to the current status of the research project the results must be seen as a first step for a proof of concept and do not claim to be fully representative.

Apart from that, the data gives a hint about the possibilities of the introduced data mining approach above. Table 2 gives a basic market overview, while figure 5 shows a negative correlation of price changes and number of days for the total sample of products tracked within in the period.

Market Overview

Classification	Ratio
First data	July 2018
Last data	June 2019
Month (total)	12
Product models (total)	580
Unique products (total)	1.603
Brands (total)	55
Price range unique products	50 – 1.179 €
Median price unique products	249 €

Table 2. Selected online shops.

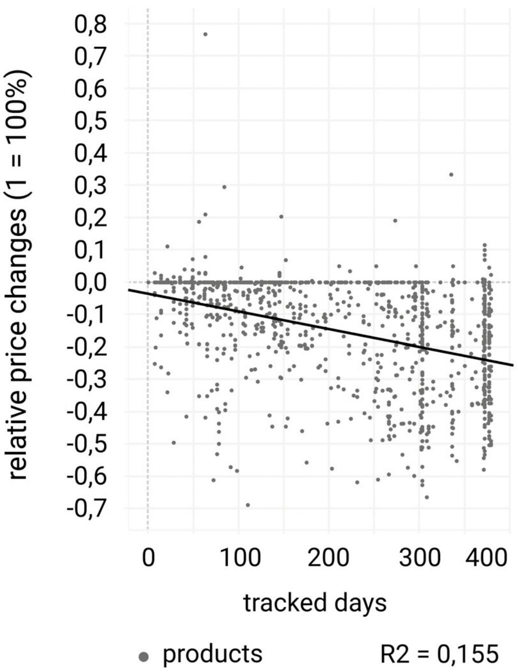

Figure 5. Price change within the tracked period.

Total market entries and withdrawals

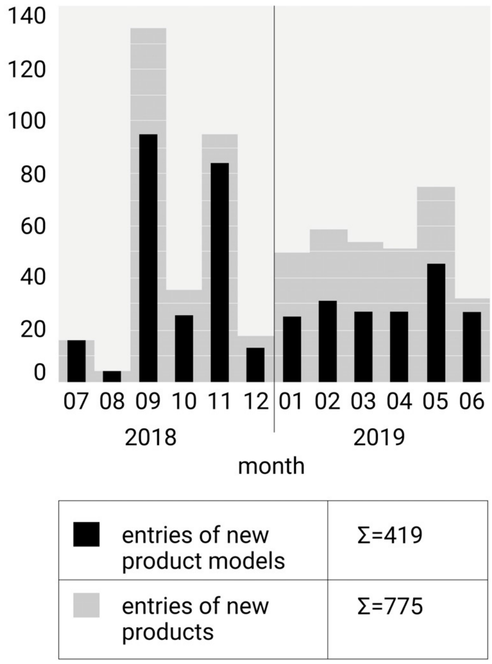

Figure 6. Total market entries of smartphones from July-2018 to June-2019.

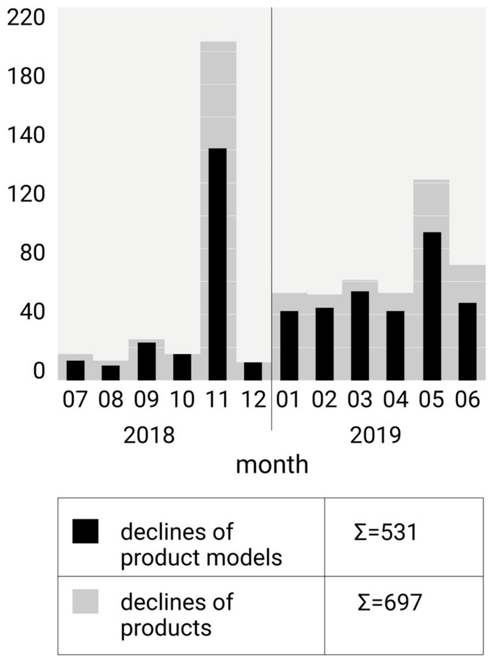

Figure 7. Total market declines of smartphones from July-2018 to June-2019.

Figure 6 and 7 are showing the total market entries and declines of smart phones on the level of product models such as an iPhone Xs or Huawei P10 (*product models*) and its various configurations such as color and memory size (*products*). The data indicate a cyclical trend with a high in the pre-winter season and decline in the holiday season in winter and summer. According to worldwide smartphone sales figures, sales always peak in the winter season (Business Wire 2019), so it can be assumed that the increased product rollovers from September to October will be realized in advance in order to prepare for the high season.

Within the tracked time period of 1 year and a total of 1.603 gathered unique products a total of 775 new products entered the market. Within this group almost 53% stay in the market for longer than the tracked time period of 12 month and the rest of 46% disappear (*fast mover*).

By contrast 697 products disappeared from the market within one year. Within this group 51% belong to the group of new product entries in this period and 49% to the stock that was already listed before the data tracking started.

Taken together the total market entries and declines suggest a high product rollover rate in the overall market. Around 40-45% of the total stock of products in the tracked shops are replaced within one year.

TIM for fast moving smartphones

Within the product group that entered the market and disappeared from it within one year (fast mover), it can be observed that almost 70% of this group have a shorter TIM than 100 days (16% of total products).

Figure 8 shows especially short TIM for products from one to 10 days (25%) in the fast mover group. A first qualitive analyses suggest that these products belong to the lower price segment (median 206 €, mean 296 €). Further qualitative research could examine whether short market cycles are caused through products specific criteria, market circumstances or the shop owners market strategy. However, such short cycles are certainly not induced by acute innovation leaps, thus provoking the fundamental question if they are economically rational. The observed data shows a significant proportion of short traded goods in the market (16%).

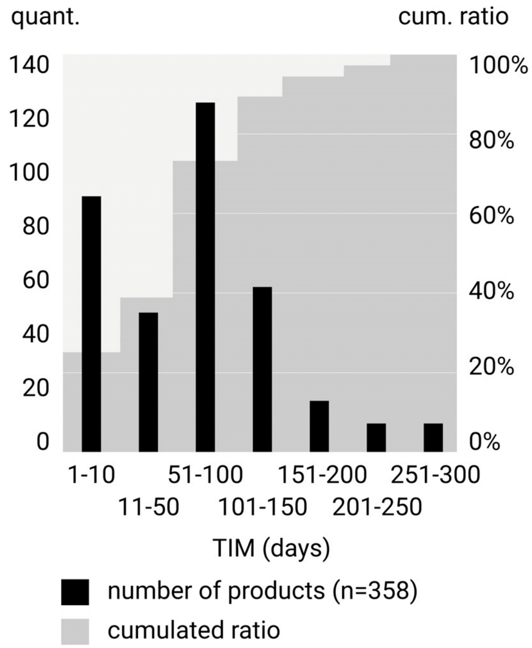

Figure 8. TIM (days) of fast moving smartphones.

Conclusion

The aim of this paper was to introduce the concept of time in market (TIM) as a new indicator for the assessment of product lifecycles. The concept has been shown to address important issues in assessing the shortening of product lifecycles and obsolescence issues.

In order to distinguish between different markets and products a model was presented to operationalize TIM. It becomes obvious, that TIM highly depends upon the selected marketplace and product group. By analogy with stock markets, the indicator must be considered as an index for specific markets and their product portfolios. For instance, re-commerce vendors are expected to realize longer TIM than retailers with a focus on new products.

Furthermore, an automated internet-based data mining approach was introduced that can gather highly available semi-structured product data from 5 German internet shops for electronic consumer goods. Product data were captured for a period of one year, including 40.000 unique product items of different product groups and corresponding timeseries with over 2 million datapoints (*events*).

Due to the limited time period an exemplary analyses of product data for smartphones provided a first proof of concept. The data mining approach works, and above all, it is possible to identify unique products from one store to another using their unique European Article Number (EAN). Furthermore, a first brief analysis shows that of the 1.603 products captured, around 40-45% are replaced within one year. Around 16% of smartphones in the online shops tracked have a remarkably short TIM of less than 100 days.

Fast market cycles can be seen as a main driver for obsolescence and need to be addressed to mitigate the risk of misplanning, overproduction and business damage. The applied data mining concept for TIM can help to identify priorities for virtually unlimited product groups and can provide long term insights into shortening product life cycles.

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PLATE
Product Lifetimes And The Environment

Living Labs for Product Circularity: Learnings from the 'Innovation Network Aiming at Sustainable Smartphones'

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Keywords: Circular Economy; Living Labs; Co-Creation; Consumer Electronics; Smartphones.

Abstract: Adopting the concept of a circular economy at a product level requires firms to rethink their business model and collaborate with partners across their value chain. Reaching product circularity through closing, slowing, and narrowing resource loops can be understood as a systems innovation, which calls for transdisciplinary research approaches. This paper presents insights from the 'Innovation Network aiming at Sustainable Smartphones' (INaS) located at the authors' institute. INaS is a living lab that brings together actors from the entire smartphone value chain to co-create circular product and service innovations. We contribute to research and practice with a process framework for leveraging partnerships through living labs for product circularity.

Introduction

Sustainability transitions require technical innovations, but also novel production, organisation and consumption patterns with implications for entire value chains. The circular economy (CE) provides a comprehensive framework to envision this transition with key concepts such as product-service systems and (collaborative) circular business models (Bocken, Olivetti, Cullen, Potting, & Lifset, 2017; Stahel, 1984). The CE thus requires a systemic transformation beyond a single product or organization to realize circular product and material flows. Given the complexity of this challenge, companies need to collaborate with external actors across a product's life-cycle (Krikke, Hofenk, & Wang, 2013).

We are interested in facilitating and researching early stage collaborative innovation processes, particularly how value chain actors can be brought together in order to embark towards circularity. Inspired by the transdisciplinary research paradigm for (corporate) sustainability science (Lang et al., 2012; Schaltegger, Beckmann, & Hansen, 2013) we take a transformative role through developing a platform for learning, sharing and collaborating with practitioners at eye level (Pereira, Karpouzoglou, Frantzeskaki, & Olsson, 2018). In this conference paper, we present initial insights from a living lab for product circularity as a "forum for innovation" (Voytenko, McCormick, Evans, & Schliwa, 2016) with a special focus on the smartphone industry.

Key concepts

Product circularity for consumer goods

The CE concept envisions circular flows for both, products of consumption (e.g. biodegradable tire abrasion) and products of use (e.g. smartphones) (Braungart, McDonough, & Bollinger, 2007; EMF, 2012). For the latter category, we refer to the concept of product circularity with three basic strategies of slowing, narrowing, and closing resource loops (Bocken, Pauw, Bakker, & van der Grinten, 2016; Stahel, 2010). These are based on the fundamental environmental strategies of eco-efficiency, sufficiency, and consistency respectively (Huber, 1995, 2000). Thereby strategies for slowing resource loops refer to each end-of-use phase and include practices like repairs, second-hand markets, refurbishing and upgrading. Narrowing strategies include eco-efficient product design and flows. The third strategy of closing loops applies to the end-of-life phase and aims at comprehensive material recycling. As for most technical consumer electronics major environmental impacts result from the production phase, product lifetime extension (i.a. cascading use-phases) generally is a valuable approach to improve product sustainability (Cooper & Gutowski, 2017).

Living labs
The CE concept can be understood as a systems innovation with implications for technological change, firms' business models, industrial infrastructure, and user behaviour (Geels, 2004). Transdisciplinary (TD) research approaches are proposed to guide systems innovations as they require tactic knowledge from various stakeholders (Schneidewind & Scheck, 2013). In TD research, academics and practitioners address real-world problems with societal relevance and high uncertainty, jointly formulate goals, processes and solutions, and pilot actions (Lang et al., 2012; Wittmayer & Schäpke, 2014). Various participatory approaches like open innovation, learning-action networks, living labs, and real-life experiments have been discussed as forums to generate sustainable futures (Schneidewind & Scheck, 2013).

Living labs originally emerged in user-centric research in the 1990s at MIT in urban areas and have since then been applied to the business context to facilitate solutions to environmental problems that require collaboration from various organizations and thus transcend firm boundaries (Liedtke, Baedeker, Hasselkuß, Rohn, & Grinewitschus, 2015). Previous participatory projects in the CE context focus on material recycling from a disciplinary perspective (e.g. engineering or natural science) (Sahamie, Stindt, & Nuss, 2013). Applying the living lab concept to the CE context is a novel approach to facilitate collaborative innovation environments and intervention spaces to co-create circular products and services with practitioners (Leminen, Westerlund, & Nyström, 2012).

Method
To analyse our collaborative setting we draw on a single longitudinal case study method (Yin, 2014) as it is considered particularly valuable to "unravel the underlying dynamics of a phenomenon that play out over time" (Siggelkow, 2007). In this article, we present insights from the 'Innovation Network aiming at Sustainable Smartphones' (INaS) over a period of three years (2016-2019). Given that we setup the living lab ourselves and coordinated the interventions, our case study developed in an action research context (Huxham & Vangen, 2003). As an embedded case with multiple units of analysis, we cover both the lab level (e.g. composition, process, interventions) and the level of individual actors (e.g. companies and their representatives). To evaluate and reflect our innovation lab we employ multiple data sources from different stages along the process (see Table 1), including questionnaires, participatory observations, and interviews with participants (Babbie, 2013). In our analysis we use an iterative approach to reflect on transdisciplinary research principles (Dubois & Gadde, 2002; Lang et al., 2012).

Data type	#	length	Documents
Interviews (formal/informal)	5/6	10,8h	Transcripts/ field notes
Participatory observation	4	32h	Workshop documentation
Questionnaires	4	--	Results report
Archival data	35	--	PDFs, internal documents

Table 1. Data sources and types.

Industry context: Consumer electronics
Smartphones are one of the most iconic consumer products of our time but they are also an archetypical artefact for the linearity of our economy. We find the smartphone industry a particularly useful example to study product circularity for two key reasons. First, numerous sustainability challenges are associated with their global production and consumption systems, which makes them an archetypal example for complex sustainability problems (Kates, 2001; Lang et al., 2012). The societal diffusion of smartphones brings sustainability challenges such as short first use-cycles, resource intensity, and e-waste to the public awareness (Moran, McBain, Kanemoto, Lenzen, & Geschke, 2015; OECD, 2012; Suckling & Lee, 2015). Second, various sustainability pioneers are currently emerging in the field. They establish more sustainable practices such as take-back and refurbishing business models or modular design strategies, most of which can be associated with the CE concept (Schischke, Proske, Nissen, & Lang, 2016; Watson et al., 2017).

Innovation Network aiming at Sustainable Smartphones (INaS)
We have set-up the INaS as a living lab to facilitate collaboration of various actors from the entire smartphone value chain and to research inter-organizational collaboration. In this way we aim to address sustainability challenges in the industry and co-create

circular product and service innovations. With the INaS we aim to develop an open innovation space outside boundaries of individual firms to facilitate technological and societal innovations. In setting up the innovation lab, we have followed the transition management framework by Loorbach (2010) with consecutive strategic, tactical, operational, and reflexive activities. The following sections provide an overview of these activities.

Participants

We selected participating organizations from the entire smartphones' (circular) value chain, including suppliers, manufacturers, distributors, circular services providers (e.g. repair shops), and end-of-life facilities (e.g. recyclers). Each of these industry players links into circular value creation architectures via make, ally, buy, or laissez-faire relationships (Revellio & Hansen, 2017). Additionally, the network includes industry associations, societal practitioners, and universities as facilitators for knowledge transfer and absorption (Bishop, D'Este, & Neely, 2011). In total 22 organisations are currently members of the INaS. Figure 1 presents an overview of participants as of March 2018.

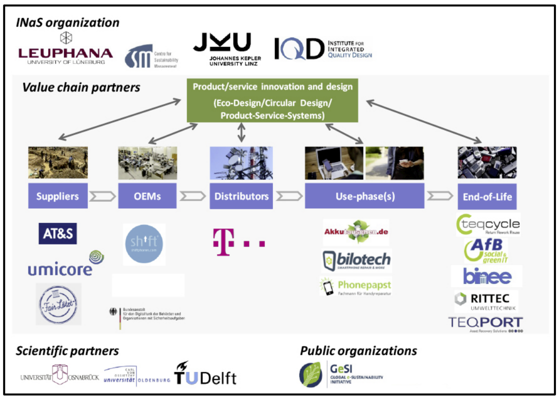

Figure 1. INaS participants 2016-2019, adapted from CSM (2018).

Lab vision through backcasting

To gear towards the desired future state of circular product and material flows we applied a backcasting approach. Backcasting was originally developed by Robinson (1990) and is since then successfully established to life-cycle management as a strategic planning tool for the management of product and material flows (Ny, MacDonald, Broman, Yamamoto, & Robért, 2006). This approach supported our exploratory and collaborative research design by providing direction and scope to the complex CE context (Mendoza, Sharmina, Gallego-Schmid, Heyes, & Azapagic, 2017). We termed our joint circular vision 'the service point of the future'. At this potential future customer interface, users could access circular products and services at a single point of contact to reduce transaction costs. Based on this vision we identified various circular challenges to jointly develop appropriate solutions with INaS participants and to achieve the desired future state of product circularity.

Facilitation processes and workshops

We have met with INaS participants regularly to jointly define challenges, co-develop ideas, and create low-resolution prototypes of circular products and services. Over a timeframe of two years (2016-2017), we conducted four consecutive full-day workshops (i.e. one workshop every 6 months). We covered both product and service innovation approaches with foci on product design, supply chains, product-service systems, and circular business models (Table 2). While this paper focuses on these completed, self-contained workshop series, it should also be noted that the lab has evolved into a second phase, with a new wave of workshops on modular product designs and complementary circular business models currently being prepared.

No.	Workshop topics	Duration
1	Sustainable product design and supply chains	8h
2	Product-service systems as sustainable consumption systems	7,5h
3	Devices as material banks. How to keep devices for value creation	8h
4	Value creation architectures and business models for the "Service Point of the Future"	7,5h

Table 2. INaS workshop overview.

Each thematic workshop comprised both a "learning" element and an "action" element (Clarke & Roome, 1999). Learning elements consisted of academic and practitioner inputs on CE and sustainability topics to provide state of the art knowledge and best practices. For the action sessions, we applied user-centric design methods inspired by design-thinking techniques to bring knowledge into action. Following the learning sessions, small groups of 5-8 participants developed tangible prototypes for circular solutions, which then functioned as

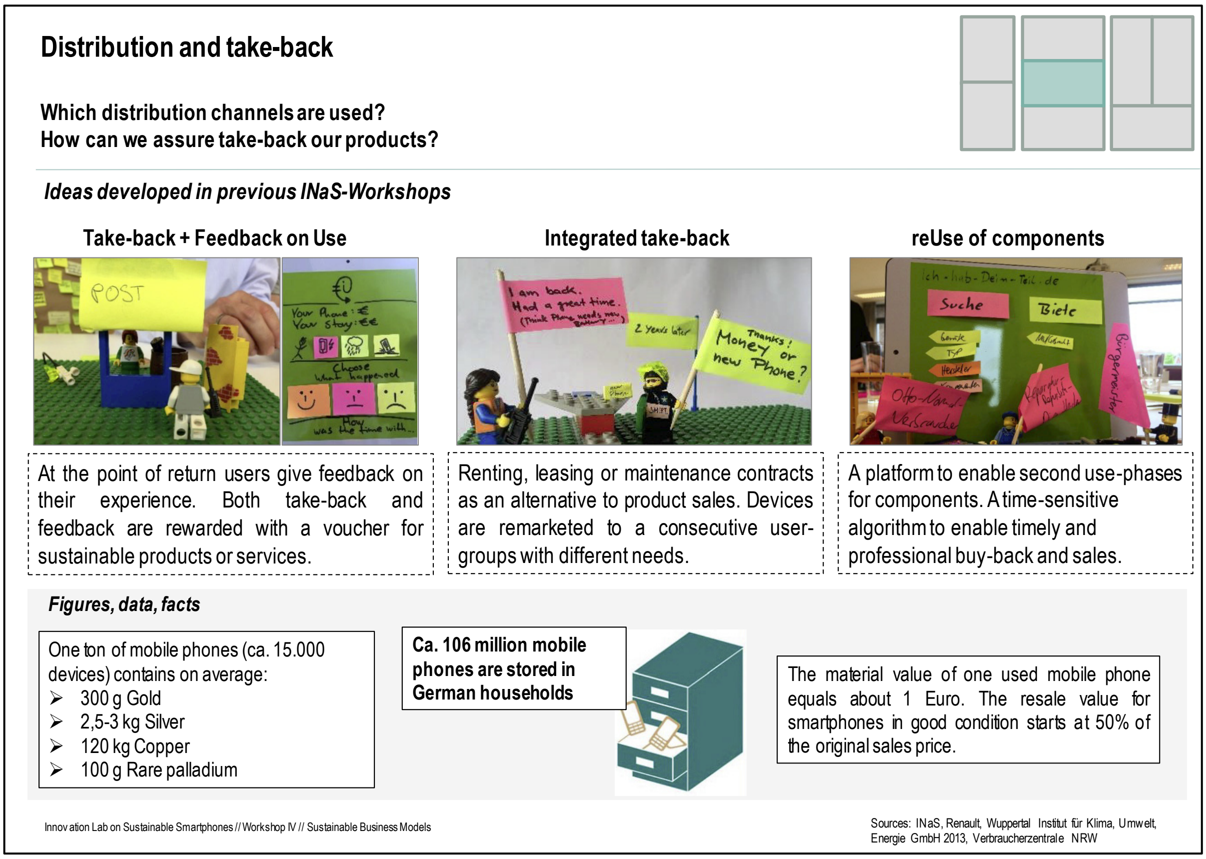

Figure 2. Exemplary facilitation card for the fourth workshops on circular business models. © CSM 2017.

boundary spanning objects for reintegration in participants' organisations.

Exemplary workshop

We focus on the final "integration" workshop on (circular) business models (BMs) as an exemplar for our facilitation approach. The aim of the workshop was to support the implementation and commercialization of circular practices identified throughout the lab in the participants' organisations by developing viable BMs. In an introductory session, we raised awareness and provided basic knowledge through interactive key-notes from BM experts. In the following co-creation session, we used an adapted version of the business innovation kit (Breuer & Lüdeke-Freund, 2018), a business game for developing sustainability-oriented business models. To facilitate solutions based on the previous workshops we developed a proprietary extension with special facilitation cards for each BM element (see Figure 2 for an exemplary card). These facilitaion cards consist of three components. The top part contains guiding questions for the corresponding BM element extended with CE specific features. The middle part contains previously developed solutions from INaS participants in prior thematic workshops. The bottom part contains a slection of related market data. Facilitated by one of the developers of the business model kit, participants co-developed collaborative business models for product circularity. In a third session, we integrated and discussed the results from each individual group to find complementarities. Exemplary BMs included platforms for third-party repair centres (for details see Hansen, Revellio, Schaltegger, Zufall, & Norris, 2018).

Exemplary innovation outcomes at participants' organisations

Practical outcomes from the innovation lab include product, process, and organizational innovations. *Product innovations* developed especially in the field of services. They include full-service offers for B2B customers focused on life-cycle management. An exemplary implemented *process innovation* is a proprietary deposit system for smartphones implemented by one of the participating OEMs to increase return rates for their own devices and to develop a closed-loop system for

products, parts and selected materials. *Organisational innovations* include a number of partnerships between participating firms. For example, an e-waste collection firm now collaborates with a repair firm to exchange harvested spare parts.
Additionally, a number of intangible and indirect outcomes emerged that cannot directly be traced to the INaS activities. These include loose collaborations between partners, inspiration for adapted product designs, and impacts on corporate strategies.

Discussion

We have developed a process framework for circular living labs to facilitate product circularity across the life-cycle (see Figure 3). The framework contains the basic planning elements of actors, processes and outcomes.
Through consecutive thematic workshops and participatory co-creation sessions at the impartial location of a university, we have created and maintained a "transformation space" for corporate actors to envision circular solutions. This "safe enough" environment of our lab proved to be an important feature appreciated by corporate actors, as it enabled experimentation with new mental models outside of the conventional linear solutions space (Pereira et al., 2018). As a result, participants developed both exploratory and exploitative capabilities (Bishop et al., 2011). Participants acquired exploratory knowledge and improved their fundamental understanding for the CE during the workshops and prototyping sessions. An example of exploitative learning is the commercially realized deposit system for smartphones by one of the participants that also influenced their overall CE strategy.
We find that the CE concept is a suitable framework for a relatively comprehensive perspective on (environmental) sustainability in the consumer electronics industry. It can not only spur sustainability-oriented innovation and collective learning processes across all phases of a smartphone's life-cycle, but also across technological and non-technological (service) domains (Hansen, Große-Dunker, & Reichwald, 2009).

Reflection

Our roles as researchers in the project changed over time (Wittmayer & Schäpke, 2014). During the workshops series we took knowledge broker and process facilitator roles. Overtime, our role developed into a continuous relationship facilitator and change agent while continuously assisting partners inside and actors outside the network in the development of new products, services, and partnerships in the industry. This confirms that innovation labs flourish through active management and continuous communication (Kirschten, 2006). Furthermore, we used outcomes and observations from the innovation lab in our role

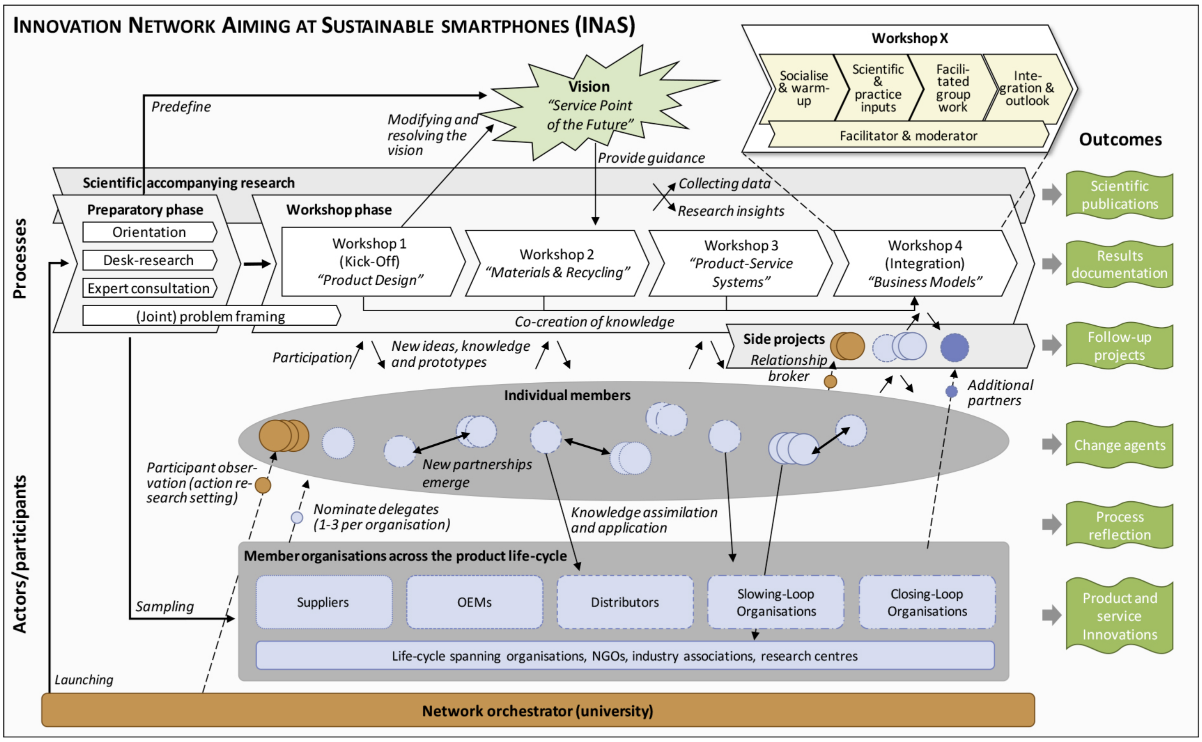

Figure 3. INaS process framework for living labs facilitating product circularity.

as reflective researchers to analyse implications for the circular economy on a more abstract level.

With the lab located in Europe, we did not succeed in reaching the desired representation of the smartphone's production system primarily located in Asia and therefore miss the direct impact on mainstream product designs. However, the coverage of entrepreneurial niche actors from the European production and consumption system turned out to be a valuable advantage, as it enabled fast implementation of pioneering approaches. Moreover, independent from product design changes, it allows to more deeply explore slowing loops strategies for consumer electronics in the use-phase. This also demonstrates the CE concept's potential for regional job creation (EC, 2015; Stahel & Reday-Mulvey, 1976).

Conclusion

We find that innovation labs for product circularity benefit from value chain spanning compilation of actors, transdisciplinary and participatory approaches, prototyping sessions, and follow-up bilateral side projects. In this way, INaS was established as an (national) incubator for product circularity in the consumer electronics industry. Our work contributes to the existing literature at the intersection of the CE, innovation, and living labs with a process framework for leveraging co-creation of product circular in transdisciplinary settings. Practical implications of our research involve improved process knowledge for leveraging partnerships to innovate and commercialize circular offers as well as policy implications for supporting circularity.

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Stakeholders, Drivers and Barriers for Local Electronics Repair: A Case Study of Southern Sweden

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Keywords: Repair; Repair Café; Electronics; Governance; Circular Cities.

Abstract: Promoting repair of electronics is an important strategy to slow material loops, particularly of critical raw materials, as part of a transition to a circular economy. This contribution accounts for a case study of southern Sweden conducted in order to examine drivers and barriers for repairing electronics, as well as better understand the roles of different stakeholders. Repair activities in the region were mapped, including professional for-profit repair activities as well as private and public non-profit activities. Structured interviews were conducted with stakeholders representing professional repairers (8), municipal actors (7), second-hand stores (6), and electronics-specific non-profit community repair organisations (2). The organizational structure of repair organisations and the how municipalities currently support repair organizations were also analysed. A survey of consumers was conducted to gauge their attitude towards extending the lifespan and engage with repair activities. The findings indicate that most people surveyed were positive towards repair activities. The professional repairers consider growing consumer awareness as the main driver for increasing repairs, but there remain many barriers. Community driven activities are still in early development and dependent on collaboration with municipal actors. Municipalities emerged as key actors in community repair initiatives, with different municipal departments either initiating, promoting, or supporting repair activities.

Introduction

The growing consumption of electrical and electronic products has major negative impacts on the environment. The most prominent impacts include energy consumption and leaching of hazardous materials depending on the end-of-life management, but also increasingly resource-intensive manufacturing processes and the extraction of virgin materials (many of which are critical raw materials) (André, 2018). Longer lifetimes for electronic products are beneficial in slowing consumption and avoiding the high impact of extraction and manufacturing processes (Bakker et al., 2014). As a strategy for prolonging lifetimes, repair has been promoted to slow material loops for electronics as part of the transition to a circular economy (Montalvo, Peck, & Rietveld, 2016).

Prior literature has found a variety of barriers to repair of electronics. These include legal barriers, such as IPR infringements by repair activities and use of spare parts (Heath & Sanders, 2009; Svensson et al., 2018), as well as design barriers such as planned obsolescence, lack of modularity and reparability (Maitre-Ekern & Dalhammar, 2016). Lack of awareness, knowledge, tools, manuals or spare parts can also impede repair activities (McCollough, 2010; Pérez-Belis et al., 2017; Sabbaghi et al., 2017). Repair services can be less competitive than new product purchases when considering the total costs of repair, time and inconvenience (Sabbaghi & Behdad, 2018; Sabbaghi et al., 2016; Wieser & Tröger, 2018) A lack of trust, risk of poor quality service and availability of cheaper new products can also make repair a less attractive option (Camacho-Otero, Pettersen, & Boks, 2017). Others note cultural aspects of a "throw-away society" that make repair less desirable, independent of costs and other barriers (Ahnfelt, 2016; Dewberry et al., 2016; McCollough, 2010; Wieser & Tröger, 2018).

Further empirical evidence from case studies can help to advance the understanding of drivers and barriers for repair in a local context and from different stakeholder perspectives. This contribution focusses on a case study of southern Sweden and maps key repair organisations as well as drivers and barriers for repairing electronics from their perspectives.

We also briefly discuss options for overcoming barriers to increase electronic repair activities.

Methods

The study used a mixed-method approach and was scoped and designed by the authors. The data collection was conducted by Master's students as part of two research courses at the IIIEE in spring and autumn 2018.

Local repair activities in the region were mapped through a review of online material (e.g. websites of repair organisations) and 23 stakeholder interviews. Structured interviews were conducted with professional repairers (8), second-hand shops (6), municipal actors (7), and non-profit electronics repair organisations (2). Details of the interviews are found in Andersson et al. (2018), Arabi et al. (2018), and Wadsten (2018).

As the non-profit electronics repair organisations were relatively new in the region, these were further analysed to better understand the different types of organisational structures. Similarly, the roles of municipal organisations in supporting repair activities was a gap in previous research, so their roles in repair were further analysed using a framework employed in previous research of municipal roles in promoting environmental agendas (Kern & Alber, 2008; Zvolska et al., 2018).

A public quantitative questionnaire survey was carried out in the two cities of Lund and Malmö in southern Sweden. Respondents were approached in several locations in the city centres and were given a chance to win a cinema ticket for participating. The survey was exploratory only as there were only 90 respondents and the method meant there was selection bias (see Andersson et al. (2018) for further details about the survey methods).

Findings

For-Profit Repair Shops

A mapping of repair shops for electronics in southern Sweden found 114 repair businesses operating in the region. The interviews with for-profit repair shops found that they considered the main driver for repair of electronics to be interest and awareness among consumers; this interest is increasing and half observed an increasing market. However, there were still many barriers observed, as noted in Figure 1.

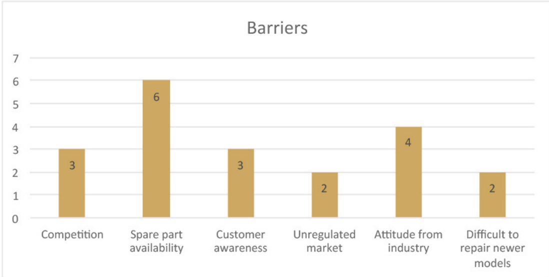

Figure 1. Barriers noted by interviewed repair shop representatives. Source Andersson et al., (2018).

The majority of representatives had a positive attitude towards DIY and community repair. Many believed that these initiatives raise the awareness of repair opportunities, which are benefiting the repair industry and the environment. Some repair shops could see possible competition between their business and DIY initiatives, but argued that their professional experience was a clear advantage.

Second-hand Shops

Six second-hand shops in Lund and Malmö were interviewed regarding their operation and selling of home electronics and electrical equipment. The larger stores estimated that approximately 30 boxes of home electronics are donated every week. The donations are mainly lamps, but also kitchen tools, stereos and televisions. However, shops estimated as much as half of the donations are broken and cannot be sold. Only one of the stores had a staff member who could repair some electronic products (this requires certification). The products chosen to repair have a high value and feasibility of repair. All other interviewed shops stated that repair activities would not be economically viable. The stores send the electronics that are non-functional or unsellable (e.g. CRT TVs or stock that has been on display for several months) to the recycling system.

A couple of the interviewees said that it is not uncommon for customers to purchase old or faulty electronics, such as “vintage” items and older computers for spare parts. One of the shops recently began allowing a non-profit repair organisation to take non-functioning electronic equipment to try to repair it rather than sending it directly to the recycling system.

Non-Profit Repair Organisations

Non-profit repair organisations for repair of bicycles and makerspaces that do minor repair activities have been common for some time in the region, but repair catering to electronic products has only recently emerged. A municipal-led organisation in Lund, FixaTill, began hosting repair activities in 2015. Repair Café Malmö began running occasional events in 2017 and then became an official organisation in August 2018, and began hosting weekly events.

Two different types of non-profit repair organisations were identified in the region based on the following activities:

1) repairing *with* people where people bring their products and repair them together with knowledgeable volunteers;
2) provision of space, tools and/or spare parts for repair activities

In other regions in Sweden and Denmark, there are additional types of activities, e.g. repairing in exchange for a service, donation or membership fee or repairing for payment to cover costs only (see Arabi et al, 2018).

In addition to the focus of their activities, non-profit repair organisations differed depending on whether they organised from the bottom up (i.e. grassroots), top down (i.e. government/ municipality initiated), or a hybrid of these approaches (see Figure 2).

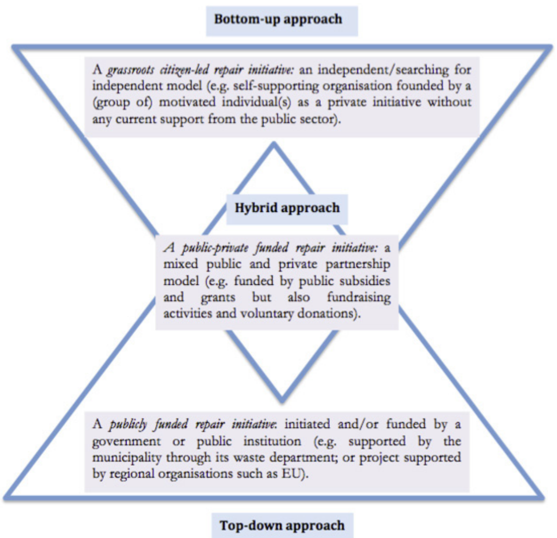

Figure 2. Types of organisational structures for non-profit repair activities. Source Arabi et al. (2018).

The majority of the non-profit repair organisations in the region have top-down or hybrid structures. While community repair cafes and repair-oriented social enterprises could be considered bottom-up, the viability of these organisations is still tied to municipal involvement. In addition, the grassroots organisations are linked to umbrella organisations. In this case, Repair Café Malmö is part of both Repair Café International and the Restart Project. The umbrella organisations have influenced the approach and protocols for repair at Repair Café Malmö; for example, that repair is done *with* participants rather than *for* participants, disclaimers about repair activities are displayed by the local organisation but originate from the umbrella organisations, and data is logged on open platforms supported by the umbrella organisations.

Municipal Organisations

The roles of municipal organisations have been a topic of research in the context of environmental challenges such as climate change (see e.g. Kern & Alber, 2008) and the sharing economy (see e.g. Zvolska et al., 2018). These studies identify four possible modes of municipal governance: initiating, governing by provision, governing by enabling and governing by authority. These modes of governance are also relevant for examining the possible roles of municipalities in repair activities. In this research, municipal representatives were interviewed from five municipalities in southern Sweden: Malmö (2), Lund (2), Vellinge (1), Åstorp (1), and Ystad (1).

Governing by Initiating

In the initiating mode of governance, the municipality owns, initiates, and is responsible for the repair activities. This mode of governance was identified in the case of Lund, specifically in its waste management department, which promoted reaching an annual municipal waste reduction target of 2% through establishment of FixaTill. FixaTill is physical shop-like space equipped with tools and knowledgeable staff. It also hosts free regular workshops run by external experts, which provide citizens with the necessary infrastructure, tools, and skills to conduct their own repairs and/or upcycling.

In interviews, FixaTill representatives claimed the initiative has been successful, with success measured by participant numbers and surveys on repair attitudes. Citizens have shown great interest, with many making frequent use of the facilities. The municipality is financing the project for another two years, with a possible prolongation depending on its continued success.

Governing by Provision
In this governance mode, the municipality supports repair activities with resources or services. The support can be financial (e.g. grants or salaries), equipment, insurance, and/or space for hosting activities.

The provision can be small and short-term, as in a starting grant. In Lund, for example, the social enterprise “Electronicsmix” received a one-time grant in its start-up phase. In Malmö, “Repair Café Malmö” received a small financial starting grant of €500 from the municipality. Other provisioning is longer term, such as Lund municipality’s funding for FixaTill.

In addition to funding, both Lund and Malmö municipalities also make space and resources in their local community centres “Stenkrossen” and “STPLN”, respectively, which are freely available for repair (as well as creative and upcycling) activities organised by other groups. The activities have to be approved by a governing board established by the municipality and the organisations must have safety training for the venue (e.g. fire safety training). The venues also have insurance for the approved activities. This provision of space and insurance allows Repair Café Malmö to run weekly repair events at STPLN.

The governance mode of provision is highly valued by the repair organisations. Without the provision of grants and space, the repair organisations interviewed said they would struggle to exist in the first place. Yet some still find it challenging to know what types of provisioning they are eligible for and how for how long they can depend on it. Some repair organisation leaders suggested that municipalities could communicate their long-term intentions more clearly, as provisioning was key to the long-term viability and strategies of many repair organisations.

Governing by Enabling
This governance mode involves the municipality supporting repairing activities by acting as a communicator, matchmaker, or partner. This includes support in the form of coordination, communication, promotion, public education, awareness building, and facilitating partnerships.

All the municipalities interviewed identified with this role for the municipality in communicating about repair opportunities and encouraging citizens to engage in repair. This is largely done through channels like the newsletter of the municipal waste company. The municipalities also encourage educational activities in schools and other institutions.

The city of Malmö not only communicates about repair activities in the city calendar and waste newsletters but also brings together key stakeholders such as repair organisations, educators, public institutions like libraries, etc. when it initiates special events such as “FixaGrejen” (“Fix the Thing”) and “FixaJulen” (Fix Christmas).

Governing by Authority
In this governance role, the municipality uses its formal authority to restrict or regulate certain activities through laws and policies. The authority of the local governments is highly influenced by national or international regulations. For example, regulations dealing with health and safety are relevant for electronics repair activities but such regulations are decided at the national level and merely implemented by municipal authorities, with little perceived influence the other way. The same is true for access to potentially reparable e-waste, which is governed by national laws.

However, local policies also set agendas and priorities that influence repair activities. For example, promotion of repair is seen as part of Malmö municipality’s vision to help citizens “maintain a high quality of life despite minimum use of resources” (Malmö City Council, 2009). Currently repair activities are perceived as an environmental activity and only integrated into policies stemming from the waste or environmental departments.

Some interviewed representatives noted the social benefits of community repair could be increasingly relevant for the cities for integration, identity building and resilience. The city of Malmö’s waste department is currently exploring repair activities in more disadvantaged neighbourhoods (currently repair activities mainly take place in a newly built neighbourhood, Western Harbour).

Consumers
In the survey, half of the 90 respondents had a mobile phone that was 1 year old or newer. The most common reason for buying a new phone was that their previous one broke or that they wanted to modernise.

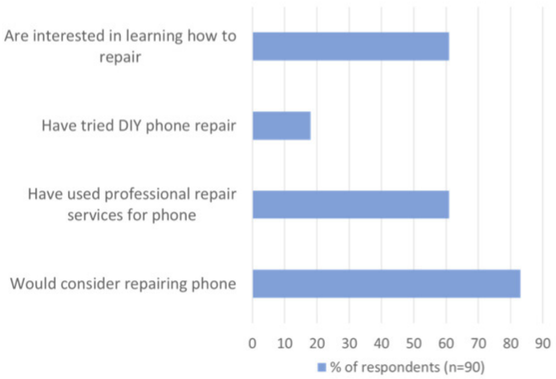

Figure 3. Attitudes towards repair of mobile phones in southern Sweden.

Figure 3 summarises the respondent attitudes towards repair. The majority of respondents said they would try to repair their mobile phone if it broke, but it was often a question of price. Many respondents had never actually brought their phone for repair and those that had repaired their phone did so mainly when the repair was covered by warranty. The majority had never tried to repair their mobile phones by themselves, and the reasons were lack of knowledge and that they did not believe that they could repair a mobile phone. People were largely positive to learn about how to repair their mobile phones by themselves, and thought that having easy instructions and instructional videos available online would help enable this.

Concluding Discussion
Repair activities are growing in southern Sweden but they are still perceived by all stakeholders to be much lower than their potential. In addition to environmental goals, the municipalities increasingly recognise social benefits in promoting repair, which implies a possible need for integration of repair activities beyond only the waste and environmental departments.

While consumers expressed willingness to engage in repair, almost a third of the surveyed respondents bought a new phone to modernise. This stresses the significance of fashion obsolescence and “throwaway society” culture as a barrier to repair, despite the perceived growing awareness of repair possibilities. This barrier was mentioned by all stakeholders in this study as a large systemic barrier to repair requiring action on all levels.

Municipalities, for-profit organisations, and non-profit organisations also referred to other systemic barriers such as the lack of eco-designed products and national or international policies to further promote repair. Indeed, such policies are only recently being considered on the EU level (RREUSE, 2015; Svensson et al., 2018). In addition, policies such as VAT reduction for repairs are still limited in scope (in Sweden reduced VAT applies to second-hand stores and repairs of larger equipment by professionals, but only in homes, not electronic repairs in shops). Expansion of such policies could further promote upscaling of repair on a local level, but it remains to be seen which and how different stakeholders are incentivised.

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Material Eco-replacement: Correlating Product Lifespan and Material Durability When Evaluating the Substitution of Plastic with Novel Circular Materials

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Keywords: Material Replacement; Product Lifespan; Material Durability; Circular Materials; Eco-properties.

Abstract: Synthetic polymers surround us, being used in almost every field of application. In the last century, plastic has been covering a starring role in production processes thanks to attractive qualities: it is an economic, versatile, flexible, lightweight, moisture resistant, strong and durable material. Despite this, plastics represent one of the most widespread environmental pollutant. The transition to the Circular Economy model has led to the development of Circular materials characterized for staying within a closed-circuit system by using natural and renewable resources. Circular materials are taking small steps into consumer sectors, starting with disposable and single use products but are rapidly emerging in medium and long lifespan consumer sector as green solutions. This study represents a good practice for designers who operate eco-replacement activities or want to develop new product concepts from innovative circular materials. In order to conceive a sustainable application from material replacement, the work highlights that it is necessary to take into consideration different aspects: product lifespan, lifetime product expectancy, material aesthetic and technical durability.

Introduction

There are more and more concerns about irreversible processes into climate changes due to human activity (Burton, 2018). In the past years, starting from concerns regarding bio-accumulation inside e.g. oceans and concerns for wildlife, research and public opinion focused on the implications of polymers and additives for human health, having as an outcome legislative measures to reduce risks linked to these substances (Thompson, Swan, Moore, & Vom Saal, 2009). Numerous legislative proposals (e.g., EU Plastics Strategy [1]) are seeking to address this issue by limiting the production and use of synthetic polymers, asking producers for product redesign and material replacement measures. In particular, some plastic product categories, characterized by a short life-time, have been highlighted as critical from an environmental point of view: packaging, personal care consumables and toys (Ellen MacArthur Foundation, 2016).

Materials are one of the factors that most influence the sustainable nature of the final product, due to its technical and aesthetic aspects (Ljungberg, 2007). Material science research is currently focusing in finding alternative design approaches and non-fossil based materials for these products. Circular materials are those staying within a closed-circuit system with the aim of allowing the use of natural sources, reducing pollution or avoiding the use of non-renewable resources and supporting economic growth.

Novel "circular" material (Pellizzari & Genovesi, 2017), developed from biomass, waste, scraps or recycled resources, are increasingly recognised as "sustainable" alternatives to traditional synthetic polymers (Asdrubali, D'Alessandro, & Schiavoni, 2015; Karana, 2012; Sauerwein, Karana, & Rognoli, 2017). Although, in selecting the most suitable "circular" alternative for a specific product application, technical and aesthetic properties of materials must be carefully evaluated (Piselli,

[1] European strategy for plastics. Available at: http://ec.europa.eu/environment/waste/plastic_waste.htm

Baxter, Simonato, Del Curto, & Aurisicchio, 2018). These novel materials, characterized by expressive-sensorial properties (smell, touch …) that drive unconventional material experiences, must ensure an appropriate performance and durability according to the specific product lifetime expectation (Bridgens & Lilley, 2017; Gnanapragasam, Cole, Cooper, & Oguchi, 2017; Wieser, 2015).

Materials durability vs product lifespan

A crucial moment when designing in a circular perspective is the materials selection. For this reason, during the selection are to be considered selection criteria that contribute to optimize all the phases of the product life cycle. Allione, De Giorgi, Lerma, & Petruccelli, 2012 have divided these parameters into 3 categories:

- Use of materials with low environmental impacts: promote eco-efficiency, short distribution chain, non-toxicity and the involvement of renewable resources.
- Material lifetime extension: aiming to postpone waste disposal while targeting alternate approaches to the materials and life;
- Ethics: looking at the creation of comfort between manufacturers about their environmental responsibilities.

These guidelines, if used together can improve the environmental performance of the product. In accordance with their point of view, the topics of materials durability and product lifespan have been studied in depth, with a view to following a top-down approach to actively consider the end of life in the selection and replacement process of materials.
The durability of a material is defined as the ability of a material to maintain its functional properties without significant deterioration by mechanical and chemical stresses, wetting, heating, freezing, corrosion, oxidation, etc., for a long time[2]. Materials durability depends not only on the physical and mechanical properties over time, but also on aesthetic ones (Celadyn, 2014). To get a comprehensive view of these properties, specific accelerated aging tests can be carried out to simulate to simulate the decay of technical properties and the looming aesthetic obsolescence (Bridgens & Lilley, 2017). This creates a fundamental perception for the user about the overall quality of the product to which the material it is applied. Materials quality perception is strongly correlated to the absence of surficial defects and to durability property in time (Bridgens & Lilley, 2017; Lilley, Smalley, Bridgens, Wilson, & Balasundaram, 2016). Users often associate surface material qualities with an indirect measure based on contextual conditions where material is applied, to conform to expectations or consumer experience with similar materials in product application (Crosby, 1979; Garvin, 1987; Parasuraman, Zeithaml, & Berry, 1985). There are also aging behaviors of the material that the user knows, for example products made of natural materials e.g. paper, wood, leather, are expected to acquire antiquity and preciousness during their aging period (Rognoli & Karana, 2013). Product Lifetime or Product Lifespan is the time interval since a product is sold to when it is discarded. This is a designed life, known by the designer, who also designs the obsolescence of the product. It represents an important area of enquiry with regards to product design, the Circular Economy and sustainable development.

Durability of bioplastics

The introduction of bioplastics in consumer sectors was first focused on biodegradable and/
or compostable characteristics, directed to the single-use packaging sector (Rognoli, Karana, & Pedgley, 2011). For example, in the case of Polylactic acid (PLA), these applications take advantage of its fast degradation in an industrial compositing environment. But the sensitivity to heat and temperature still lack the long-term durability required for durable applications (Harris & Lee, 2010). Because of this, many material suppliers of PLA have developed injection-molding grades of PLA blended with petroleum-based resins such as polycarbonate (PC) or bio composites (Harris & Lee, 2013). These multiphase system, where plant-derived fiber or mineral / synthetic filler is dispersed in the biopolymer matrix have a far greater potential for minimizing the limitations of PLA (Nagarajan, Mohanty, & Misra, 2016).
However, the introduction of a new material into consumer products represents a critical issue for both producers and consumers. The producer aims at establishing a market and

[2] The Business Dictionary, Available from: http://www.businessdictionary.com/definition/durability.html

refine the technical feasibility, while the material is faced with the public assessment for the first time (Bahrudin & Aurisicchio, 2018).
Consumers can perceived new materials in different ways: appreciate them or feel them unattractive also through their previous perceptual knowledge.
Evaluating the application of circular materials instead of commodity plastics, two fundamental parameters must be taken into consideration: their durability / quality perceived by the consumer and their technical performances and aesthetic aging over time. The goal is to map the applications of circular materials in the different consumption sectors finding correlations and trade offs basing of the lifespan of the sectors they have been applied. These may lead to the outcome of strategies and guidelines to be adopted to apply circular materials to durable consumer sectors. By mapping the current state of circular materials already marketed and placed in consumer sectors, the aim is also look for application sectors for a composite material (biopolymer matrix and natural filler) developed within Making Materials Lab. of the Department of Chemistry, Materials and Chemical Engineering "Giulio Natta" of Politecnico di Milano. The material is called Poly-Paper and brings together the production versatility of plastics and the virtuous end of life of cellulose fibers based materials.
RQ1: In what consumer sectors were circular materials introduced? What is the lifespan of products in these sectors?
RQ2: How can circular materials be incorporated into high-lifespan consumer sectors?
RQ3: Which consumer sectors can be directed to a new circular material still in development?

Methods

This research analyses 26 "circular" materials, both traditional and innovative, taking into consideration their distinctive features and properties, typical applications and production processes and which materials are they substituting candidates.
Following Ashby's method and charts (Ashby & Johnson, 2014), the materials were initially filed, defining them eco-properties (bio-based content, biodegradability, compostability, durability over time). For each material, all of them on the market, were researched the products to which they were applied, and then grouped by commodity sectors. For each sector of application, thanks to the studies of Wieser, 2015 it was then reported the estimated life period and finally the materials that the new solution has gone to replace on the market.

Results

The case studies of circular materials have been categorized according to their "Material biography" (Bahrudin & Aurisicchio, 2018; Wilkes et al., 2014), based therefore on their composition and source of resources as shown in Table 1.

Material	Materials' Biography
Cellulose Acetate CA (Tenite®)[3]	Bio-based bioplastic
Polyhydroxyalkanoate PHA - Mirel®[3]	
Poly Lactide Acid PLA - Nature Works®[3]	
Thermoplastic Elastomer (TPE-E) Apinat Bioplastic®[4]	
Thermoplastic Starch (TPS) Materbi®[3]	
Arboform®[5]	Bio-based bioplastic / Natural filler
Fluidsolid®[6]	
Jelu-Plast® Green composite[7]	
Natureplast®[8]	
Orange Peel[9]	
The salt pup®[10]	
Timberfill®[11]	
Carton board[3]	Cellulose fibers
Chipboard[3]	
Corrugated board[3]	
Honeycomb cardboard[3]	
Paper[3]	
Paper board[3]	
Paper pulp[12]	

[3] Cambridge Engineering Selector (CES2018) Software
[4] https://www.apiplastic.com/prodotti/ bioplastics/
[5] https://dornob.com/liquid-wood-fantastic-100-organic-bio-plastic-material/
[6] https://www.fluidsolids.com/en/about/media/
[7] https://www.jeluplast.com/en/
[8] http://natureplast.eu/it/fornitore-di-bioplastiche/fibre-biocomposite-e-co-prodotti-commercialisation/
[9] Lefteri, C. 2014. Materials for Design. Laurence King Publishing. https://books.google.it/books?id=g59LnwEACAAJ.
[10] http://buildingwithseawater.com/#insta http://www.newmaterialaward.nl/en/nominations/the-salt-pup
[11] https://fillamentum.com/products/ fillamentum-timberfill-cinnamon
[12] http://www.davidgardener.co.uk/?p=70 https://www.kadltd.jp/project-14-mould

Acrodur®[13]	Formaldehyde-free acrylic binders
Bayonix bottle®[14]	Fossil-based polymer
IKEA Patented "Odge chair"[15]	Fossil-based polymer / Natural filler
Jelu-Plast® biocomposite[6]	
S.Cafè®[16]	
Accoya wood®[17]	High performances wood
Qmilk®[18]	Natural fibres

Table 1. Circular materials selected as case studies classified basing on their composition.

Starting from the 26 selected materials, a sampling of products to which these materials were applied was done and 107 products were found. Most of them are included in the general furnishing sector and progressively in the disposable and Single-use products sectors as shown in Figure 1. Afterwards, the Figure 1 represents the product lifespan and the replaced materials in product application. It can be observed that the majority of products made of circular material have a life span of less than six months. Despite this result, which was to be expected, it's possible to notice how the other commodity sectors and their related lifespans resulted also populated.

The replacement of fossil-based polymers with circular ones have touched all the commodity sectors represented. Cellulose-based materials are equally averagely inserted in the various commodity sectors i.e. also those > 10 years of lifespan, however, in some of this cases the material will not ensure the same durability of the replaced one, but the eco-replacement has to be properly evaluated.

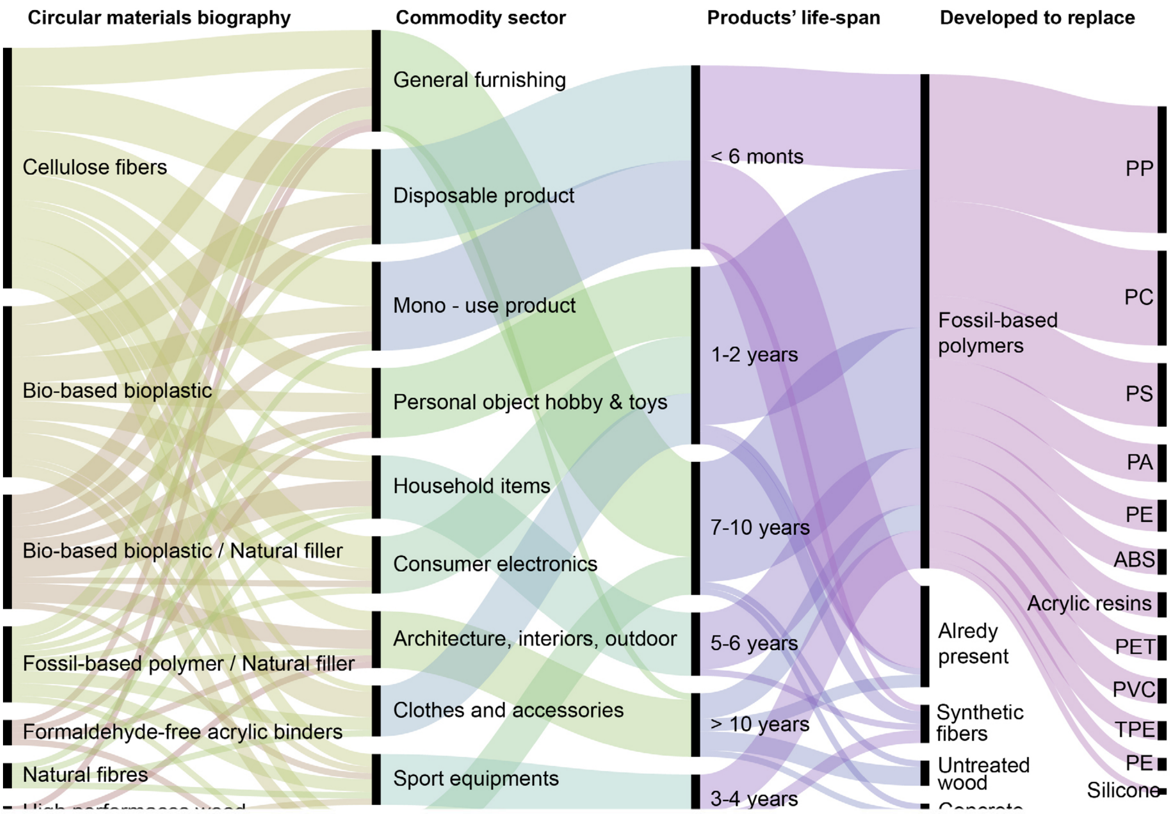

Figure 1. Analysis of the data collected from the application of circular materials in the commodity sectors translated into data visualization by the authors via https://rawgraphs.io/.

https://paperwaterbottle.com/
[13] https://www.basf.com/us/en/products/General-Business-Topics/dispersions/Products/Acrodur-acrylic-resins.html
[14] https://bayonix.com/
[15] https://www.dezeen.com/2017/11/13/ikea-form-us-with-love-odger-recycled-wood-plastic-sustainable-chair/
[16] http://www.scafefabrics.com/ en-global/about/development
[17] https://www.accoya.com/sustainability/
[18] https://www.qmilkfiber.eu/?lang=en

Cellulose fibers based materials have been taken in evaluation since they represent a forerunner of that of bioplastics or bioplastic composites. In fact, cellulose fibers materials had mostly been destined for short-lived sectors but, in recent years, they have also been included in more durable commodity sectors as "green" alternatives.

Materials that aim to replace the synthetic fibers are constantly increasing their presence on the market, as sustainable textile materials in relation to growing environmental issues i.e. micro plastics dispersion. The analysis carried out represents a state of the art of how circular materials are entering consumer sectors, but are they always preferable to fossil-based plastics? Based on this open debate, in the discussion of the results two indexes will be proposed to better argue materials eco-replacement.

Poly-Paper (Santi et al., 2018) is a material developed to respond to the problems of disposal of multi-material packaging, therefore initially directed towards low-lifespan consumption sectors. Thanks to this study, it was possible to elevate the material to design for sectors such as personal objects, hobbies and toys and the consumer electronics. Following the materials substitution design strategies for sustainability (material eco-replacement) (Bontempi, 2017; Vezzoli, 2013), design concepts and prototypes (Figure 2) have been elaborated as part of a Master's Degree in Design Engineering (Testa, 2018) .

Discussion

The selection of case studies was decisive for the results. For this reason, the research was carried out on circular materials already applied in the most diverse consumer sectors. This section will go into detail on how to use the new materials for the circular economy along the selection or replacement of commodity plastics. Therefore, evaluation indices are suggested for an effective eco-replacement material.

As first consideration, the perception of durability of the material has to be greater than the life expectancy of the product.

According to the studies of Wieser, 2015, the consumer lifetime expectancy of a product is greater than its lifespan. The material applied to the product must satisfy this consumer expectation, appearing more aesthetically durable and of higher quality. Its finishes and soft skills have to be designed in this sense, so that its aesthetic appearance resulted ennobled. How many times do people think: "I'd better buy a top with satin finish for my kitchen so I won't see scratches over the years". However did happen to do the same reasoning with a product with a short life expectancy such as packaging, personal care products or toys.

A relationship can therefore be envisaged:

$$\frac{Materials\ perceptual\ durability}{Product\ lifetime\ expectation} > 1$$

As an example, the "Miss Sissi" lamp made in PHA produced by Flos and designed by Philippe Starck responds to the aesthetic requirements of perceived durability thanks to the wise use of materials and has been included in the general furnishing sector which has a life expectancy of 5-7 years (Wieser, 2015) according to consumers perception. On

Figure 2. Product design concepts for the application of Poly-Paper into medium-lifespan commodity sectors designed by Testa, 2018.

the other hand, based on the properties of technical and aesthetic durability, the material must ensure the performances throughout the lifespan of the product:

$$\frac{Materials\ durability}{Product\ lifetime} \sim 1$$

By-passing this parameter and therefore designing with materials with lower aesthetic and technical durability, the product will be decommissioned and replaced earlier than expected (for aesthetic or functional reasons) producing a waste of resources and energy. In case of short lifespan products made by fossil polymers, which have a durability of over 450 years in contact with the soil or dispersed in the environment, this ratio will skyrocket. This comparison can be made by designing durability in different environments and / or substances and relating them to the lifespan that the product to be designed must ensure.
Based on the criteria, requirements and constraints of the product on carrying out a materials selection, it is possible to select the relative durability parameters or perform aging tests (Manley, Lilley, Hurn, & Lofthouse, 2017) in order to relate them to the product lifetime.

Conclusions

New circular materials are complex systems.
Equally complex is the definition of their parameters, because in addition to the primary source, they rely heavily on their life cycle, energy used and issued for their transformation, emissions and their recovery at the end of life. The criticality is to find a right application, which justifies their inclusion in the market as truly sustainable resources.
In relation to the sectors of application, however, the consequences of their introduction on consumer behaviour are also to be considered. Brand owners and transformers cannot be limited to an "eco- material replacement" because the new circular materials are stand-alone systems and the related product of application needs a complete redesign.
Circulars materials have to be ennobled for their expressive-sensorial characteristics and for their meaning such the transmission of ethical values. By enhancing their aesthetic quality, the related products could also pre-choose them in the case of applications in durable sectors. Despite this, circular materials must be closely linked to the application product ensuring its performances throughout its life period neither more (which would be a divestment of resources still active), nor less (which would result in an early disposal of the product). This paper aims to provide critical exploration for eco-replacement addressed to designers and technician in providing investigative tools. Both designers and producers must be aware that the product development by the selection of circular materials involves the management of a complex system. In order to make the circular material effective, the work highlights that it is necessary to relate different aspects:

- The expressive dimension of the materials quality and expected durability has to be greater than the life expectancy of the product
- The ratio between the aesthetic/technical durability of the material and product lifespan have to approach to one.

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Promoting Life Cycle Thinking: a Training of Public Officers for Green Public Procurement

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Keywords: Education for Sustainable Consumption and Production; Training for Sustainability; Employee Engagement; Green Public Procurement; Life Cycle Thinking.

Abstract: Several European Union (EU) policy tools, like Green Public Procurement (GPP) or the EU Ecolabel, aim to reduce the impacts of products along the whole life cycle. Nevertheless, despite having existed for decades, we observed that their use is not yet widespread, also in institutions that have environmental protection as a mission.
This study aims at exploring the impact of an experimental training course ("Introduction to the Circular Economy and Life Cycle Thinking") delivered to a group of public servants by looking at the group's comprehension and value given to the importance and feasibility of activating more Sustainable Consumption and Production patterns, such as GPP. The course design was based on the research and practice framework provided by Education for Sustainable Consumption and Production (ESCP). This was drawn from an idea of transformative Education for Sustainability (ES), seen from a constructivist, critical and complex perspective. Particular attention was given both to the cognitive and emotional aspects of the learning process. Thus, the course was specifically tailored to the participants.
The different training sessions were carried out in 2018 and involved a total of 95 public servants. Mainly qualitative methods (document analysis, observation, quantitative and qualitative questionnaires) were used for the research. The findings show that the learning activities, which designed, performed and evaluated in this study using ESCP principles, are valuable to draw the participants' attention to many sustainability topics that they are rarely exposed to. Moreover, they demonstrate to contribute to inspire sustainable actions. Overall, further research and implementation of extended processes of this kind should benefit the innovation of professional training and accelerate the transition from a linear to a Circular Economy (CE).

Introduction

Public procurement in the European Union (EU) comprise over 14% of GDP (European Commission - EC, 2019). Therefore, Green Public Procurement (GPP) and other voluntary policy tools, such as the European Ecolabel, have a strong potential to promote Sustainable Consumption and Production (SCP) and a Circular Economy (CE). At the national level, most EU Member States have published GPP National Action Plans (EC, 2018), however, there are no systematic statistics in the Member States (EC, 2016) on the real GPP uptake.
In particular, as Sustainability professionals based in Italy and Spain, we noticed that, although these tools have existed for decades, up to 2017 they had barely spread when compared to the World's environmental-socio-economic problems; even in institutions that have environmental protection as a mission.

On the other hand, from our experience as Education for Sustainability (ES) or Education for Sustainable Development (ESD) professionals, we observed that in Italy and Spain the training on sustainability issues, such as GPP, is almost totally focused on transferring information without taking into account participants' background knowledge and interests, mainly administrative personnel. In short, more transformative methodologies characteristic of ES do not seem to be applied.
However, to promote the change from a Linear to a Circular Economy, we must acknowledge that the irresponsible and hyperconsumeristic behaviours of our society are comparable to those of a sedentary person addicted to exceedingly abundant food, high in fat, sugar and salt. If information delivered within a few hours was sufficient to learn and find the strength to eat healthier, overweight people

would not exist today. Similarly, the influence of Life Cycle Assessment (LCA) may remain limited if it enters the decision-making with no anchoring in organisational culture and decision-makers personal world-views (Heiskanen, 2000). When combined, Education about and for Sustainability provide people also with the capacity to motivate, plan and manage change towards sustainability within their organisation (Tilbury, Crawley and Berry, 2005).
Indeed, there is international recognition that an improvement in the quality of education, in addition to quantity, is critical to advance in the Sustainable Development agenda (Ofei-Manu and Didham, 2018). *"We believe it is necessary to establish a thorough understanding, not the least among leaders, of the character, magnitude and urgency of the sustainability challenge as well as the self-benefit of competent proactivity for sustainability"* (Broman and Robèrt, 2017, pg. 18).

These reflections fed our interest in investigating the potential of ES, traditionally directed to children (Scalabrino and Oliva, 2013), in involving adults in more conscious and sustainable personal actions. As Tilbury (2011) affirms, many studies agree that educators associate ESD with active and participatory learning processes, despite the lack of empirical evidence that demonstrates the effectiveness of these methods in achieving the objectives of Sustainable Development. We focused our research on an Education for Sustainable Consumption and Production (ESCP) drawn from an idea of transformative (Mezirow, 1991; Sterling, 2011; Blake and Sterling, 2013; Sterling and Baines, 2002) ES, seen from a complex (García, 2002, Bonil, Junyen and Pujol, 2010, Bonil and Pujol, 2005), critical and constructivist (García, 2002, García, Rodríguez and Solís, 2008) perspective.

Context and research question

The opportunity to explore the contribution that this ES can make to professional training and to the transition towards a more sustainable economy arises from an acceleration of the formal commitments of several international institutions, starting in 2015. Among them, the Sustainable Development Goals of the UN's 2030 Agenda and the Paris Agreement to prevent dangerous climate change. At the European level, the Circular Economy Strategy, and at the Italian level, the obligation to include Minimum Environmental Criteria in all public bodies' procurement procedures and various Regional Action Plans for GPP.
Finally, in this context of positive turning point for the Sustainable Development policies started over half a century ago, in 2018 we proposed to develop and study the one day workshop "Introduction to the Circular Economy and Life Cycle Thinking". In particular, our research scenario was one of the 19 Italian Regional Environmental Protection Agencies. These are organisations, which are in charge of the environmental monitoring and control (air, waste, marine and terrestrial waters, meteorology etc.) in their regional territory. The group of individuals studied was formed by the 95 participants in the eight editions of the eight hours course. Among them, public employees with administrative profiles and, in the vast majority of cases, environmental technicians or professionals with a degree in environmental and natural sciences, biology, geology, chemistry, physics, computer science and engineering.

As anticipated, it is complex to evaluate the effectiveness of a training activity designed to provide concepts, scientific data and ideas for reflection, to promote critical thinking and reasoning abilities in the context of "Wicked problems", to move emotions and stimulate individual and collective action. *"Additionally, the impact of… ESD… interventions may be a long-term engagement with issues and questioning assumptions, rather than immediate measurable results"* (O'Flaherty and Liddy, 2017, pg. 13).
Nevertheless, being aware of the complexity of reality, does not mean giving up trying to know it (Mayer, 1998). For all these reasons we chose the qualitative methodology, which explores social phenomena from the perspective of the actor, seeking to understand through descriptive data, such as the words and behaviours of the research participants (Scalabrino, 2017). In qualitative research, quality and in depth information is preferred to quantity. In this contest, there are questions to explore rather than initial hypotheses. In our case:
What is the impact of the course on the participants' perception of the importance and viability of Sustainable Consumption and Production?

The journey

The journey that led to the completion of eight editions of the course included different phases. As shown in Figure 1, some overlap in time, while in other cases different qualitative instruments were used to collect the information necessary for the design of the course, its continuous feedback and its final evaluation.

Context analysis, design and realisation

Given the interest in developing GPP in the organisation, we started an analysis of the global, national, regional and organisational context, that continued throughout the journey.
From the preliminary analysis, a first introductory awareness course was organised. The aim was to foster a systemic vision of the interconnected problems of the World and the solutions, highlighting complex relations between topics that, at first, people usually see distant from each other. Further, to exercise critical thinking, move emotions and contribute to motivate more responsible decisions.
The course was designed and carried out taking as reference the main components of ESCP, drawn from an idea of transformative ES, from a complex, critical and constructivist perspective (Scalabrino, 2017).
In this framework, the trainer will make *"a reasonable use of the different didactic methods, designing the educational process according to the desired objectives and following a coherent unifying thread... Will adapt the contents and methods to the participants, their previous knowledge and personal interests, and will feed back the design and implementation of the educational process based on the continuous evaluation of the results and the reactions of the apprentices during the process"* (Scalabrino, 2017, pg. 69).
In addition, some "organising issues" or *"thematic containers, essential for a teaching-learning process for Sustainable Consumption and Production"*, are proposed (Scalabrino, 2017, pg. 67). The contents of the course, based on the training needs detected during the preliminary study, were organised around these "organising issues" (Figure 2).
The final version of the program included several thematic areas of intervention (Figure 2) that were approached with different flexible, dynamic and participatory teaching tools, capable of working both cognitive and affective aspects.

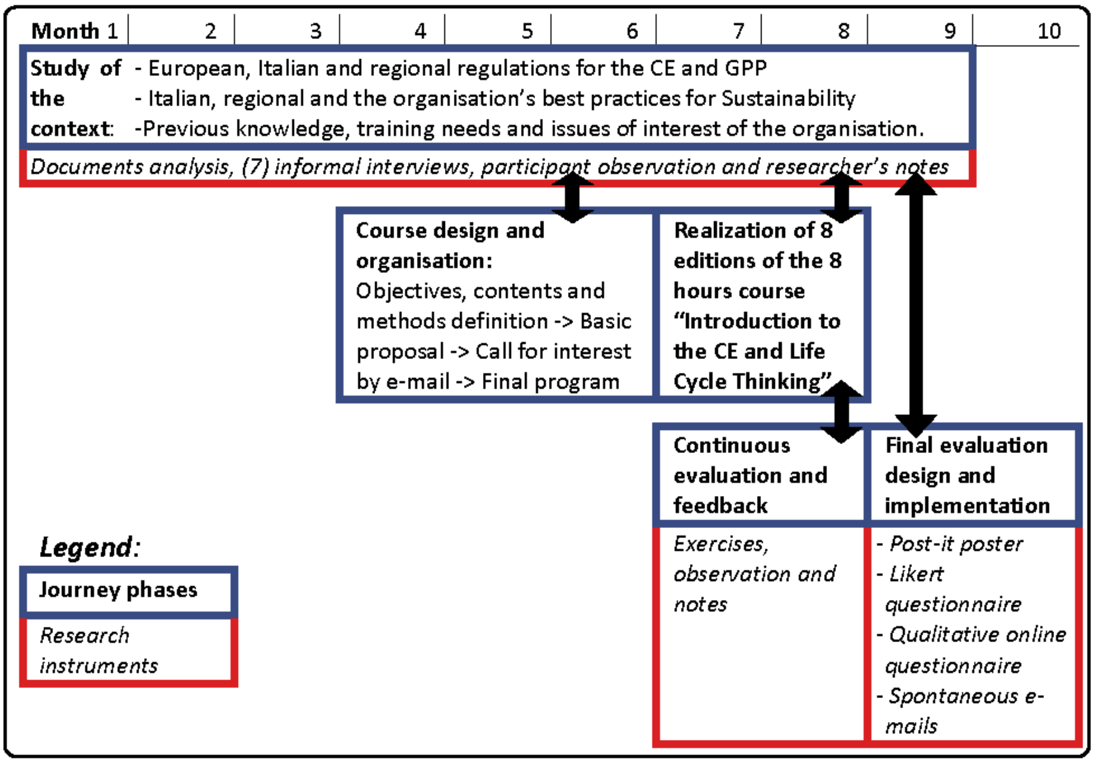

Figure 1. Diagram of the phases of the journey and the instruments used.

Complex, critical and constructivist perspective

Organising issues	*Thematic areas of intervention of ECPS*
What	1. "Introduction to the Circular Economy and presentation of the course"
Towards what	2. "Business case studies: examples of innovative companies"
Why/ How	3. "reasons for the transition to a more sustainable economy: environmental-socio-economic challenges and bases for Life Cycle Thinking"
With whom	4. "Main global and European policies for a more sustainable economy"
How	5. "The Pubblic Administration: tools and implementation" 6. "Environmental criteria and eco-labels"
When	7. "The evolution to the future economy: schools of thought"
Who	8. "Considerations on change and transition"

Methods and tools of ES, ESD y ESC: Active and cooperative learning, based on problem solving. Informal disposition of the classroom. Case studies, work groups and debate, images, videos, articles, sustainability indicators, humour, presentations, exercises and personal reflection...

Figure 2. Thematic areas of intervention of the course, in the framework of Education for Sustainable Consumption and Production (ESCP) from a complex, critical and constructivist perspective.

In principle two editions of the course, of 8 hours each, were scheduled. Then, due to the wide demand, they became eight. Moreover, being the participation on a voluntary basis, we insisted in the involvement of key, for GPP, employees

The course evaluation and research instruments

Assessing the outcomes of a learning process, which occurs through personal reflection, reconstruction and social interaction and by which an individual assimilates information, ideas and values and thus acquires knowledge, know-how, skills and/or competences (Cedefop, 2008) is complex. Therefore, the following qualitative research tools were applied:

- The analysis of documents (poster of the main socio-economic-environmental concerns and spontaneous emails).
- The participant observation, reflected in the notes in which the educator compiled the information obtained through various evaluation activities integrated in the course.
- The Likert satisfaction questionnaire of the training department, completed by 67 participants at the end of the course.
- A questionnaire with open questions to explore the feelings at the end of the course, the main learnings and the proposals for the future. This was tested by three participants with experience in education and training. The final version, that permitted the optional name insertion, was sent as a Google form a week after the last edition, to the people who participated in the whole course or almost (89 of the 95). This is because a course with an holistic approach, carried out with constructivist methodologies and with a common thread that links a sequence of activities and contents that is important it remains complete, is like a film in which each dialogue, corporal expression and scene are fundamental for the enjoyment and full understanding. Being a voluntary participation action, we did not insist on its completion and the respondents were 40.

Main findings

From the context analysis phase, considerable premises emerged:

- With regard to the level of integration of sustainability, there were no visible signs of greater consideration of the environment, taking into account the objectives of the organisation and in comparison with other private organisations committed to sustainability.
- During the course, many participants indicated that they did not have a clear and shared vision of the organisation's mission.
- The individual knowledge of the employees was very specific (on the control and status of some environmental aspect of the regional territory) and, in general, more global and systemic knowledge on the state of the world, life cycle thinking and sustainability instruments seemed to lack.

- The participants' main concerns were social (Figure 3).

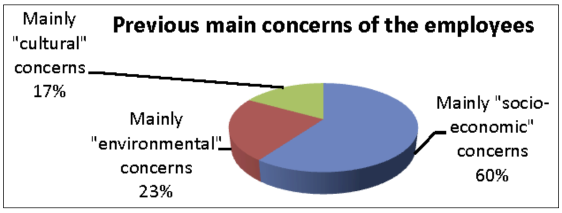

Figure 3. Participants' previous main concerns.

From the information gathered after the course, the following main results emerged:

- The quantitative analysis of the 67 Likert questionnaires indicated an almost full level of satisfaction with the course. However, of even more interest were the comments in the space for notes of the Likert questionnaire and in the spontaneous emails:
  "Finally an interesting course"
  "The topics discussed are very interesting and involving, they should be deepened more"
  "...topics of extreme interest, ...all the staff was satisfied and enriched".
- Many of the above informants highlighted the need for everyone, including managers, to participate in a course like this:
  "It must be made mandatory for all, employees and managers. The management must start investing to reduce environmental impacts, since we are an organisation for the protection of the environment"
  "I try small actions to cause the least possible impact... Presentation/information that… goes straight to the heart, there should be other courses like this and... more circular economy actions in the place where we work"
  "I hope... it finds more and more spaces, in the organisation and outside".

According to the 40 completed open questionnaires:

- The course seemed to have had a significant positive impact on the perception of the importance and viability of Sustainable Consumption and Production. For many informants it was interesting, enlightening and necessary (Figure 4c, d, e and f). Most of the aspects that were more appreciated were related to the educational tools (Figure 4e). To give some examples:
  "The experience of the closing video was the icing, but the whole course was a tasty cake"
  "The course method allowed participation at the front line, the issues and their exposition: without personal judgment, the lecturer's capacity to support with communicative expressions of 'relief', the alternation of information and images that are emotionally difficult to sustain (for example, the image of the slaves)".
- From the feelings declared at the end of the course, the degree of satisfaction and the desire to propose actions to continue the journey, the treatment of the most overwhelming issues (for example, the state of the world) with respect to the more motivating ones was quite balanced and the reaction of "discouragement" did not surpass the stimulus to personal action (Figure 4a).
- There was a wish in the group to activate good practices in the organisation and to deepen the topics covered by the course (Figure 5). It should be noted that a quarter of them spontaneously specified that they would expect that future training and information actions to update themselves on the topics of the course, should be, using their words: *"continuous", "not intermittent", "cyclically repeated", "periodic", "scheduled"...*

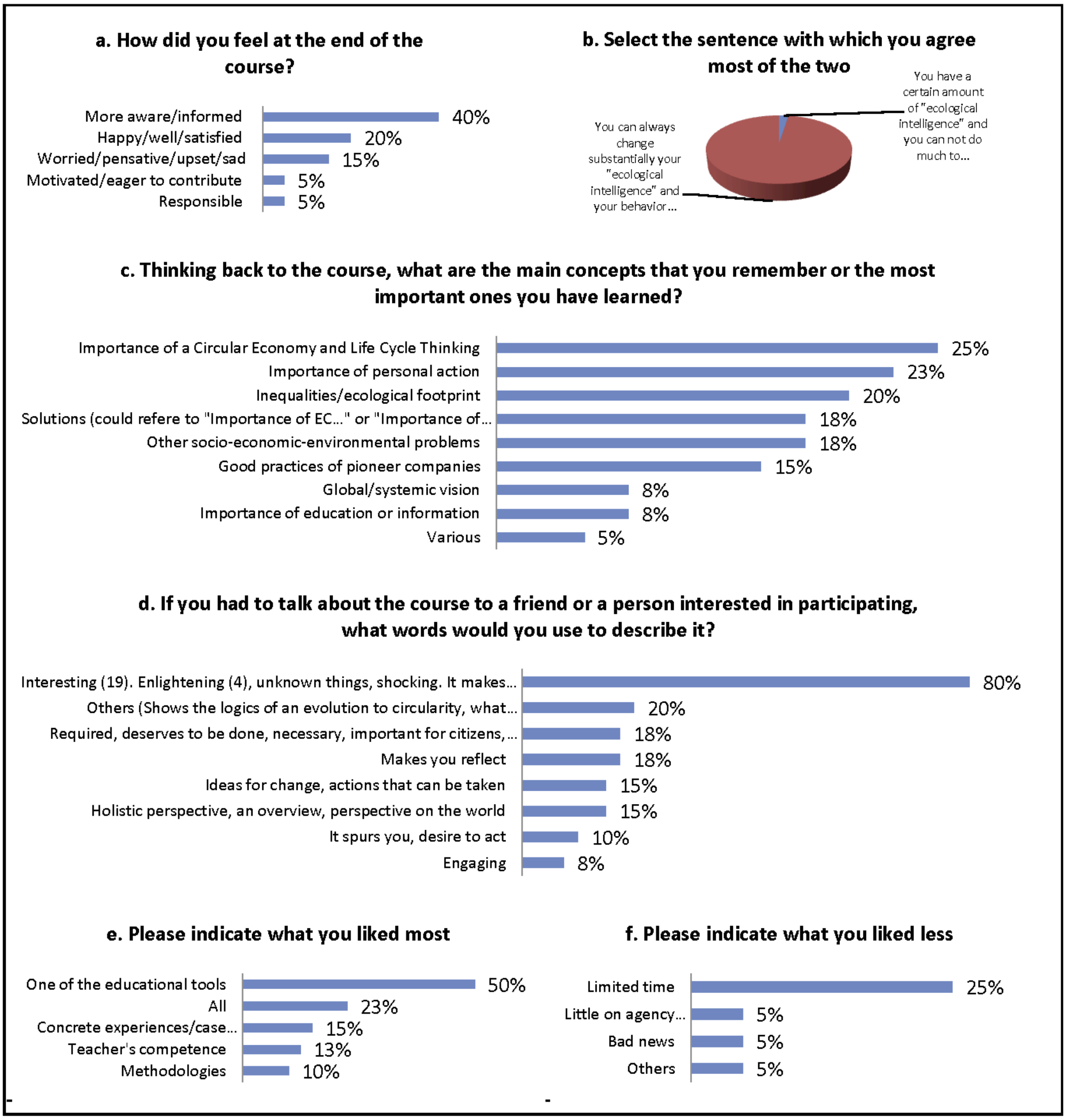

Figure 4. Main results of the qualitative questionnaire on the course "Introduction to a Circular Economy and Life Cycle Thinking". The histograms indicate the % of informants that use the keywords on the left.

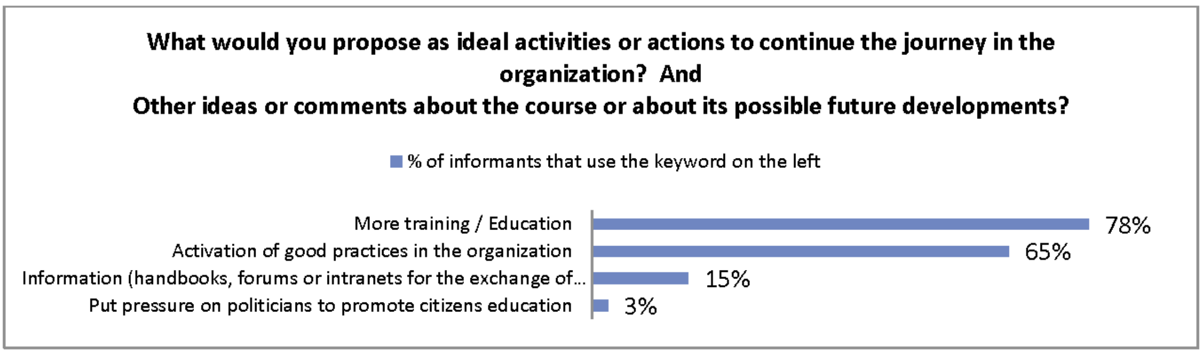

Figure 5. Proposals to continue the journey in the organisation.

Conclusions

"Sustainability is not a destination... but an ongoing learning process. Educators need to build the capacity... to address sustainability issues at a more systemic level, and to collaborate with multiple stakeholders for their resolution" (Tilbury, Adams and Keogh, 2005, pg. 27).

In general, further research and longer learning processes, as the one presented in this paper, could help to innovate professional training to accelerate the transition from a linear to a Circular Economy. Transformative (Mezirow, 1991; Sterling, 2011; Blake and Sterling, 2013; Sterling and Baines, 2002) ES approaches like the one studied, and not the transmissive ones, should be taken more into consideration in policy making, to support the implementation of sustainability policy tools.

In particular, for the organisation studied, which has institutional purposes of environmental protection, in principle there is an important potential for improvement in terms of sustainability integration.

Results suggest that a training approach from a transformative Education for Sustainable Consumption and Production, based on a complex, critical and constructivist perspective, could contribute to engage the employees of the organisations that decide to move towards sustainability (for example, by activating Green Public Procurement, mobility management or energy savings and efficiency), so to be more effective. For example, well-trained and motivated employees can contribute to the important task of monitoring green public contracts.

To accelerate the transition to a Circular Economy, this type of courses could be proposed as compulsory and perhaps with the incentive of training credits to meet the training needs that many people are unaware of or that, *a priori*, do not wish to fill. Training could also be supported by other measures, such as economic incentives, internal work groups or legislation.

"The essence of any organisation depends on the thought and interaction of its members" (Senge, 2005, pg. 50), as in a living organism, where the interest of the organs that compose it must coincide with that of the whole (Eguiguren and Barroso, 2011). Thus, to achieve greater sustainability, an organisation should share a clear mission and vision of the future that integrates sustainability (Doppelt, 2003). Indeed, during the different editions of the course, many participants highlighted the need for all, included managers, to participate in a course like this.

The research had some limits that should be taken into account in the design of any course for sustainability in any organisation, as well as for future research.

For example, the course studied was short in time and not supported by other organisational change instruments. When courses of this kind are mandatory, even for management, it would be important to facilitate the participation of all the employees, as well as to investigate the inclusion of specific activities on personal values.

It would be of interest to further explore the attitudes towards learning and the degrees of satisfaction of employees who voluntarily attend non compulsory courses and the ones of employees that do not, to study how attitudes influence their attendance.

Moreover, as proposed by O'Flaherty and Liddy (2017), it would be important to present in more detail the values and beliefs of the researcher/educator. Further, to evaluate among the results, the participants' development of a "bottom up activism for positive organisational change" in the longer term. In our opinion, it should be possible to go beyond the theoretical proposals of the participants to continue the journey, for example through detailed participant observation of employees' actions in the longer term.

Acknowledgments

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PLATE
Product Lifetimes And The Environment

Repair or Replace? Is It Worth Repairing an Old Device From a Consumer Perspective?

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Keywords: Household Appliance; Lifetime; Repairability; Consumer Survey; Life Cycle Analysis.

Abstract: When household appliances break down users have to make a decision. Is it better to repair the existing device or to replace it by a new one? Our studies show that we can support the decision with the help of life cycle assessments, cost balances and other data obtained from surveys (e.g. prices, repair frequency). We focused on following product groups: fully automatic coffee machines, vacuum cleaners, washing machines and dishwashers. Specific conclusions have been drawn for each product group to help consumers make their choice and how to analyse further product groups. Three steps towards longer service lifetimes are proposed.

Method

What burdens household budget and environment more - repairing or replacing? Our life cycle assessments and cost analyses take into account several thousand answers to our reader surveys on test.de as well as surveys of 506 independent workshops of Meinmacher.de portal and 111 repair cafes of Reparatur-initiativen.de portal.

Life cycle of a product is divided into several stages for Life Cycle Assessment (LCA): Production, packaging, transport, operation (with German electricity mix), disposal / recycling. Products were disassembled in the testing institute and the masses of metals, glass, plastics, electronic components, etc. were recorded separately for the Ecoinvent LCA database. Not only materials used, but also processes involved (e.g. shaping of metal; transport by truck or freighter) are recorded, including all material and energy consumption of the upstream processes from the respective raw material extraction.

For cost analyses we determined when equipment breaks down, average purchase prices and repair costs for most common defects. In addition to electricity and water costs, usage costs also include expenses for auxiliary and operating materials such as dust bags, detergents, descaling agents or coffee.

We also asked the suppliers how long they keep spare parts in stock, what service life they calculate for the products and how long they guarantee their products.

According to suppliers, spare parts for coffee machines, vacuum cleaners and washing machines around 10 years old can still be obtained often. Prices vary strongly. Typical repair costs were called us by manufacturer independent workshops. Spare part prices are only taken into account in cost calculations where consumers replace components themselves, e.g. dish baskets of a dishwasher.

In a further survey we asked our readers about their satisfaction with their household appliances. We received answers from more than 14,000 people. We evaluated reliability of brands and the satisfaction of the users in age groups of the brands from up to 2 years old, over 2 to 8 years old and over 8 years old.

Vacuum Cleaner: Repairing is rarely worth it

If the vacuum cleaner breaks down after warranty period, it is almost always cheaper to buy a new one instead of having the old one repaired by a professional. Only hobbyists who repair themselves can save money.

Repairing is of little ecologic use

A vacuum cleaner contains around 55 g of electronics, 5.7 kg of plastics and 2.4 kg of metals. Repairing or replacing it is almost irrelevant for environment. Electricity consumption during vacuuming has a greater impact than production. Only with old 2000 Watt power guzzlers exchange is worthwhile in any case: new models need less than half the power thanks to European Ecodesign regulations.

New purchase is cheaper than repairing
According to our reader survey, vacuum cleaners break down on average after 8 years. Devices that have been repaired have a defect again one year later. Who buys the new device for 170 € and repairs twice, has in 10 years about 500 .. 690 € total costs (1 .. 2 hours suction/week). Those who never have it repaired but buy a new one at the first defect only pay 400 .. 580 €. Cheap repairs are only worthwhile in the first four years.

Cable winders, hoses and motors
Manufacturer-independent workshops repair broken cable winders most frequently. This costs an average of 70 €. The hose also often breaks. Fitters replace it for about 45 €. The third most common weak point is the engine. On average, this costs 120 €.

Spare parts for 5 to 10 years
Most suppliers keep spare parts in stock for about 5 to 10 years. They often don't provide any information on calculated service life. Data ranged between 500 hours and up to 20 years. Warranty is granted rarely more than 2 years, with on-line registration sometimes more.

Fully automatic coffee machines: Repair is worth it

Production of fully automatic machines is resource-intensive and their purchase price is high. Therefore, coffee drinkers who have their defective machine repaired save money and the environment.

Repairing makes sense ecologically
A fully automatic coffee machine contains around 600 g of electronics, 7 kg of plastics and 3.2 kg of metals. Because of these valuable raw materials, production pollutes the environment to such an extent that owners should use it for as long as possible and have it repaired in the event of defects.

Repairing usually saves money
On average, a fully automatic coffee machine fails three times in ten years. If you buy a new one for 810 € and have it repaired every time, you'll have spent a total of 2,500 .. 3,900 € (5 .. 10 cups/day) after 10 years, if typical defects will appear. Anyone who buys a new one at the first loss pays around 3,100 .. 4,300 €.

Heating, valves and pumps
According to independent workshops, the biggest weak point is heating. The repair costs 145 € on average. Secondly, repair shops replace defective valves most frequently. That costs on the average 100 €. A defective pump is the third most frequently repaired by fitters. They charge around 110 € for this.

Service life can be 15,000 coffee drinks
According to their own information, the suppliers keep most spare parts in stock for about 5 to 15 years. Some suppliers do not provide any information on the calculated service life. Data ranged between 15,000 coffee drinks or up to 20 years. Warranty rarely granted for more than 2 years.

Washing machines: Repairing is better for the environment

Getting broken washing machines up and running again usually doesn't save the owners much money in the long run, but it noticeably reduces their ecological footprint.

Ecologically, repairing makes sense
A washing machine contains around 900 g of electronics, 26 kg of plastics and 33 kg of metals. The production process is so energy and resource intensive that the owner protects the environment by using the machine for as long as possible and repairing it if necessary.

Repairing is not financially worth it
A washing machine needs on average two repairs in fifteen years. The typical repairs cost so much that in the long run a new purchase is only slightly more expensive than the repairs: If you buy a new machine for 600 € and have it repaired twice, you will have spent a total of 2,300 .. 3,500 € (150 .. 300 washes per year) after 15 years, if typical defects will appear. Anyone who buys a new one for the first damage pays around 2,400 .. 3,700 €.

Heating rod, pump and electronics.
Fitters change the heating rod particularly often. This costs an average of 125 €. The pump also often breaks down. Manufacturer-independent companies repair this damage for an average

of 130 €. The third most frequent and most expensive weak point is electronics: A repair costs on the average 250 €.

Calculated service life of 2,000 washes
According to their own information, the suppliers keep most spare parts in stock for about 5 to 10 years. Calculated service life data lay between 8 to 20 years or 2,000 wash cycles. Warranty typically granted for 2 years.

In the first 2 years, 7 percent defect
Devices that were older than 8 years already broke down or had faults on average in 30 percent of all cases. In the case of devices under 2 years old, the figure was only 7 percent, in the middle age group 20 percent.

User satisfaction was highest at Miele, Privileg and Blomberg: 82 to 60 percent of all users would certainly recommend their device to others. It was lowest for Constructa, Bauknecht and Whirlpool: only 44 to 41 percent would recommend it to others.

Dishwashers: Repairing benefits the environment

The production of a dishwasher requires a lot of energy and resources. Repairing a dishwasher instead of buying a new one pays off for the environment. Financially, it only pays off for expensive models

Repairing makes sense
Dishwashers contain around 1.3 kg electronics, 16.8 kg plastics and 20.5 kg metals. Environmental cost of 4 repairs in 15 years is lower than material and energy for production. Consumers therefor should repair. Greatest harm to the environment is caused by the use of the product, which is why it should only be switched on fully loaded, detergents should be dosed as low as possible.

Hardly any financial difference
If the dishwasher breaks down 4 times and is repaired, the costs will only just exceed the average price of a new one of around 600 €. The more expensive the machine, the more worthwhile it is to repair it: if you buy a new appliance and have it repaired 4 times, you will have spent a total of around 2,200 .. 3,000 € (150 .. 300 cycles per year) after 15 years, if typical defects will appear. Anyone who buys a new one at the first damage pays around 2,100 .. 2,900 €.

Defective pumps, electronics, door parts
Pumps are vulnerable. Repairing a drain pump costs on average 151 €, a circulation pump even 238 €. Electronic parts are also frequently repaired by workshops, around 268 €. Door components (seal, lock, hinge springs) follow in third place the frequency of defects. Spare parts are quite cheap. Users can exchange the dish basket themselves for around 110 €.

Warranty rarely longer than 2 years
According to their own information, the suppliers keep most spare parts in stock for about 5 to 15 years. The suppliers state the calculated service life between 8 and 20 years or 10,000 hours or 2,500 rinsing cycles. Warranty rarely granted for more than 2 years.

Reliability of brands scatters considerably
Devices that were older than 8 years already broke down or had faults on average in 33 percent of all cases. In the case of devices under 2 years old, the figure was only 6 percent, in the middle age group 25 percent.

User satisfaction was highest at Miele, Bosch and Privileg: 74 to 50 percent of all users would certainly recommend their device to others. It was lowest for Whirlpool, Gorenje, and Zanussi: only 30 to 22 percent of their users would safely recommend it to others.

Investigation of reparability: Dishwashers

With our own test program, we have for the first time investigated the reparability of this product group. We selected 3 devices from different price and energy consumption classes and examined three dimensions of repairability:

- Instructions (e.g. precise product identification, detailed description of the meaning of all fault indications, availability of the manufacturer's service centre, and nine further test points).
- Practical investigations on reparability (e.g. safe accessibility for troubleshooting purposes, detachability of connections and a further eight test points)
- Facilitation of possible repair cases by the supplier (e.g. the exact model designation

is permanently attached to the device, all requirements on the type plate are met, and a further three test points).

This showed that typical and frequent repairs on the selected models are easily feasible for authorised workshops. Suppliers provide them with detailed documentation such as design and connection diagrams. They can also access a test mode detecting device defects.

The situation is quite different for independent workshops without a contract with the suppliers: They often don't have access to important information, so they can't repair larger defects. This is annoying for consumers because independent repairers can be cheaper than after-sales services.

Conclusions

The question whether a defective product should be repaired or replaced by a new one can be answered in detail with the help of cost balances, life cycle assessments and some other data we got from user surveys.

Individual consumers do not have this information for the respective repair cases. However, they can use our statements valid for the product group. With knowledge of the individual purchase price, the actual intensity of use and the previous service life and repair history, the cost and environmental consequences for the individual case become visible and the decision for or against a repair can be made on an objective basis - depending on the ecological and financial preferences of the decision-maker.

In order to carry out these analyses for other product groups in future, and perhaps in more detail, we have gained experience that at least the following data are required:

- Mass and material balance of typical devices of the respective product group. Component determination after disassembly of products must be carried out in such detail that all parts can be recorded with the LCA database used, including all auxiliary and operating materials as well as the electricity mix. In the case of large household appliances, the electricity mix should be forecast over the service life of the appliance if relevant.
- Usage profiles that map the consumption of all auxiliary and operating materials for at least two different usage intensities.
- Scenarios showing different repair behaviour of consumers for at least 2 variants.
- Overall service life of the appliances and mean times of occurrence of the most frequent defects.
- Life cycle assessments using the above material balances, usage profiles, repair scenarios and service lives.
- Costs for the consumer: range and mean of the equipment purchase price, all auxiliary and operating materials, the repair prices of workshops, the prices of spare parts.
- Cost balances, calculated for the same boundary conditions as the life cycle assessments.

With regard to environmental impacts, results we obtained with these data for 4 product groups show that the longevity of large household appliances can still be significantly improved and this would have a major positive effect on the environment.
In contrast, the financial impact for consumers who opt for repairs and durable equipment is not always clearly positive today, but can be advantageous or disadvantageous depending on the product group.

In order to move closer to significantly more durable devices, further steps are needed in at least the following 3 aspects:

- Improve the reparability of the products so that they especially can also be easily repaired by independent workshops.
- Increase the durability of individual components, especially those that currently limit the service life most frequently.
- Enlarge profitability of repairs, so that the consumers financial decisions are more often in line with environmental benefits.

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Ecodesign Spinning towards the Circular Economy – the Contribution of New Standards on Material Efficiency

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Keywords: Ecodesign; Circular Economy; Material Efficiency; Resource Efficiency; Standardisation.

Abstract: Whilst the concept of ecodesign is intended to account for the environmental impacts of the product across its whole lifecycle, European ecodesign policy to date has been heavily focused upon energy efficiency in the use phase. The Ecodesign Directive and Energy Labelling Regulation have achieved substantial energy savings since their inception. For many products, the magnitude of savings available from further tightening existing energy efficiency requirements is now often outweighed by savings that can be achieved by material efficiency requirements. Further, there are some products for which there are limited gains to be made in energy efficiency but for material efficiency. In the Commission's Circular Economy Action Plan from 2015, a new direction was defined for ecodesign policy, to systematically examine considerations such as reparability, durability, upgradability, recyclability, or the identification of certain materials or substances. The Commission consequently issued a standardisation request (M/543, 2015) to the European Standardization Organisations (CEN / CENELEC / ETSI) to develop generic / horizontal standards relevant to energy-related products that address these major aspects of material efficiency. In this study we evaluate the potential contribution of these new standards (with specific focus on the standards for repair, durability and recyclability) to future developments under the European Ecodesign Directive. Opportunities for the impact of these standards to be enhanced by future work are highlighted.

Introduction

Within the European Commission's Circular Economy Action Plan (European Commission, 2015, 2017, 2019) clear statements are made regarding the aspects of a circular economy that should be embedded in existing legal frameworks. The need for requirements addressing the durability, reparability, upgradeability and recyclability of energy–related products is asserted. The action plan identified the Ecodesign Directive as a suitable mechanism for implementation of such requirements (European Union, 2009). Up until very recently, the regulations under the Ecodesign Directive primarily addressed the energy efficiency of energy-related products, achieving substantial savings. For the majority of the products covered by the Ecodesign Directive, the magnitude of savings available from further tightening existing requirements is now often outweighed by savings that can be achieved by material efficiency requirements. Further, there are some products such as smartphones for which there are limited gains to be made in energy efficiency but for which material efficiency is key. To support the setting of such requirements, the European Commission issued standardisation request M/543 to the European Standardization Organizations CEN, CENELEC and ETSI in 2015 (European Commission, 2015 ; Hughes, 2017). Most of the deliverables requested under M/543 are not intended to be directly applied to a certain product, but rather to be used as framework for the development of product-specific material efficiency standards by product-specific standardisation groups. This paper presents the approach of deliverables developed under the M/543 and explores their potential for future application.

New standards

To undertake the work specified in M/543, the joint CEN-CENELEC Technical Committee 10 (CEN-CLC/JTC 10), was established to develop the standardisation deliverables as summarised in Table 1. A driving principle was that the standards should enable an evaluation of the material efficiency aspect to be carried out with reasonable effort and costs and that the result would be reproducible and repeatable such that they could be verified by market surveillance authorities. A deeper discussion of the potential of the three key standards dealing with Durability, Reparability-Reusability-Upgradeability and Recyclability, is presented in the three subsections below.

Reference	Subject
prTR 45550	Definitions
prTR 45551	Product level application (postponed)
prEN 45552	Durability
prEN 45553	Remanufacturability
prEN 45554	Repair, reuse & upgrade
prEN 45555	Recyclability & recoverabiity
prEN 45556	Re-used components
prEN 45557	Recycled material content
prEN 45558	CRM declaration
prEN 45559	Information provision

Table 1. Summary of M/543 deliverables. The Standards discussed in this study are highlighted in grey.

Durability

Fundamental to the development of the standard prEN45552 was a clear definition of durability, particularly in relation to temporal aspects. It was determined that for the purposes of legal requirements the most applicable condition was durability until first repair action, and the standard was oriented accordingly.

The assessment described in this standard follows the principle of the “weakest link in the chain”. After a functional analysis, a failure (or limiting state) analysis of each function follows, and the parts involved in the most relevant failures are identified. Afterwards, durability tests can be developed by product-specific technical committees which are specific to these parts (weakest links) of the whole product (chain). By focusing on parts, testing effort can be reduced and made more cost-effective for both the manufacturer and market surveillance authorities. Further, it is recommended that tests where the parts remain within the product are preferred. This avoids the need to simulate the parts’ environments to test under conditions which are close to application.

Such an approach may result in parts being addressed that are defined as products within the Ecodesign Directive such as electric motors, fans, pumps etc. (European Commission, 2019a; European Union, 2011, 2012). Horizontal requirements for products such as these may be very general and/or require a high level of effort. Tackling these “products as parts” within one or more specific product groups may be appropriate where they have significantly different applications that would result in different requirements on their durability.

A recent draft research study by the European Commission (Mauro Cordella, Alfieri, & Sanfelix, 2018) partially applies the approach outlined in the standard for a smartphone. The outcome is a list of parts, failures and failure mechanisms, and possible measures to increase durability including assessment and verification approaches.

The methodology outlined in the prEN 45552 standard provides useful guidance to facilitate the identification of key parts of relevance to durability at a product-specific level. There is potential for further work to build upon this standard developing the following areas:

- Presentation of outputs from durability assessments. For example, the specification of tables listing parts, failures and failure mechanisms.
- A general list of options for qualitative (pass/fail) criteria relating to durability e.g. compliance with standards on dust ingress, battery longevity of certain number of cycles. The European Commission’s Joint Research Centre has begun to explore this in their studies on TVs and smartphones.
- Exploration of definitions around product lifetime (technical, functional etc.) and labelling considerations. Research to investigate if / how lifetime could be considered in labelling.
- Examination of testing approaches. Research to determine how a balance can be reached between test approaches that are affordable, practical, robust and repeatable and those that best emulate real-life usage conditions.

Reparability, Reusability, Upgradeability

In recent years, several approaches have been developed by different organisations aiming to improve the reparability of products (CEN/CENELEC/ETSI; European Commission, 2016b; M. Cordella, Alfieri, & Sanfelix, 2019; M. Cordella, Sanfelix, & Alfieri, 2018; EC-JRC, 2018; Flipsen, Bakker, & van Bohemen, 2016; IFIXIT, 2018; ON, 2014; SEB, 2018). In general, they address three key aspects of reparability: (i) product-design related aspects e.g. type of fasteners (ii) support-related aspects e.g. spare part availability and iii) information-related aspects e.g. disassembly instructions.

The standard prEN 45554 builds upon the work of these organisations to establish a number of criteria that influence not only the ability and ease of repairing products, but also their reusability and upgradeability (The scope of the draft standard includes the technical ability of a product to be repaired, reused or upgraded, and does not cover elements related to hazards, hygiene issues, as well as economic, legal and environmental aspects). All three aspects have the potential to extend product lifetime. Some criteria relate to priority parts, others to the product as a whole.

Design-related criteria include disassembly depth of a priority part, the type of fasteners used, and the prerequisites for a repair, reuse or upgrade operation to take place in terms of necessary tools, working environment and skill level. Support-related criteria include the availability of diagnostic tools and those for data deletion and reset, and availability of spare parts and repair information. Time for disassembly (of priority parts) is also considered as a possible assessment option. Most criteria are accompanied by a classification system to enable product-by-product assessment. The relevance of each criterion for repair, reuse or upgrade will depend on the specific product group in question. The criteria are also very much interrelated. For example, even if the owner of a product receives all the information necessary to repair their product, it may be that they are still unable to implement the repair as they are unable to purchase the spare part required or do not possess i) a special tool necessary to open the casing, or ii) a diagnostic tool to help them identify exactly which fault has occurred. Thus, in order to be able to assess the overall reparability of a product it is necessary to aggregate the repair characteristics into a single overall reparability score (and similarly for reusability and upgradeability as necessary). Such a score can also facilitate comparison between different products.

The approach described in the standard prEN45554 is comprehensive and aims to provide a flexible toolbox from which to select criteria as relevant to a product group. As such it has already inspired other studies addressing reparability. In particular, the European Commission's Joint Research Centre have used the approach as a foundation for a reparability scoring system (M. Cordella et al., 2019) and for their methodological guide for the assessment of material efficiency of products which is the further development of a former methodology used by European Commission for the resource efficiency assessment of energy-related products (Ardente & Mathieux, 2014). This method has already been applied in detailed studies for smartphones and televisions (Sanfelix, Cordella, & Alfieri, 2019).

The criteria of the standard have also contributed new perspectives and possibilities to regulatory discussions on revisions of ecodesign regulations for products ranging from electronic displays to washing machines. For example, proposals discussed from 2018 to 2019 included draft requirements such as ease of disassembly/dismantling of priority parts, spare parts availability and delivery time, and availability of repair information. (European Commission, 2016a, 2016c, 2017a, 2017b, 2017c, 2018a, 2018b).

The prEN 45554 standard provides a valuable resource for the development of product-specific repair considerations. Further research could expand on this to develop the following areas:

- A general list of options for qualitative (pass/fail) criteria for repair e.g. software updates are offered for at least X years after placing on the market etc.
- Exploration of labelling approaches for repair: A study exploring the possibilities and proposing options for a label based upon the scoring approaches in the standard, including graphical representation, classes etc.

Recyclability

The prEN 45555 standard provides the methodology from which to develop a product-specific standard on recyclability (and recoverability, which is not discussed here). It explains the need for a specific end of life treatment scenario to be applied consistently across a product group to enable comparison between products. Guidance is provided on how to define the treatment scenario in a representative way, considering product-related, technological, temporal and geographical aspects.

Once the recycling method for each material has been determined, it is possible to set a recyclability factor for each. This enables the calculation of the overall recyclability rate for a

product based on the types and quantities (mass) of materials.
Design-related criteria affecting recyclability are also listed, including aspects such as the identification (e.g. marking) of, and ability to remove, parts requiring selective treatment, and compatibility of material combinations with recycling processes. A basic recyclability rate calculation is provided.
The recyclability standard enables a recyclability rate calculation to be defined for a specific product group. Further work could build upon this such as investigation into feasibility of application of recyclability rate for specific product groups. Further studies could consider how a recyclability rate calculation can be applied for specific product groups whilst considering the viewpoints of a wide range of stakeholder groups.

Conclusions

The standards in the numerical range of 45550–45559 developed under standardisation request M/543 establish a range of new material efficiency criteria and methods. They provide a strong foundation for the systematic consideration of material efficiency within Ecodesign regulatory discussions. However, they do not consider product group specificities, and therefore cannot usually be directly referenced for testing and verification purposes.
The focus of ecodesign regulation in the past has been upon energy efficiency. When a new product group was to be addressed within ecodesign, a preparatory study would be carried out to assess the potential policy options using the MEErP methodology (VHK, 2013). Now that material efficiency aspects are to be considered in more detail, discussions have begun around the revision of the MEErP methodology. Nonetheless, it is not necessary to delay legislative processes until revised methodologies or product-specific standards are available.
Some product groups covered under the Ecodesign directive (vacuum cleaners, washing machines and lighting products) have already had material efficiency requirements in place for years, supported by product-specific testing standards. These products were already addressed because they also had significant energy efficiency potential. However, there are products included on the 2019 Circular Economy Action Plan (European Commission, 2019) where the key savings are to be accessed by material efficiency.
Smartphones are an example of a product where addressing material efficiency has much greater savings potential than energy efficiency, which is already covered to some extent under the external power supply regulation. During revision of this regulation, a draft Ecodesign regulation was created which would be consulted upon stakeholders in consultation forum and regulatory committee meetings (European Commission, 2019b). Within this process, the new standards can contribute generic approaches to the study on various material efficiency aspects. To support the final regulation, transitional testing methods would be defined, referencing existing non-harmonised approaches. In addition, a standardisation request for product-specific material efficiency standards could be launched by the European Commission. These standards could be drafted by European Standardization Organisations to support the requirements within the new legislation as well as providing a basis for the development of future revisions of the regulation. Ideally, the product-specific standardisation processes would be commenced as early in the Ecodesign policy making process as possible (Tecchio, McAlister, Mathieux, & Ardente, 2017). In this way the product-specific standards can be developed pragmatically in parallel with legislative processes to ensure that the timings for introduction of new regulatory requirements are streamlined.
Further research in the areas indicated in this paper would optimise the contribution the new material efficiency standards can make to the transition to a circular economy. Despite their generic nature, they have considerable potential to contribute to a paradigm shift in the development of regulations under the Ecodesign directive. Analysis methodologies are in the process of being refined and product-specific testing standards may lag the development of legislation. As such, pragmatic approaches are necessary during this transitionary period to arrive at sufficiently rigorous approaches to addressing the material efficiency characteristics of energy-related products within agile timescales.

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Adopting an Emotionally Durable Design Approach, to Develop Knitted Prototypes for Women Living with Raynaud's Syndrome

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Keywords: Knitted Textiles; Well-being; Emotional Durability; Human-centered.

Abstract: This paper reports on an aspect of current research into designing knitwear products for Raynaud's Syndrome: a condition triggered by the cold or a drop in atmospheric temperature; causing numbness, pain, dexterity and mobility issues. Participatory research with a group of women, between the ages of 26 and 68 who suffer from Raynaud's, has identified a range of 'design issues' within existing products, some of which fail to mitigate the effects of cold and poor circulation effectively. In addition, many available products have limited appeal in terms of style, colour, pattern and texture. By considering the identified needs of this group, a range of knitted garment prototypes have been developed that respond to users' practical, aesthetic and emotional needs. This emotionally durable design approach, informed by IPA (Interpretative phenomenological analysis) builds on recent research into the development of new collaborative methodologies and business models that support product attachment and longevity (Townsend et al 2017 & 2018).

Introduction

In Raynaud's sufferers, narrowing of the blood vessels in the extremities occurs more quickly and extremely than normal. The process can cause numbness, pain and chilblains which can be irritating and uncomfortable, making everyday tasks and activities difficult and frustrating. This paper reports on an aspect of current research into design of knitwear products in response to knowledge and understanding of the daily experiences of women living with Raynaud's syndrome. For these women, living and coping with Raynaud's requires constant strategic management to remain warm through the careful selection and layering of clothing and accessories. However, not all products meet the women's physical wellbeing needs in terms of material performance, fit of the garment and comfort. Neither do products meet their psychological desires to feel stylish, to be provided with choice in aesthetics of a garment and to feel less self-conscious.

The paper begins by presenting a theoretical framework that underpins the human-centered methodology adopted in the research project. The methods and findings are reported, before describing how the needs and desires of the user are translated into design (knit) prototypes, including interim feedback from two participants of the prototypes.

Theoretical Framework

"as people become more sensitive to dimensions of products that go beyond traditional aspects of usability, the need to create emotional resonance between people and products increases"

(DiSalvo, 2004, p.251)

There is potential in products to generate psychological happiness as well as stimulating physiological wellbeing (Demibilek and Sener, 2003). In *Emotionally Durable Design*, Chapman (2005) urges industrialists to consider emotional durability alongside physical durability in new product development, to avoid product replacement or discard, due to customer dissatisfaction. Users' needs, and expectations of a product are changing and becoming more sophisticated as they increasingly seek a *"psychological lift"* (Tyagi and Goel, 2013, p312). Catering towards the potential for products to generate psychological wellbeing or happiness, increases the strength of the relationship between product and consumer, preventing functional products being discarded (McDonagh-Philip et al, 2009). There are many theories as to how emotions are important in social and creative cognition (Neidderer and Townsend, 2014), how emotions are influenced by experience (Dewey, 1934), and how emotions elicited by a certain situation attract an individual's continuous engagement with that situation or stimulus (Frijda, 2009).

Within Desmet and Hekkert's (2007) product experience framework, three contributing elements are identified that affect the relationship between a user and product: aesthetic experience, experience of meaning and emotional experience. The aesthetic aspect is the sensorial feedback from the way a product looks, feels, sounds and smells. What a product means to its user, is defined through his/her cognitive processes *"like interpretation, memory retrieval, and associations"* assigned to the product (Ibid, 2007, p.4). And lastly, a product has the capacity to elicit emotions such as joy and desire, or fear and unpleasantness when using or imagining its usage.

Jordan argues that *"pleasure-based approaches to product design consider all of the potential benefits that a product can deliver – those of practical, emotional and hedonic benefits"* (2000, p12). Designing for product durability, goes beyond the physical mechanisms of artefacts, *"moving away from rational and practical issues to more subjective fields of experience"* (Mattelmaki, 2003, p119). The different elements of product attachment discussed by previous authors, underpins a design philosophy, to include a *"wearer's physical, psychological and social preferences"* (Moller and Kettley, 2017, p35). Implementing a human-centered design approach supports communication, interaction and empathy methods to develop a deeper understanding of the needs, desires, daily experiences and aspirations of participants (Giacomin, 2014, Bush, 2015). Gathering information on what is labelled as 'emotional' data (Crossley, 2003), includes terms such as feelings, aspirations, and emotional needs, by empathic design techniques and tools, such as in-depth interviews (Postma et al, 2012). Therefore, the project adopted a semi-structured interview method informed by IPA (Interpretive Phenomenological Analysis) (Smith and Pietkiewicz, 2012). This builds on recent research into emotional design to support product attachment and longevity (Townsend et al 2017 & 2018).

Method

The project carried out a series of in-depth, semi-structured interviews (Oct 2017-July 2018) with ten female participants living and coping with Raynaud's Syndrome. The interview schedule consisted of open-ended questions about different aspects of the women's experience with Raynaud's, to understand the meaning of living and coping with the condition: how the condition affected them; what daily challenges they faced; how they self-managed the condition; and their thoughts and feelings on topics discussed (Hassenzahl, 2008). Additionally, the inclusion of personal objects (Klepp and Bjerck, 2014; Townsend and Sadkowska, 2017), chosen by the interviewee prompted personal stories of meaningful experiences, making for a more productive interview (Martin and Hanington, 2012).

Findings: emergent themes

Analysis of the interviews generated three overarching themes: (1) Self-management strategies, (2) Material Affairs, and (3) Social Awareness. Theme (1) is concerned with how the women select and wear garments and accessories, to self-manage symptoms and support their physical well-being. The women's concern is for their health when reaching *"that level of cold"* where blood flow is restricted, causing numbness and pain. This impression of change to wardrobes is repeated across different women's testimony, as the women focus on *"being warm and comfortable"* (Louise, 61) as a prevention strategy. (Note that the names given for participants are pseudonyms.) Several of the women commandeer men's jumpers and jackets as they are more 'fit' for the women's needs. The sleeves and hem are longer, the fabric is warmer and there is room for layering underneath the garments. Furthermore, to augment practical design elements, the women make items such as wrist bands and toe covers to provide extra warmth. Bands on socks are stretched over bottles to ease tightness around the ankle. Additionally, leggings and socks are worn inside out to avoid discomfort from the toe seam when the women's feet are cold. Additionally, the women had difficulty with standard fastenings such as buttons and zips when their hands are cold. Consequently, the women describe their wardrobe change from *"fashionable"* or *"stylish"* clothing, to *"practical"* or *"utilitarian"*. However, in doing so, there is a sense of compromise in *"style decisions"* (Mandy, 26).

Analysis of theme (2) finds that, whilst warmth and comfort are important for the women to self-manage their health, choosing clothing solely for warmth is mundane. According to Valerie, she's *"a bit boring"* in her selection of clothing, for this reason, Valerie seeks to find an alternative to fleece material. In similar vein, Carol explains that fleece fabric helps keep her warm, however she does not *"feel very smart in them"*. Margaret confesses that she does her best to search for *"aesthetics but thinking around my[her] health"*. Brenda (57) conveys her desire for more interesting and colourful garments, so much so that it's almost an addiction *"I, I'm almost… addicted to buying summer clothes that I can't wear just because they, they look so lovely and bright and, the textures, the textiles are so lovely".*

Theme (3) highlights the women's awareness of how *"dressing accordingly"* for their condition, affects them in social situations, or in the company of others. Jane (35) highlights an issue with layering, which is common throughout the testimonies: layering might be an effective approach to keeping warm, however, this causes the women to "*sweat an incredible amount"* underneath the arms, which is *"really embarrassing"*. At times, Jane is reluctant to layer, which results in her feeling cold. Brenda describes a blue and white striped summer jumper. The jumper allows her to remain warm, but more importantly, it provides Brenda with a sense of fitting in, as the colours *"seems quite acceptable, that lots of people have blue and white shirts".* Daisy (28) prefers gloves with a Velcro fastening, however, she is self-conscious of the sound they make whilst removing them in-doors. Daisy feels attention is drawn to her when she removes the gloves during meetings, *"hey, look at me, signing what everyone else signed without needing to wear gloves".* Similarly, Jessie (51) expresses a desire for gloves and garments which blends into an everyday wardrobe *"something that's functional, you can wear every day, that, that, you're not gonna look odd".*

The findings show the women self-manage the symptoms of Raynaud's by dressing strategically. 'Design issues' which the women contend with are highlighted. These inform knitted garment design solutions: a cardigan, a jumper and a pair of socks. The solutions include the lengthening of sleeves and hems for extra coverage; resolution of irritation of seams on socks; and the tightness of the band around the ankles. The requirements for fabrics are: warm, lightweight and aesthetically pleasing; and helping to prevent underarm sweating. Style, colour and texture are taken into consideration to produce attractive garments. And lastly, alternative fastenings to buttons and zips are explored to make it easier for the women to open and close the garment when their fingers are cold and painful.

Informed Knitted Prototypes

Figure 1 shows a knitted cardigan prototype, with a 'plush' knitting technique, where loops in the fabric create pockets of space to capture air for insulation purposes. This is located on the inside of the garment, except for the under-arm panels, as shown in Figure 2(D). These sections are knitted using a 'plating' technique, where two yarns were knitted side by side, creating a lined fabric. These panels reduce excess fabric under the arms and enhance breathability to reduce overheating. The collar (Figure 1(A)) and the wrist panels (Figure 1(C)), incorporate 'plush' on both sides of the fabric. This allows the fabric to be slightly rigid, allowing the collar to stand up, providing extra neck coverage. The cardigan's sleeves have extra length and Figure 2(E) shows the shaping of the cuff to provide extra coverage over the top of the wearer's hand.

The design elements of the cardigan responds to the women's desire for more stylish and warm clothing. The cardigan contains variations of texture and colour: teal coloured bespoke panels under the arms which contrast with the peach colour and baby pink collar and wrist panels. The grey centre front pockets (Figure 1 (B)) contain magnets to fasten the cardigan.

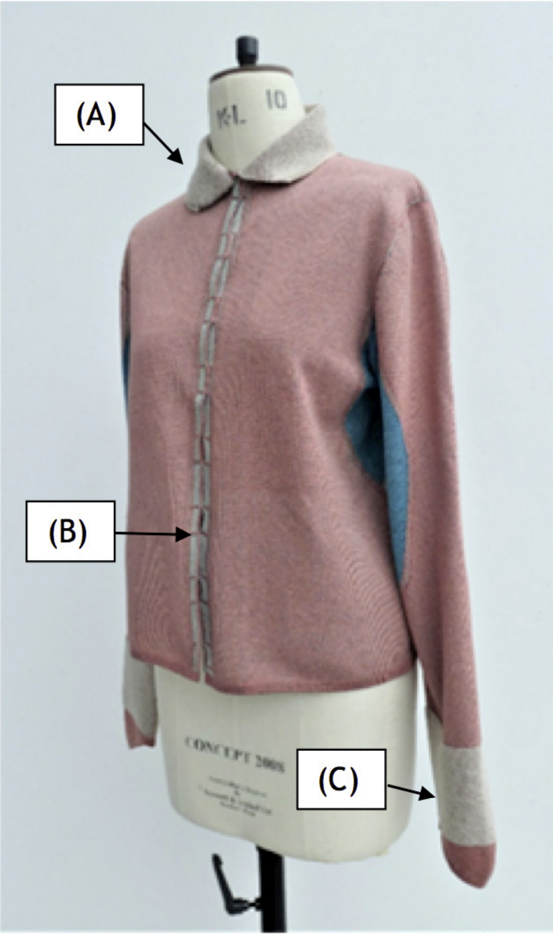

Figure 1. Knitted Cardigan Prototype, Lisa Shawgi, 2019.

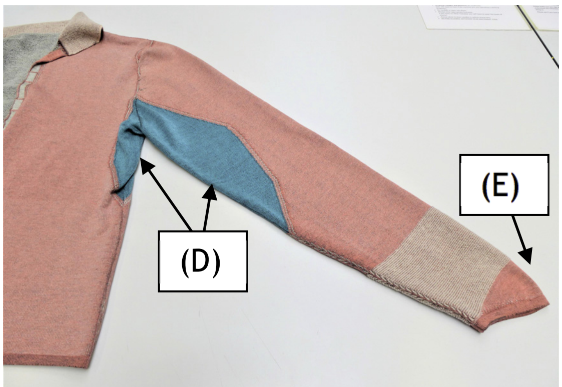

Figure 2. Knitted Cardigan Prototype, Lisa Shawgi, 2019.

Figure 3 shows a knitted jumper prototype. The jumper combined 'plush' and 'plating' knit techniques in one fabric. Figure 3(A) shows the 'plush' side of the fabric and Figure 3(B) shows the 'plated' side of the fabric. The large collar, attached to a boat neck, allows the wearer to drape the collar over the shoulders, or bring it up to cover the head, similar to a hood, as seen in Figure 3. The jumper has extended sleeves to cover the hands with thumb holes, seen in Figure 4, and can be folded back on itself to create a cuff like effect (Figure 3(C)).

The jumper is designed to be reversible, allowing the wearer to have the 'plush' side close to the body to feel the warming benefits of this knit technique; or to have the 'plating' on the inside. As the viscose feels cooler to the touch, the wearer can reduce the sensation of being uncomfortably warm, by reversing the garment. Additionally, the jumper provides a sense of playfulness, as the shape can be altered by styling with a belt or the collar reoriented for a more off-the shoulder effect. The delicate pink stripes enhance the visual aesthetic and attractiveness.

Figure 3. Knitted Jumper Prototype, Lisa Shawgi, 2019.

Figure 4. Close up of cuffs on the jumper (reversed) fully extended to cover the hands, Lisa Shawgi, 2019.

Figure 5 shows a prototype of a pair of knitted summer socks. The sock design contains the knitting techniques 'plush' (Figure 5 (A)), and 'plating' (Figure 5(B)). The 'plush' fabric provides extra warmth and a cushion effect. The outside yarn in the 'plating' section (Figure 5(B)) is a combination of Lycra© and Crimp Nylon. This provides stretch, to give a more comfortable fit around the ankles and to improve durability. The band of the sock is knitted using a 'tubular' technique, as seen in Figure 4(C), it allows for a more comfortable fit around the ankles. The seam along the toes is brought further back along the foot (Figure 6(D)). The sock is shaped to accommodate a left and a right foot, see Figure 6, it creates a bespoke fit, conforming to the natural shape of the toes. The toe seams are linked 'point-to-point' to produce a flat seam and the front seam is hand sewn to prevent irritation due to bulky seams.

The sock is designed to provide extra warmth and comfort around the toes, sole and heel of the foot. The women's feet got cold in single layered socks, and when they do, the toes became sensitive to seams that come across the toe area. The moving of the seam and shaping the toe section to mirror a left and right foot, means the seam is below the toe line. The colours adds to the visual appearance of a fresh and light summer style, with a zig-zag eyelet lace pattern along the top. The inside of the band is a soft baby pink yarn, which adds to the sensual feel of the sock around the ankle and gives a contrasting visual effect.

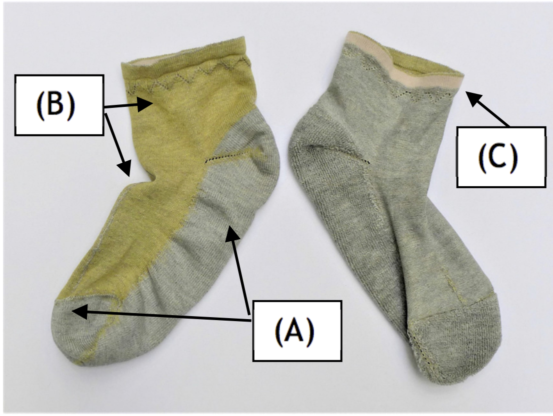

Figure 5. Side View of Knitted Socks Prototype, Lisa Shawgi, 2019.

Figure 6. Top View of Knitted Socks Prototype, Lisa Shawgi, 2019.

Interim Feedback

Interim feedback from two participants offered insights into the level of success in developing designs to meet the physical and subjective attributes of the prototypes. Both women commented on the aesthetical, sensorial and functional qualities of the prototypes, describing the garments as warm but lightweight and flexible, making them comfortable to wear. They referred to the garments as stylish, yet very practical in the design detail of the sleeves and collars. They appreciated design considerations to help with over-heating under the arms in the cardigan and were pleasantly surprised at how cool they felt wearing the jumper with the viscose close to their bodies. The sock felt comfortable to wear around the toes and ankle, and both noted the lace feature. A suggestion was made for a winter sock, knitted entirely in the 'plush' fabric and longer in length. Additionally, both women commented on how the magnetic closing feature on the cardigan would greatly help when their fingers are too cold to open and close buttons and zips. Another request was to increase the size of the collar on the jumper, to add more coverage for the head, as it is a design feature they liked. Both women found the prototypes to be refreshing and exciting to wear.

Discussion

By adopting a human-centered design approach, the project considers the emotional dimension when understanding women's experience with Raynaud's. Using IPA methods to analyses the data, rich qualitative narratives are produced to explore the role textiles play for the women physically and psychologically. The findings lead to a design approach, to create a harmonious product relationship, where the technical coincides with the aesthetic properties (O'Mahony, 2011) for a higher chance of a successful product user attachment on an emotional level (Chapman, 2014).

The research illustrates the importance of designing for the emotional needs of the user, to enhance the subjective wellbeing of the wearer. The knitted prototypes developed considers the emotional durability alongside the usability of a product. This is achieved by considering comfort, style and aesthetics within the knitted prototypes. The cardigan, jumper and socks are designed to be functional, yet stylish and allow for a more positive experience when wearing the garments. The interim feedback from two participants corroborated the level of success the prototypes meet their emotional needs to feel good physically and psychologically. The outcomes are elegant, sophisticated, contemporary women's knitwear samples, engineered to enhance emotional durability through positive experience. Further discussion with a focus group will inform future practical and theoretical recommendations when designing for product longevity.

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Exploring Social, Economic and Environmental Consequences of Collaborative Production: The Case of Bike Repair Maker Spaces in Three European Countries

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Keywords: Bike Kitchens; Do-it-yourself (DIY); Sharing Economy; Maker Spaces.

Abstract: Cities have emerged as leading forces in transforming societies towards sustainable development. Numerous repairs, do-it-yourself (DIY) and maker communities across European countries are established to: improve resource efficiency by extending the lifespan products through repair and part recovery from urban material streams; create new sources of income for local communities by sharing resources and skills; and enhance social cohesion by enabling new kinds of social interactions. The aim of this research study is to examine the contribution of such initiatives to the environment, economy, and society. The study focuses on cases of maker spaces in Sweden, Switzerland, and Spain engaged in bicycle repairs as study objects. The study addresses the following research question: What are the main social, economic and environmental impacts of collaborative production organizations? Overall sustainability effects of collaborative production activities depend upon the design, operational activities, and institutional contexts. Thus, this study analyses these cases of maker spaces from socio-economic, environmental and institutional entrepreneurship perspectives. Qualitative data is gathered through interviews with the organizers of maker spaces to formulate a systemic understanding of key activities (repair, resource recovery etc.) and exchanges (spare parts, skills, tools, financial etc.) carried out at the maker spaces in the context of the circular economy. A user survey focusing on the benefits of the maker spaces to the users is carried. The study contributes to identifying critical system dynamics associated with collaborative production in the circular economy context and highlighting main areas of further research assisting a better understanding of the systemic impacts of collaborative production.

Introduction

Cities have emerged as leading forces in transforming societies towards sustainable resource management through collaborative production and consumption. Indeed, cities across Europe have been supporting circular economy and collaborative production and consumption initiatives, such as, repair cafes, do-it-yourself (DIY) places and maker spaces.

These activities are recognised as solutions to closing and slowing the material loops in an urban context by extending product lifetimes through repair, upgrade, reuse and recovery of resources from urban waste. Product sharing, mending and repairing initiatives are often taken as environmentally sustainable due to their potential to avoid new purchases of products and spare-parts. Further, these initiatives are closely associated with their positive social and economic benefits for the local communities by enhancing repair skills and sufficiency, and social cohesion. In addition, these activities have potential to create new complex socio-economic interactions by stimulating behavioural changes in individual time-use and consumption disrupting the sustainability status-quo. Indeed, individual time-use, socio-economic conditions and resource consumption are closely linked to carbon footprints (Wiedenhofer, Smetschka, Akenji, Jalas, & Haberl, 2018a). Therefore, exploiting these consumption-behaviour relationships offer an untapped policy option.

Nonetheless, the overall sustainability impacts of collaborative production activities depend upon the design, operational activities, and institutional contexts (Winslow & Mont, 2019). Therefore, from a sustainability point of view, socio-economic, environmental and institutional entrepreneurial perspectives are needed to evaluate these initiatives. However, theoretical frameworks to evaluate the sustainability potential of these initiatives in context to closing the material urban cycles and stimulating behavioural changes among users are unavailable.

Taking the cases of bike repair maker spaces in four European countries, this study addresses this gap in research by exploring the direct and indirect social, economic and environmental implications of collaborative production activities. The main objectives of the study are to examine the contribution of collaborative production activities at these maker spaces to slowing and closing the urban material cycles, and broader sustainability implications of user behaviour stimulated by such maker spaces. A framework to evaluate the sustainability potential of maker spaces is proposed.

Theoretical background

Collaborative production: Production, consumption and presumption

In contemporary economies, we understand that production always follows consumption and vice-verse. However, this was not the case. At the very outset of the Industrial Revolution, western societies were defined predominantly by production (Ritzer & Jurgenson, 2010). However, it was only in the latter half of the 20th century that consumption gained vital importance, especially as compared to production, due to increases in the objects of consumption (e.g. consumer products), the subjects of consumption (i.e. consumers) and consumption processes (such as marketing, advertising and branding). Toffler (1980) called this 'the second wave' of marketisation (Ritzer & Jurgenson, 2010). Production and consumption were two separate functions dividing two entities what we know as the producers and consumers (Ritzer & Jurgenson, 2010).

The term prosumer was coined by Toffler (1980) meaning the one who consumes and produces a product. He argued that modern-day internet-era presumption, what he called 'the third wave', was indeed predominant in pre-industrial societies (the 'first wave'). In contrast, collaborative production as a part of this 'third wave' is defined by Oxford dictionary as "*the production and sharing of information or physical assets based on social collaboration and knowledge sharing within horizonal peer-to-peer networks open to all members of a community, facilitated by the use of the internet and social media (as in the case of Wikipedia).*" Proponents of collaborative production claim that it brings economic empowerment for individuals, improves social cohesion, and minimizes environmental impacts by decreasing demand for new products (Botsman & Rogers, 2011). The marketed interests in do-it-itself culture and sharing of skills, tools and spaces have been supported by several cities across Europe and beyond as means to drive sustainable consumption among urban population.

Circular economy and sustainable consumption through DIY "Bike Repair" movements

DIY bike repair studios or 'bike kitchens' or maker spaces are mainly organized by grassroot initiatives, in many cases, supported by government and non-government organizations (Bradley, 2018; Lehner, 2019) due to their potential contribution to sustainability. Bradley (2018) explores the phenomenon of 'Bike Kitchens', DIY non-profit bicycle repair studios, around technology in relation to degrowth. Some of the anticipated positive benefits of DIY bike repair studios include: recovery of valuable spare parts from the waste streams, sharing of tools, reduced consumption of virgin part materials, and benefits of product life extension through repair. Based on Illich's (1985) notion of tools for conviviality, Bradley (2018) proposes that bike kitchens, by providing practical knowledge for repair to the citizens enhances autonomy and creativity among them by liberating them from commercial relations and enabling formation of non-capitalist relations. Bike Kitchen are considered as an example of democratisation of technology in practice that enables easy access to low-cost technology, tools and know-how to anyone (Bradley, 2018). Lehner (2019) argues that bike kitchens could reduce consumption among the bike kitchen community through their time expenditure in the repair activities.

However, systematic sustainability analysis of such DIY initiatives including broader sustainability implications including the unintended consequences is still lacking. Based on empirical evidences, this study provides a theoretical framework to evaluate sustainability implications of DIY repair movements.

Methods

Semi-structured interviews with key personals associated with bike repair studios were conducted in order to have an overview of the key activities, value proposition, and societal benefits, and success factors and barriers to their operations. In total, seven semi-structured interviews were conducted (see Table 1). The semi-structured interviews followed the following questions:

1. What are the main motivations behind establishing the bike studios or maker spaces?
2. What are the main social, economic and environmental benefits of the bike studio for the users?

Country	Organisation(s)	Total interviewees
Sweden	- Bike Kitchen, Malmö - Bagarmossens Cykelköket, Stockholm	3
Switzerland	- Point Vélo, Laussanne	2
Spain	- Biciclot, Barcelona - Biciosxs, Barcelona	2

Table 1. Information on the interviewees used in the study.

All of the interviews were recorded with the consent of the interviewees and transcribed. The interviewees were selected from different countries representing different types of bike studio in order to get a broad perspective on their activities.

In order to collect empirical information relevant to the socio-economics impacts of bike kitchens on the users, an online survey of the users of the Bike Kitchen in Malmö was conducted. The survey was utilized to gather information on the key activities performed by the individual users and their motivations to take part in the repair activities, perceived social, economic and environmental benefits, and average time spent at the Bike Kitchen. In total, 46 individual responses were collected.

Results and Discussion

Motivations

The organizational characteristics (e.g. financial, operational, etc.) of the bike repair studios or bike kitchens included in this study significantly vary. However, the common motivation behind establishing these was the lack of DIY spaces recognized by bicycle enthusiasts who share a common interest of cycling and repairing bikes themselves. For instance, Biciclot in Barcelona was started in 1987 by a small community of urban bicycle enthusiasts, which now has taken a shape of well-established institution that closely cooperates with the City Council of Barcelona on various urban mobility projects. Similarly, the Cykelköket, Malmö and Bagarmossens Cykelköket were also started by group of individuals who jointly created DIY bike repair space.

An increased trend of bicycling in the recent years has also contributed to the demand of such places. For example, the Point Vélo, Laussanne was established in cooperation of EPFL – École polytechnique fédérale de Lausanne after recognizing the need for a DIY space in the university campus as a result of increased number of students bicycling.

These spaces are financially supported by a variety of means such as by the city governments or non- governmental organizations or self-financed. The bike kitchens are supported by volunteers who share their time and skills for free or part-time workers. For example, Point Vélo, Laussanne employs students during 1-hour lunch break because many students come to repair bikes during lunch breaks. Malmö Municipality supports the salary of 2 full-time personnel employed at Cykelköket, Malmö. Bagarmossens Cykelköket is fully supported by volunteers working few hours a week in the evening, and funds the rented space by membership fees. Point Vélo, Laussanne has contract with the EPFL – École polytechnique fédérale de Lausanne who offers the students free use of tools and small repairs works.

Social, economic and environmental impacts of the bike repair studios

Interviews with the key organizers/volunteers at the bike repair studios revealed that a variety of activities are performed by these studios. These include recovery of bike parts from discarded bikes, sharing of tools and skills for bike repair, providing special courses on bike repairing, organizing special events, providing bikes on rent, donation of recovered bikes to under-privileged sections of society.

These studios also provide spaces to people for cultural exchange. According to Interviewee 1, *"Each time we open, 8-9 languages being spoken at the same time. It is very diverse in a way, people coming in from all around the city."*

"we still have lots of spare part that people could get for free to fix their bike." (Interviewee 1)

Effect on individual time-use

Studies have found a close relationship of individual time-use and consumption, with carbon footprints (Jalas & Juntunen, 2015; Torriti, 2017; Wiedenhofer, Smetschka, Akenji, Jalas, & Haberl, 2018b). Out of 46 responses in the survey, 30 respondents appear to spend more than 3 three hours each time they visit the Cykelköket, Malmö. The survey found out that the main motivations behind visiting the Cykelköket, Malmö are to carry out bike repair works and attend special events. Out of the total respondents, 36 visited the Cykelköket, Malmö more than 10 times in the past one year. Thus, the users spend a significant amount of time at this bike studio that could be replacing some of the usual individual consumption activities.

However, the overall environmental impacts of this alternative time-use may vary depending upon the type of institutional settings of the maker spaces. For instance, municipality-run Cykelköket, Malmö which is a non-profit organization provides spare-parts and skills exchange for free without any mandatory membership fees. Due to its organization, Cykelköket, Malmö is not allowed to sell recovered bikes without official auctions. From an economic perspective, the users positively benefit from free repairs and recovery of spare-parts; however, Cykelköket, Malmö struggles to secure funds to run the space as there is no viable financial mechanism.

"One challenge we have been having is stemming from the financial part, changing to be more a volunteer-based organisation." (Interviewee 1)

Whereas, the Point Vélo, Laussanne which is is only partly supported by EPFL – École polytechnique fédérale de Lausanne, offers only free use of tools by users but subsidized prices for repair operations and replacement of spare parts. The Point Vélo also supplies bikes on rent. Because of a viable economic model, the Point Vélo been a success from an economic perspective for both the users as well as the organizers. In contrast, Biciclot, Barcelona which is a totally volunteer-run organization has been successfully in operation for the past more than 25 years due to its social cause. Thus, institutional settings do affect the overall impacts generated by these maker spaces.

This study has conducted survey of users of only one type of organization. In-depth studies of the users of different types of maker spaces, therefore, could be conducted in order to investigate the types of activities that were replaced and their environmental, economic or social impacts. In order to positively influence the sustainability profile of maker spaces various institutional constellations could be examined to support sustainable development through grassroot innovations.

A framework to evaluate overall sustainability potential of collaborative production

Based on this study, a framework to evaluate social, economic and environmental consequences of collaborative production activities is proposed. Various steps of this framework are as follows:

1. Conceptualize the major activities at the maker spaces in context to the socio-economic and environmental interactions
2. Evaluate the social, economic and environmental impacts
3. Set goals and agendas for the maker spaces in sustainability context
4. Identify management strategies to meet the goals of the maker spaces

The first step involves conceptualizing the socio-economic and environmental exchanges taking place at the maker spaces. In the studied cases, for example, this involves the direct (positive as well as negative) impacts are repair with less or no cost, part recovery from urban waste streams, socializing and skills exchange, and changed/alternative consumption patterns due to the time spent by users etc. This step also includes exploring the rebound effects, if any, induced by maker spaces due to such as economic savings from cheaper/free repair spent on other consumption activities. Methods such as participant observation, user surveys and semi-structured interviews with organizers and users could be employed to explore these exchanges. In this study, these interactions were explored through semi-structured interviews and a user survey.

Evaluating the social, economic and environmental impacts of maker spaces requires quantifying the interactions explored during the first step. Methods such as material flow analysis could be employed to trace to the materials saved from a life cycle perspective.

In order to analyze the influence of institutional context on sustainability profile of maker spaces, various system goals and agendas could be set. In order to achieve these systems goals Different scenarios could be explored under diverse business model settings and institutional constellations for the maker spaces. Based on this analysis, various management strategies for the design, value proposition, operational practices and institutional contexts of maker spaces could be devised and implemented to maximize their sustainability potential.

Conclusions

The study concludes that the maker spaces for bicycle repair do contribute to improve resource efficiency by extending the lifespan products through repair and part recovery from urban material streams. Evidences show that these maker spaces enhance social cohesion by enabling new kinds of social interactions. through sharing of resources and skills. The activities at these maker spaces do influence individual time-use, and therefore, could have significant positive impacts on consumption (and carbon footprints). However, the type of institutional settings of the maker spaces may influence the social, economic and environmental impacts emanating from these maker spaces, especially, the ones concerning the individual time-use of the users. Thus, in-depth studies of the users of different types of maker spaces is needed in order to devise institutional constellations to positively influence to the sustainability profile of these maker spaces. The study proposed a framework to evaluate overall sustainability potential of maker spaces.

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WOT? Insights into the Flows and Fates of E-waste in the UK.

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Keywords: E-waste Estimation; WOT, Dynamic Model; WEEE Regulation; WEEE Directive.

Abstract: In 2019 the EU Waste Electrical and Electronic Equipment (WEEE) Directive documented a sizable increase in e-waste collection targets alongside a wider scope of electronic and electrical products covered by the legislation. These changes have significant impact for the UK, as for the past two years UK waste collected has failed to meet the newly adopted set of targets. Understanding the flows and fates of products on and off the market becomes of paramount importance, especially for producer-led organisations who have the responsibility to achieve the targets and cover the operational costs. Historic e-waste estimation methods often assume that one product on the market will equate to one product in the waste stream. In this article, we report on a project commissioned by one of the largest UK producer-led organizations – REPIC Ltd, in search of an explanation of the observed drop-in products on the market and WEEE collected, and the relationship between the two. We argue that we should move away from "one product in and one product out" assumption to include wider parameters that are tailored specifically for the UK, including those linked with the state of the market for electronic and electrical products and of the wider economy, examples include inflation-adjusted GDP per capita, consumer confidence index (CCI), inflation indices (CPI or RPI), number of households, wealth distribution etc. We show how this can be achieved by adapting a state-of the-art e-waste estimation model (Waste Over Time) to the UK context and developing it further to include additional drivers.

Introduction

In 2019, the European Union's Waste of Electrical and Electronic Equipment (WEEE) Directive (2012) documented a substantial increase to the waste collection targets for EEE products Placed on the Market (POM). In addition, the scope of products covered by the legislation increased (European Commission, 2017), to include all EEE unless otherwise stated (Defra, 2017; Defra, 2018), which is referred to as Open Scope. Setting realistic and robust targets is fraught with difficulty due to the current consumer economy and multifaceted routes to disposal (e.g. second-hand markets, incorrect disposal in household bins, theft etc.), among other factors (Borthakur and Govind, 2017; Dindarian et al., 2012). These changes have significant implications for the UK, as the legislation is transposed into UK WEEE Regulations, as the recently published 2017 Environment Agency data[1] showed a drop both in EEE POM and waste EEE collected relative to 2016 in the UK. This trend continued in 2018. At the same time, "the proposed overall UK WEEE collection target for 2019 is 550,577 tonnes – over 57,000 tonnes higher than the total amount of household WEEE collected and reported in 2018". (REPIC 2019: para. 2).

With the Directive being premised on the principle of Extended Producer Responsibility (EPR), this places accountability, collection and funding for the end of life products with manufacturers (producers) and retailers. Therefore, understanding the economic life-cycle and value of products is vital for producer-led organisations. With the reliance on historical data (Van Straalen, 2016), the changes in post-consumer disposal practices (Borthakur and Govind, 2017; Dindarian et al., 2012) provides the opportunity to re-interrogate the flows of EEE and fates of WEEE in order to see how these changes can contribute to target setting and policy delivery (Stowell, Yumashev, et al., 2018).

[1] Data is available from https://www.gov.uk/government/statistical-data-sets/waste-electrical-and-electronic-equipment-weee-in-the-uk.

In this article, we report on a project commissioned by one of the largest UK producer-led organisations' – REPIC Ltd. One of their aims is to better understand WEEE target setting and the fate of used consumer EEE goods. In search of an explanation of the drop-in POM and waste EEE collected, this project's main aim was to investigate the relationship between the two. Building upon previous academic studies enhancing the estimations of e-waste (Wang et al., 2013; Magalini et al., 2016; Van Straalen, 2016) and industry research (WRAP, 2011; 2012; 2016), we sought to understand, this phenomena in further depth.

Our two key findings suggest that, first of all, the amount of WEEE available for collection needs to be determined for legislative targets. Unreported EEE and WEEE flows (in particular unregistered sellers placing EEE onto the UK market for the first time and via second-hand markets), along with changes in EEE product weight, product design lifespan and/or its household residence time,[2] are the key factors to take into consideration to design better compliance targets, understand the implications of Open Scope, and help improve the overall WEEE recycling rates.

Second, in order to accurately predict WEEE generated, detailed production, trade, age distributions of the products in the household and in the waste stream, and unit weight data should all be taken into consideration, including trends in all these parameters. In support of Wang et al. (2013), we also argue that there is a need for a new dynamic WEEE model, which has the ability to estimate annual fluctuations in POM and waste generated (WG) in response to wider socio-economic conditions and specific EEE market conditions. We conclude by putting forward a proposal for what this model could look like, building upon current state-of-the-art model for WEEE generated (Van Straalen, 2016), and show how e-waste estimates could be improved as a result.

[2] Period between product purchase and its disposal as e-waste.

Results and Relevance

Unreported flows – survey

As part of the project, we conducted surveys of EEE producers, retailers and those operating in the reuse or recycling space. The results of the surveys included individual product line or aggregate category-level estimates for residence times, unregistered sellers, product trends and other factors.

The key challenges for WEEE management stated by producers and collectors include:

- Unreported flows, second-hand markets, weight changes in products, differences in product design lifespan and household residence times (including hoarding), and component part removal/theft were indicated as factors that could impact the differences between WG and waste collected and cause an imbalance in National Target setting for PCSs.
- Ever-tightening restrictions on hazardous - chemicals in new EEE products will further limit the viability and demand for recycled materials from WEEE, at least for the manufacture of new EEE. An example of this is legacy POPs in plastics.
- The UK market has limited processing capacity for cooling equipment. There has been no mapping of the capacity requirements available and necessary to meet higher collection targets. Objectively assessing future demand for infrastructure would enable, alongside other measures, some certainty in investment.
- Scrap metal and iron spot price volatility affect the profitability of the dismantling of end of life appliances. If spot prices are high, the PCS access to WEEE reduces as products with high metal content such as LDA becomes more attractive to other actors, including for illegal export. Conversely, when spot prices fall, other actors can be driven to illegally remove the higher value components only, leaving a lighter carcass to be recycled.
- Retailers, and others, in the market may conduct activities that indirectly restrict access to WEEE by PCSs. For example, retailers collect old products on home delivery for a fee paid by the consumer, so they have an income stream to offset the cost of collection.

- Small appliances are less viable to reuse, with the exception of mobile phones, tablets etc. New goods continue to be put on the market at low cost and with limited durability. This means low value items should be more likely to arise in the WEEE stream. However, the official UK figures indicate this does not always happen, most likely due to the small size of the product making it easier to hoard/store or being discarded in the household waste bin.
- Collection undertaken by third parties involved in reuse and/or recycling and not financed by PCSs may not be reported in the official system, e.g. some small-scale operations operating under an exemption may not be an AATF or associated with one that can issue evidence.
- Socio-economic changes, for example, Brexit, Circular Economy (CE), inflation, labour costs, business rates and material pricing all impact on where WEEE flows and how accessible it is to a PCS.
- Future innovation and technological trends could be crucial for managing WEEE. Examples include artificial intelligence, network connected vehicles, voice recognition, Internet of Things, security products, etc.
- Understanding reuse, particularly in the context of the CE package, will be an increasingly important factor in assessing WEEE targets.

UK EEE and WEEE data, models and methodologies

Table 1 below summarizes the key policies and product categories considered in our study. The best available (W)EEE forecasting model, Waste Over Time (WOT), uses historic sales data expressed for 54 UNU product categories, in combination with product lifespan or residence time distributions (Van Straalen, 2016). However, the output of the model has not previously been tailored for the 14 UK (W)EEE categories. This is one of the main gaps that our project addressed by going to the more granular CN product level (Table 1).

Key Policies
EU WEEE Directive (2012/19/EU)
UK WEEE Regulation (2013)
Implementation Regulation (2017/699)
Move to Open Scope (2019)
Product Categories and Codes
6 EU Open Scope Categories
14 UK WEEE Categories
54 United Nations University (UNU) Codes (referred to as "UNU keys")
500 PRODCOM (PCC) Codes (approx.)
1150 Combined Nomenclature (CN) Codes (approx.)

Table 1. Key policies, product categories and codes.

One drawback of current methods is that the residence time distributions are fixed based on the year of sale. However, in reality, these distributions are likely to change due to various factors, such as economic influences, consumer preferences and new product developments (or lack thereof). The prototype dynamic model developed during the project, which is described below provides a feasible way of rectifying this shortcoming.

Adapting state of the art model to the UK context

The project team identified two extensive lists of CN product codes relevant to UK EEE market: WEEE Europe (which has CN codes mapped onto UNU and UK categories, prepared by WEEE Europe in conjunction with REPIC) and WOT (with mappings onto PCC and UNU codes, but no UK categories). These lists have 671 and 762 and CN codes, respectively, of which 292 codes overlap, while the rest are unique to each of the two lists. Combined, the two lists contain around 1150 unique CN codes.

Following these findings, REPIC reviewed all the CN codes from the two lists combined, assigning UK codes to the WOT CN codes not on the WEEE Europe list for the first time, and updating the UK codes for the WEEE Europe list (part of which overlaps with WOT). REPIC also indicated possible changes to the CN-UK mapping due to the implementation of Open Scope. This was a difficult and sometimes ambiguous task given the terms used to describe the CN codes and the on-going development of the UK guidance on scope. This assessment is, therefore, on-going.

The analysis of the CN-UK mapping defined by these lists showed that multiple UNU keys map to 2 or more of the 14 UK categories. Therefore, to convert the WOT model output for POM and WG, which is provided at the UNU level, into 14 UK categories, special mapping protocols are required. The protocols are different for POM and WG, with the latter relying on the former, and both types of protocols are time-varying, which reflects on the evolution of the individual products and aggregate categories with time.

Exploring crucial improvements of the model to aid understanding

As mentioned earlier, the current generation of the WEEE quantification tools, such as the WOT model, are based solely on historic EEE POM and products' residence times (Van Straalen et al., 2016). Although the POM data in these tools captures historic variations in production and trade across a wide range of products, there is no underlying economic model to link these variations with wider socio-economic conditions. Moreover, the residence times are largely static, implying that the results for WG are smooth and do not reflect on year-on-year fluctuations in the WEEE arising observed in the official data. Therefore, the key suggested feature of a new model, which will build on the existing WEEE tools, is the ability to estimate annual fluctuations in POM and WG in response to varying wider socio-economic conditions and specific EEE market conditions in the UK.

The wider socio-economic parameters will include UK's inflation-adjusted GDP per capita, consumer confidence index (CCI), inflation indices (CPI or RPI), number of households, wealth distribution across the population, percentages of households with no or multiple units of a given product, number of businesses owning a given product, etc. The specific EEE market parameters will include inflation-adjusted prices of a given EEE product and other replacement, as well as new market drivers that affect the sales.

The model would build on the existing body of qualitative and quantitative research on EEE markets to derive statistical relationships between the socio-economic and market conditions introduced above, and the products' annual sales, stock and residence times. Where the data is not available, the quantifications of the proposed relationships will have to rely on tailor-made surveys across the EEE sector.

To achieve the best possible description, the model could be configured to operate on the CN or PCC product levels. However, calibrating all the necessary parameters for the hundreds of EEE products described by these codes, especially when it comes to defining variable residence times, would require a considerable effort. Therefore, it is sensible to consider aggregate categories such as UNU keys. The results could then be aggregated to UK14 categories.

Conclusions

Our research enhanced UK e-waste estimations through the adaption of the current EU-wide Waste Over Time (WOT) model for WG. This required special new protocols to be developed that map weight flows from one set of aggregate EEE categories to another. The protocols improve our understanding of how the aggregate EEE categories adopted in the UK and EU relate to the underlying granular product databases in the trade statistics (Eurostat), which includes the time-evolution of the mapping as old products get disconnected and new ones enter the market.

Our results compliment previous industry studies with some similar findings (WRAP, 2011; 2012; 2016). Overall, collecting data within the following areas should be prioritized:

-Mass balance – missing components (e.g. compressors, hard-drives etc.) and changing product weights should be better represented;

-Product lifespan and residence times – more information needs to be gathered from households and e-waste collectors since current data mostly comes from producers;

-Unreported flows – further insights into second-hand or used EEE, as well as legal and illegal WEEE flows are required.

Capturing products as they enter the market, their weight and their fates gives insights into EEE POM and WG trends. The collation of product weight, in particular, would also provide the ability to estimate future protocols for substantiated estimates, e.g. Small Mixed WEEE and Large Domestic Appliances metal scrap, or identify the need to develop the new protocols. Accurate information regarding product lifespan and residence times would give much needed insights into time horizons from EEE POM to WG. In addition, gathering further intelligence on unreported flows will identify system losses and possible entry points for unregistered sellers.

These new insights could help redirect the flows of EEE POM and WEEE, e.g. by boosting the demand for secondary materials from WEEE and/or by stimulating growth in the second hand or used EEE sector. The desired outcomes of these investigations are especially important given the UK's Circular Economy and Clean Growth strategy (BEIS, 2017; Defra, 2017), which includes an ambitious target to achieve zero waste by 2050.

In conclusion, we argue that in order to have a more robust understanding of UK EEE and WEEE flows there is a need to move beyond the "one product in and one product out" assumption to include:

- historic production and trade statistics, in combination with product residence time distributions that can be derived from the surveys of household stock and collected e-waste
- outputs for EEE POM and WG that are tailored for the 14 UK Categories
- socio-economic factors that reflect consumption trends
- market and technology trends that impact on purchase, weight, end of life patterns, reuse and recycling
- better quantification of the fates of WEEE which are unreported or unknown.

Achieving these goals would be beneficial both to (W)EEE practitioners operating and researchers focusing on e-waste estimations regardless of EU member state.

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Has the Durability of White Goods Changed Between 1998 and 2017? – In What Direction and Why?[1]

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Keywords: Refrigerators; Freezers; Obsolescence; Replacements; Durability; Product Lifetimes; Product Design; Premature Obsolescence; Product Lifetime Optimisation.

Abstract: The author performed a nationwide representative survey of the durability of freezers, refrigerators, TV sets and stereos in Norway in 1998, as part of his doctoral thesis. In 2017, the Norwegian Consumer Council financed a replication of the survey for the cold appliances, enabling us to conclude on the question of whether product durability goes up or down. We also consider survey material on the age of households' washing machines, dishwashers and tumble driers, why these products are replaced, repair practices etc., but the comparison between 98 and 17 is restricted to refrigerators and freezers.

Between 1998 and 2017 the number of years a household uses the refrigerator; what we here define as the lifespan of the product, has decreased by one and a half year on average. Likewise, in the same period, the lifespan of freezers has also decreased by a bit more than one and a half year. It seems as if the reason for this decrease is that households today, more often than 20 years ago, replace cold appliances that are not malfunctioning. If this is correct, the importance of technical quality/mechanical durability is reduced, while psychological obsolescence and 'new consumer needs' has gained importance. However, qualitative (technical) obsolescence remains the main reason for replacement of cold appliances, even if we observe an unwanted change. For washing machines, where we do not have comparable data over time, it seems as if technical quality/durability is more important than for cold appliances. The same tendency, but somewhat weaker, is observed for dishwashers. Generally, the consumption of washing machines, dishwashers and tumble dryers is different from the consumption of refrigerators and freezers, as these products more often get repaired. This probably indicates that washing machines etc. to a larger degree are seen as functional objects and less as aesthetical objects.

Introduction

The potential contribution from increased life span of products to more sustainable life styles is about to be more broadly recognized (Cooper ed. 2010). Increased product durability is a kind of "three-for-the-price-of-one" solution; reducing energy consumption, reducing pollution and materials use. In addition, it might even be a socially acceptable take on the challenge of reduced consumption in the richer parts of the world.

This presentation explores two research questions:

1. For how long do consumers keep (use) their products? (specified for different products, but the focus here is on cold appliances)
2. Do these products in 2017 last for a longer or for a shorter period than they did in 1998?

Both questions are tricky to answer precisely, but I try to address them by posing identical survey questions at two different points in time, in order to measure any changes in our operational definition of product life spans. In

[1] The presentation builds on a Norwegian language only report from 2018 by Pål Strandbakken and Randi Lavik; *Har hvitevarenes levetid endret seg fra 1998 til 2017?*, Oppdragsrapport nr. 2 – 2018, SIFO Consumption Research Norway; Oslo Metropolitan University. The report was commissioned by the Norwegian Consumer Council.

addition, I want to find out *why consumers replace their products*, and if their *reasons for replacement* have changed during the 20 year period.

This research field comes with a lot of different conceptualizations and definitions. I use *product life span* as the number of years a household has had its number one product; how many years since acquisition? The concept "number one product" is constructed in order to deal with the fact that many households have more than one refrigerator or freezer. We are interested in the newest, which presumably will be placed most visible, in the kitchen.

One might reasonably argue that from an environmental perspective it would be more interesting to study *use time* than *life span* (as we defined it above), because this would give us more information about *durability*. On the other hand will life span come with an interesting relation to use time because it indicates something about the availability of second hand products. Further, and more interesting, our object of study is real social life spans and not potential technically defined use time. It is a problem, however, that most consumers will regard the questions about increase or decrease in life spans as questions of technical quality/durability.

To the extent that we succeed in measuring life spans, and potential changes in them, we should try to explain the reasons for change. Then we have to consider much more than just technical quality. Theoretically, we might have a situation where the technical quality is constant, but that (Norwegian) consumers have become more affluent and replace (buy) products more often than they used to, even if it has nothing to do with technical quality. We could, however also imagine that a more affluent population buys more expensive, hence presumably more durable products.
The measuring of product life spans in the population is based on a picture taken at a specific time at something that is a result of what has happened in the previous ten to twenty years, "historical" consumer decisions taken in markets with different brands with varying product quality, decisions taken by individuals and households in different economic situations.

Project design and methods
In a certain sense, we enter the material backwards, when we claim that the key to understanding product life spans is to understand why consumers chose to replace their previous product. For a product that is new on the market, that question is meaningless. I have never before owned a tumble dryer - it is my first - so I am not able to answer questions of replacement. For other products, like refrigerators, freezers and washing machines we might by and large suppose that households have changed products, excepting young people in new households. The different reasons for obsolescence is key to understanding how we could influence product life spans in the future; qualitative (wear and tear, technical breakdowns), functional, aesthetic, changed consumer needs or "Diderot" obsolescence.

This paper is based on two nationwide (Norwegian) surveys. As part of the author's PhD (Strandbakken 2007), a consumer survey was conducted in 1998 that studied product durability/life spans (product's age) and reasons for product replacements for refrigerators, freezers, TV-sets and stereos. In Early 2017, the Norwegian Consumer Council asked the author/SIFO to replicate the original survey, in order to determine if product life had increased or decreased in the 20-year period after 1998, the initiative was partly a reaction to some rather negative European reports. We decided that due to technological change, stereos clearly were irrelevant, and TV-sets quite irrelevant. Hence, the specific question in the title is about white goods. Sadly, I did not include washing machines in the original study.
In the 2017 study we repeated the original sets of questions from 1998 for the cold appliances. In addition, we included similar questions (and some new ones) for washing machines and dishwashers, plus some material on tumble dryers.

We have not considered if the difference between a telephone survey (1998) and a web survey (2017) might reduce comparability.

Life span
Our estimate for the product's life span is based on the question "How many years ago (approximately) is it since the household acquired the refrigerator/freezer that is in use today? If more than one, answers should

consider the newest". Responses to this question give us the average age of a number of products in Norwegian households. With a degree of humility and some reservations. The number is not the same as the product's technical durability, which is longer. It is a number that estimates for how many years a household has had its number one product. A study of "use time" or technical durability would require a different research design.

Here, we aim at studying the product's social life span. This means that if the owner is redecorating his kitchen and simply "has to" replace his avocado green cold appliances after four years, we register the life span as four years. This brings up a number of questions about environmental benefits (and perhaps the opposite) of second hand markets etc., but I will not go into them here. The basic idea is that with all its possible inaccuracies we will, by posing this question at two different points in time, be able to give a tentative answer to the question of whether product life spans go up or down. We also analyse any changes in the reasons given for product replacements. How often are replacements resulting from malfunctioning or breakdown of the old product, and is this share increasing or decreasing?

Product obsolescence/replacement

From the environmental perspective, two questions about product life spans are interesting: why was the old product replaced, and what happened to it. We have to understand the consumers' reasons for scrapping the old product if we want to influence product life. In Strandbakken 2007 (p. 171) we offer a typology of reasons for regarding products as obsolete, developing/expanding Packard's (1960) scheme.

Obsolescence of function

Obsolescence of quality

- Aesthetic dimension
- Technical: product malfunctioning/ breakdown/damaged product

Obsolescence of desirability

- Fashion change
- Change of personal style
- Diderot effects
- Hedonism

Obsolescence due to new consumer needs

Packard's scheme contained function, quality and desirability (the last often renamed "psychological" obsolescence). The typology is basically self-explaining. Functional obsolescence might be exemplified by the transition from vinyl to CDs in the early nineties. Highly relevant for smartphones etc., perhaps less so for cold appliances and washing machines. *Quality* is the dimension most often referred to when durability is debated. Are today's products better or worse than yesterday's? Are they repairable? Questions of *planned* obsolescence might be raised, but we will not deal with that theme here. Desirability deals with the consumers' mental relation to their products, as fashion or personal style. In addition we have the so called "Diderot effect", based on the observation that consumers tend to search for consistency in the product portfolio (McCracken 1988). Hedonism refers to the well known "feel good effect" of buying new things. New consumer needs refers to real or objective changes in the consumer's life that necessitates change. Quite simplistic, like when you need plus size clothing if you have gained weight, more flexible furniture if you have to move to a two room apartment after a divorce or when you need a larger freezer because you have taken up moose hunting.

Our questionnaire was designed to cover all of these product replacement justifications.

Refrigerators and freezers 1998–2017

Ownership share and average age

Refrigerators, and to a lesser extent freezers, are part of what we might call the Norwegian households' standard package (table 1).

	1998	2017
Refrigerator	98.3	99.4
Freezer	91.3	91.3
N	893	1000

Table 1. Percentage owning cold appliances.

I started out, assuming that due to an unprecedented period of economic growth in Norway from 1995 to the present, a gradually more affluent population would have bought better and more expensive white goods (here cold appliances), and that this would have resulted in an increasing life span of the products. I was wrong. Table 2 shows that for both product types the product live had decreased by approximately one and a half year.

	1998	2017	Sig.
Refrigerator, average	7.7	6.3	***
Refrigerator, median	6	5	
N	893	932	
Freezer, average	9.4	7.7	***
Freezer, median	8	5	
N			

Table 2. Age of products.

The numbers 6.3 and 7.7 should be compared to an upmarket stakeholder estimate that their white goods are used on average for 13 years (Strandbakken & Bøyum 2017, p. 38).

The most dramatic change between 98 and 17 is that the share that reports to have had their product in ten years or more has fallen with between 13 % and 16 % in all age groups older than 29 (30-44, 45-59, 60-80). The youngest group has not changed much, which is natural as their experience with product replacements is rather limited (Strandbakken & Lavik 2018, p. 22).

Age differences between refrigerators and freezers (in both 1998 and in 2017 freezers were older than refrigerators) will probably be explained by a combination of technical and social/cultural matters. Technically, because a top opened chest freezer is simpler than a front opened 'cupboard refrigerator', technically/socially because the freezer will be opened less often than the fridge. Socially and culturally because what we will call social visibility. Today, the kitchen has increasingly become a public room, a room where you might entertain guests. Traditionally, refrigerators have been placed in kitchens, while (chest) freezers often have been placed in garages or in basements. This means that refrigerators have been more exposed to aesthetical aging or psychological obsolescence (obsolescence of desirability) than freezer. This is the difference between front stage and back stage. A freezer hidden away back stage could mentally be reduced to "pure function". The consumer will tend to not replace it until it breaks down, malfunctions, uses ridiculous amounts of electricity or has an un-convenient size. When we observe a gradual change into kitchen placed 'cupboard freezers' we expect that the difference between the products will be reduced (which it does).

Replacement and reasons for it

What do consumers do with their old products? From an environmental perspective, this is an important question. In Strandbakken 2009, we observed that electricity use in some households increased significantly when the household bought an energy efficient refrigerator or freezer. This because some of the "replaced" products were moved into the basement, to stock beer, soft drinks, frozen pizzas etc. The energy use of the efficient appliance then came in addition to the old product, not instead of it.

	1998	2017
It was sold	6	9
Given to second hand markets, salvation army etc.	2	5
Given to family or friends	8	10
It is placed in the cabin or in the basement	6	8
It was thrown or delivered to retailer, municipal dump etc.	73	64
Other	3	3
Don't know	2	2
Total	100	100
N	586	612

Table 3. What happened to the old refrigerator. Among those who had replaced a product. Percent.

In 1998, those who answered that the old refrigerator was damaged were not asked what they did to the old one. We assumed, however, that respondents answering this had thrown it (387 persons), because the filter was 'the old one was damaged/did not work anymore'. In addition, 12 persons who had replaced had not answered what they did with the old one. These we grouped together with the 'don't knows'. This we might, with some caution, compare the results from the two years. The same procedure was used for freezers.

In 1998, 73 % had thrown the old refrigerator, compared to 64 % in 2017 (table 3, the difference is significant for $p < .05$; kji square test). Most consumers throw their refrigerator because it is not working (obsolescence of quality), but some also throws well working products.

	1998	2017
It was thrown because it did not work	91	81
It was thrown for other reasons:		
The old one was unmodern	2	4
It did not fit in any longer	2	3
We needed another type	3	8
We are more well off and it is nice to buy new things	0	1
The old one lacked some functions	2	2
Division of household after divorce	0	1
Total	100	100
N	427	392

Table 4. Among those who answered that the refrigerator was thrown. For what reason? Percent.

Among respondents that had thrown the old product, 91 % in 1998 answered that it was damaged, while 81 % answered the same in 2017 (table 4, the difference is significant for $p< .05$; kji square). Surprisingly, the numbers for throwing are identical for freezers (table 6); 91 and 81 %.

	1998	2017
It was sold	5	9
Given to second hand markets, salvation army etc.	1	6
Given to family or friends	10	10
It is placed in the cabin or in the basement	4	5
It was thrown or delivered to retailer, municipal dump etc.	73	65
Other	5	3
Don't know	3	2
Total	100	100
N	333	419

Table 5. What happened to the old freezer. Among those who had replaced a product. Percent.

In 1998, 73 % answered that the freezer was thrown, compared to 65 % in 2017 (table 5).

	1998	2017
It was thrown because it did not work	91	81
It was thrown for other reasons:		
The old one was unmodern	2	2
It did not fit in any longer	1	4
We needed another type	5	11
We are more well off and it is nice to buy new things	0	0
The old one lacked some functions	1	1
Division of household after divorce	0	0
Total	100	100
N	248	273

Table 6. Among those who answered that the freezer was thrown. For what reason? Percent.

Discussion

Our two initial research questions can be answered:

1. Norwegian consumers today keep their products, specified for refrigerators and freezers, in 6.3 and 7.7 years.

2. Both products have a shorter life span than in 1998, they tend to be replaced approximately one and a half year earlier today.

Sub questions were ''why do consumers replace their cold appliances and 'have their reasons for replacing changed in the 20 year period?'

Obsolescence of quality is the main reason for product replacement, with 55 and 56 % for refrigerators and freezers, respectively (table 7). The relative importance of quality, in this technical sense, has, however decreased. It has become 12 % less important for both products.

	Fridge 98	Fridge 17	Freezer 98	Freezer 17
It did not work anymore/out of function	67	55	68	56
The old one was unmodern (colour, design)	5	4	4	4
It did not fit in any more	8	8	5	7
We needed another type (like size)	13	18	16	21
Improved economy/nice to buy new things	1	1	2	1
Old one lacked functions (ex: defrost)	4	3	1	2
Division of household after divorce	2	2	4	3
Other		7		6
Don't know		1		1
Total	100	100	100	100
N	629	671	372	543

Table 7. What was the main reason for changing refrigerator/freezer in the last time you replaced? Among those who had changed. Percent.

The observed difference in replacement reasons for the cold appliances at the two points in time might explain the observed decrease in product life span. Because we want to promote a reasonable and sustainable product culture, we wish to observe that products are replaced after a long life span because they do not work anymore, or work unsatisfactorily. We do not want to see them replaced because the owner feels that the colour is wrong or because it is nice to buy new things.

From the environmental perspective, this means that the change from 1998 to 2017 is one we do not want to see. When 12 % fewer in 2017 reported obsolescence of quality as reason, it appears as if the relative importance of technical product quality goes down. We should repeat, however, that quality remains the dominant replacement reason (table 7).

The other replacement reasons remain rather stable through the period. The changes in "unmodern", "nice to buy new things" (hedonism), "function" and "divorce" are in the range of 1 % (!). Exceptions are "consumer needs", with a 5 % increase for both product types, and for "other", that was not an option in 98, but comprises 7 and 6 % today.

To point to the (sad?) fact that product quality and technical durability does not explain the whole product exchange pattern for cold appliances is obviously not an argument for quality reductions. It is mainly to point out that there are multiple factors at work and that increased social life spans is not achievable by improving technical product quality alone.

Washing machines and dishwashers

In the 2017 survey, we also asked some questions on washing machines and dishwashers:

95.8 % reported to have a washing machine and 87.60 % reported to have a dishwasher. The average life span (comparable to material for cold appliances in 2017) was 5.5 years and 6.0 years respectively. These products were more often than cold appliances replaced because of technical obsolescence (79 % and 64 %). In our social visibility perspective, used to differentiate between kitchen placed refrigerators and basement placed freezers, this gives meaning. Dishwashers, more often than washing machines are placed in kitchens. Washing machines, placed backstage, tend to be more seen as pure function.

We tend to believe that the material we have on repair supports this view. 33 % of Norwegian consumers report to have had their washing machines repaired (15 % for dishwashers and tumble driers), versus 5 % for freezers and 10 % for refrigerators. By and large, we believe that these findings support our function/visibility perspective, even if the numbers for repair of refrigerators and freezers should have been the other way…

Conclusions

We have seen that the life spans of refrigerators and freezers have decreased somewhat (1.5 years) from 1998 to 2017. The main reason for this change seem to be that consumers today, a bit more often than 20 years ago, replaces products that still work, even if obsolescence of quality remains the primary reason for product replacement.

Even if we do not have comparable data over time, it seems as if consumption patterns (or replacement patterns) for washing machines, dishwashers and tumble driers are a bit different, with more focus on obsolescence of quality and more frequent repair.

Future initiatives for increased product life should consider the multitude of different reasons for product replacement. There are, however, years to be gained by influencing consumer attitudes to products, parallel to improvement of the products themselves. Product improvement should probably consider aesthetics in addition to technical quality, at least for refrigerators and front opened cupboard freezers. Even if the last sentence is only partially based on research

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Accessing Sustainability through the Wardrobe

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Keywords: Sustainability Pioneers; Sustainable Fashion; Minimalism; Wardrobe Studies; Material Culture.

Abstract: The two existing surveys on everyday behavior with clothing in Germany are both based on online questionnaires and contain deviations of up to 20 per cent for the same question. In this paper, we propose an ethnographic approach with a material-cultural focus to achieve more precise knowledge about everyday practices inside the household. The range of observed practices includes consumption, care and disposal. The direct presence of garments during the conducted wardrobe interviews inside the household tackles the problem of attitude-behavior gap in surveys: It offers the possibility of comparing the interviewees' answers with their observed actions and addresses the differences between them.

Introduction

Paralleling the rise of fast fashion as an economically orientated textile industry that focuses on profit maximization, awareness of the connected problematic impacts on the environment is increasing in our society (cf. Boström/Micheletti 2016: 367). A growing number of people are concerned with reflecting and refashioning their current lifestyle and consumer behavior. This often includes a re-evaluation of what is needed and appreciated, followed by reducing and changing everyday practices. In the German-speaking area (Germany, Austria and Switzerland) a minimalist lifestyle is becoming popular and the scene is growing significantly. This development is becoming apparent through multiple blogs (Figure 1), video channels and social media groups as well as the number of currently published guidebooks on the topic of minimalism (e.g. Carver 2017; Jachmann 2017; Weiß 2017; Fields Millburn/Nicodemus 2018; Klöckner 2018; Kondō 2018; Raeggel 2018; Sasaki 2018). In these how-to guides, clothing is often addressed as a separate category and it is often recommended to tackle the issue in the beginning of a minimalist process.

However, connected knowledge about the everyday household practices of consumers has been acquired through only two representative surveys in Germany. The first online questionnaire was commissioned by the NGO Greenpeace in 2015 with 1011 participants, the second one as part of the research project "Innovation for Sustainable Behavior" (InNaBe) in 2017 with 2000 interviewees. The findings show significant differences for the same questions: To make room for new clothing in the wardrobe is a reason to sort out old garments for 31% according to the Greenpeace study and for 49% according to InNaBe. The reason that clothing has only been purchased for one occasion was given by 10% of interviewees for Greenpeace and 32% for InNaBe (cf. Greenpeace 2015: 22; Kleinhückelkotten 2017: 9). The comparison of these findings indicates that further reflection on methodology about everyday practices is needed, especially as it influences circulated knowledge on sustainable behavior through mass media and social institutions such as schools.

The research project "Textile Minimalism. Pioneering Sustainable Action" aims to find out if minimalists function as performers of sustainable textile practices in their everyday life and if they pass on their acquired knowledge as multipliers. The research is based on an ethnographic study in the German-speaking area and started in March 2018. Methodically, we conducted expert and focus groups interviews as well as 45 wardrobe interviews, which were carried out inside the household of the interviewee to ensure the physical presence of the clothing. During the course of this paper, we will illustrate how using methods with direct presence of material objects can help in the area of material culture research on sustainability.

Textile Everyday Practices and Sustainability

The escalation of a growing number of material objects, from an average of 180 objects in 1914 to 10,000 objects as today's standard in Germany, results in a changing everyday life and the connected practices (cf. Shove 2003: 128f.). Referring to the area of clothing and textiles: In the period of fast fashion, garments are available in such high amounts and at such cheap prices that their lifetime decreases significantly. In combination with an often poor quality it can be economically more rewarding to dispose of clothing after a short use phase. Trying to follow the extremely sped-up fashion cycle of 14-day trends can lead to time pressure and a financial burden for consumers, as well as overflowing wardrobes. On the other hand, the decision to not follow fashion trends and develop individual standards for appropriate clothing instead can lead to stress reduction and financial relief. Adapting a minimalist lifestyle often leads to slowing down and simplifying everyday practices through the value reassessment of resources such as time, money and material objects (cf. Derwanz 2015: 200).

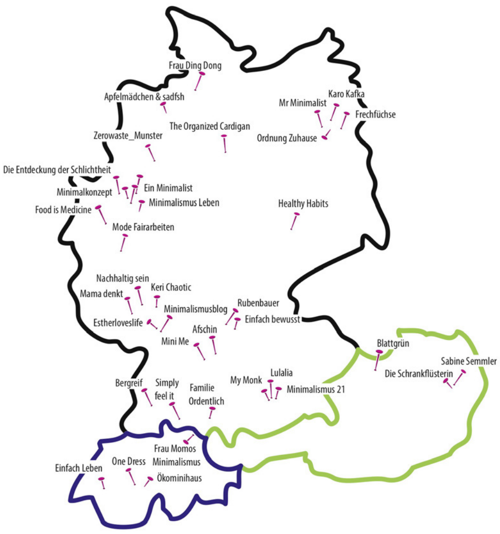

Figure 1. Selection of Minimalism Blogs in Germany, Austria and Switzerland.

Pioneers or guiding figures play a central role concerning societal developmental processes (see also Bly et al. 2015). Before a behavior is adapted by the majority it needs single persons or groups who set an example of their way of living and function as multipliers: They offer inspiration for individuals to change their everyday life and the connected practices and actions. To promote a more sustainable behavior in the area of clothing it is important that single (popular) persons exhibit possible alternative actions. On an international level, Kate Fletcher, Professor for Sustainability, Design and Fashion at the University of the Arts in London, describes herself as a "Fashion and Sustainability Pioneer"(www.katefletcher.com).

The aim of this project, however, is to focus on the level of everyday actions to research how sustainable practices are concretely exerted, appropriated and forwarded inside the German-speaking minimalist scene. Starting point of the research were local minimalist meet-ups in 10 of the 20 biggest German cities in order to gain an overview of the national scene and acquire interview partners. Minimalism bloggers (Figure 1) were additionally addressed to extend the interviewee sample (Figure 2). Apart from the executed wardrobe interviews, we used the methods of participant observation, focus group interviews as well as expert interviews, short questionnaires and textile diaries.

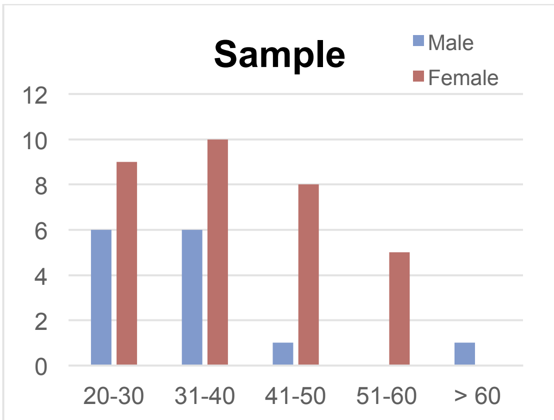

Figure 2. Gender and age distribution of interviewee sample.

Accessing the Wardrobe

On a methodological level, the research project can be assigned to the field of Wardrobe Studies, focusing on the material objects and their relationship to the research subjects. In 2017, the ethnologist Ingun Grimstad Klepp and (the earlier mentioned) Kate Fletcher published *Opening up the Wardrobe*, a collection of 50 different methods from the field of Wardrobe Studies. They describe that the methods

”provide insight into collections of clothes and the garment-related world that takes place in the extended ‘space of the wardrobe’. By this we, the book’s editors, mean the clothing actions, relationships, meanings and material effects that unfold over time and in the course of life.” (Fletcher/Klepp 2017: 3).

The conducted wardrobe interviews were developed in reference to Ingrid Hausgrud’s Wardrobe Study methodology in Fletcher and Klepp’s book and Else Skjold, who experimented with different forms of wardrobe interviews (cf. Skjold 2014: 5). Hausgrud describes her method as a “semi-structured face-to-face interview followed by photography and additional questions concerning the specific garments identified by the participants as valuable to them“ (Fletcher/Klepp 2017: 68). In contrast to Hausgrud, we did not focus mainly on the garments that were especially valuable to the interviewees, but rather on the interrelated everyday practices such as storage, care, laundry, repair, consumption and disposal. Pictures of the wardrobe, of specific garments (Figure 3) and caring tools were taken during the interview.

Figure 3. An interviewee shows her garments with moth paper during an interview.

We consciously decided to conduct the interviews inside the household to provide direct contact with the material garments for mainly two reasons: First of all, the wardrobe interview is a memory-stimulating method. By being able to visualize and haptically interact with the garments during the interview, the interviewees were able to keep a better overview of their collection of clothes and develop answers to the questions in the interview situation itself. When asked about their oldest garment, they usually had to visually search through their wardrobe. On the other hand, it was made possible to correlate given answers with what we observed. Interviewees who stated that they reject non-organic material for clothing, for instance, could present them. In this way, it became possible to observe the actions rather than just relying on the interviewees’ answers. This difference is expressed in the attitude-behavior gap, meaning that people do not necessarily show a practical behavior that matches their attitude and values (Niinimäki 2018: 50). This possible difference between the psychological mindset and actual behavior can either be consciously chosen in order to show desirable or socially accepted behavior (e.g. to act sustainably) or unconsciously adapted while not recognizing that there is a difference between thought and action (cf. Klepp/Bjerck 2014: 383). In Skjold’s words, an advantage of methods with direct access to the wardrobe is that “through observing people's emotional and physical interactions with what they store, dress objects can be regarded as material evidence of lived lives that are immediately accessible at the site of the study, and can lead beyond people's own rationalisations.“ (Skjold 2014: 33).

Sustainable Everyday Clothing Practices

To explain our findings, we developed the scheme of a typical minimalist process specifically associated with clothing:

1) Removal and transfer of the superfluous clothing and reorganization of the kept items (using concepts / rules)
2) Extension of the life cycle of the kept items through repair, care and further utilization
3) Conscious consumption of required garments through circulation / sharing / do it yourself / eco fair consumption
4) Optional: Knowledge transfer & multiplication

A minimalist process most often starts with obtaining an overview of all clothing currently owned and

(1) sorting out the redundant items by reducing and (re-)organizing the remaining clothes

There are different techniques to identify superfluous clothing, like the KonMari method, which works with the question: “Does it spark joy?”. Ways of (re-)organizing one’s wardrobe can be setting rules about the number of clothes or restricting the repertory to a specific range of colors, shapes or materials. These rules/concepts have the aim of reducing the complexity of outfit formation. A typical rule is to choose clothing that is combinable in a variety of ways, which for instance applies to the concept of a Capsule Wardrobe (cf. Jachmann 2017: 91). Even more simplification can be reached through establishing a uniform in terms of a consistent wardrobe.

After sorting out the superfluous garments, these are often passed on to other people or converted for further utilization.

The next step is the

(2) *extension of the life cycle of the remaining garments through repair, care and further utilization*

Repairing clothes requires knowledge about reparation techniques and the corresponding skills. The appropriate care for clothing starts with material literacy, meaning the knowledge about how durable a material is and with what treatment it lasts longest. This includes knowledge about appropriate washing, storing and other care techniques like using a lint shaver or an iron. At the end of the garment's life cycle it can be processed for further utilization, by passing it on for further usage or up-, down- or recycling it, for example by transforming it into a different kind of garment or cleaning rags.

(3) *Conscious consumption of the required/needed clothing*

is located at the end of the chain, as practices of anti-consumption (rejecting, reducing and reusing) display a form of sustainable behavior (cf. Black/Cherrier 2010: 443). But if consumption is necessary, some interviewees use alternative ways of purchase through second-hand or free shops, clothes swapping parties or digital groups. Sharing clothes through collective use or lending services would be another option, but this was not practiced in our sample. Buying ecologically produced and fair-trade products is of high importance, unless the knowledge and skills for creating the needed garment one one's own are available. Two of the interviewees were even professionalizing that practice and opening up their own fashion business.

Conclusions

The paper underlines the importance of conducting interviews that deal with material objects in direct presence of the items. The few times we met people outside of their households the interviewees often strayed from the topic of their clothes and the connected practices to topics they were currently engaged in or minimalism in general. Even though it is usually more challenging to find access to the private sphere of the household and especially the wardrobe of a person, it also led to a closer connection between interviewee and interviewer and a deeper level of communication and responses. It became clear that everyday textile practices cannot be researched from a distance, because of their mostly unconscious exertion and the diversity of practices. It is necessary to pose questions individually, adjusted to the present situation and to clarify unclear expressions. An example is the classification of functional clothing like sports garments, which many interviewees did not include in their clothing collection in the beginning of an interview. Furthermore, when researching sustainability and clothing, it is important to not only focus on consumption and disposal practices but to take everyday practices in the household into account, as they have a significant impact on both consumption and disposal, for example through extending a garments lifecycle by repairing and appropriate material care.

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Product Lifetimes And The Environment

A Systematic Method to Qualify the Repairability of Technical Products

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Keywords: Repair; Standardisation; Technical; Products; Reparability.

Abstract: This publication presents a general analysis of common repair processes and scenarios on which basis it continues to establish objective parameters to qualify a product's repairability by methods suitable for technical standardisation.
The concepts revealed in this paper were developed independently to improve the quality of the debate on repairability within the technical standardisation working group 3 of the joint technical committee 10 of the CEN and CENELEC european standardisation bodies, as well as the respective mirror committee in the german national standardisation body DIN.
The scope of technical standards does not consider social, economic or legal categories, nor does it explicitly reflect on the application of current or past repair practices. It is the objective of this paper to provide technically precise distinctions and clear definitions of the technically relevant aspects involved in a technical repair process of products, the latter which are necessarily also technical to be subjectable to technical standardisation.
This is the background for the claim in the title that this paper discusses technical products, which can therefore also be read as products subject to technical standardisation. A discussion of the legal application of a respective technical repair standard (or the effects thereof) for the purpose of regulation, or its socio-economic effects, are not the subject of the current paper.

Clarification

This paper does not report on a study undertaken by the European Commission. No funding supported this publication at the time of writing. The concepts in this paper were developed by the author based on a combination of decades of experience in product development, as well as with technical standards, and with the objective to streamline the debate within the beforementioned standardisation committees with clear definitions of technical repair aspects.

Objective and Subjective Repairability

The word repair suggests an again-pairing of otherwise distinct parts which share a certain degree of 'pairability' or, more commonly, compatibility.
A common understanding of the activity of a repair may be an informed and non-random action that establishes a function of something again, meaning a function that was previously performed but somehow is temporarily hindered without the process of the repair being exercised.

Figure 1. Four aspects of repairability and their respective domains. Subjective repairability (left) and objective repairability (right) and their subdivision into aquired subjective repairability (ASR) in red, supplementary subjective repairability (SSR) in purple, equipmental objective repairability (EOR) in orange, and substitutional objective repairability (SOR) in blue. © Own work.

Historically, complicated repairs have been restricted to skilled persons like craftsmen or, more recently, technicians and engineers. Also, the products undergoing repair likely were manufactured by those same persons which implied a grade of familiarity and,/ hence, insight into the workings of a given technical product. However, simple repairs may be carried out by everyone, like the replacement of a filter in an appliance at home for example. To do this, the filter is temporarily removed from the appliance and later re-paired with it. Repairability, obviously, is the ability to carry out a/repair.

As will be described below and as it will reveal itself upon closer investigation, this ability seems to have mainly two enabling conditions. Firstly, the broken product has to allow for a repair by means of its construction. And secondly, the person attempting a repair needs at least a basic understanding of the products inner workings which allows for a repair to be attempted with confidence.

Traditionally, craftsmen know how to repair because they know how to make products in the first place. This knowledge or skill allows for even very complex repairs to be concluded successfully. Simple repairs are usually enabled by a few words of encouragement and by showing someone how to do it. To what extent simple repairs can or should be distinguished from any other way of purposeful handling of a product definitely is interesting to analyse further but is not subject of this publication. However, both types of repairs, the complicated one by the professional, as well as the simple repair by possibly everyone may or may not necessitate particular tools and/or spare parts. And it's equally obvious that the level of subjective skill or technical understanding about a given product may be a necessary precondition for any attempt of repair to yield a positive result, mainly depending on the intricacy of the product in question. These two observations can be considered two seperate and independent aspects of repairability, although they are both equally necessary conditions for a successful repair. This means that both have to be fulfilled for a repair to be possible and someone to be able to do it, respectively. With the latter one depending mainly on the person and its ability to repair, it makes sense to call this aspect of repairability the subjective repairability of a product. And because the first depends on material conditions like the availability of the necessary tools and/or spare parts, it makes sense to call this aspect of repairability the objective repairability of a product.

Carrying out a test of the extrema of the above categorisation of repairability may help to establish the practical value of this distinction. In a first example, a clockwork of a mechanical wristwatch is to be considered.

The subjective understanding of the functions within such a clockwork may not be available to everyone, although the common use of clocks can be assumed. And even when being provided with particular instructions on how to 'troubleshoot' a miniature clockwork, most people may doubt their ability to follow such instructions. This already hints towards the subjective repairability sometimes requiring specialised skills. When considering the level of intricacy of such a clockwork this leads to the same conclusion. Now, on the objective side it does take special tools to properly open the housing of a miniature clockwork. The same can be said about any possibly necessary spare parts, assuming for example a broken spring. This leads to the following conclusions for this example: The repairability of the wristwatch is given when a specialist carries out the replacement (subjective repairability) of the broken spring with the spare part and the appropriate tools in a workshop (objective repairability).

In a second example, the inflating of a flat tyre is to be considered. The subjective understanding of the functions of the pressure in the tyre and the implications of any lack thereof are empirically accessible to anyone riding a bike. Furthermore, the intricacy of a tyre as part of a wheel and the compressed air inside it can be considered mildly complicated if at all. The common and widespread availability of compressed air, tyres and, so necessary, spare valves hints towards an easy objective repairability. The repairability of the flat tyre is given because the inflating does not take special training or instructions (subjective repairability) and the necessary spare 'parts' fill the atmosphere and tools, like a pump or compressor, are easily accessible (objective repairability).

Four Aspects of Repairability

Objective and subjective repairability are too abstract as to allow for a measure of repairability of any practical relevance. Also, upon closer consideration of the examples above, a further discrimination of the already established aspects of repairability becomes necessary. In case of the clockwork, the availability of the spare spring is absolutely necessary for a positive repair outcome on the objective side.

Furthermore, the repair cannot be carried out 'on the go' subjected to the elements and is restricted to the setting of a workshop with its special tools like a magnifying glass and probably several pairs of tweezers. In case of the flat tyre it is, however, very well possible to inflate it on the go and basically anywhere outside, for air molecules are abundant on the surface and portable pumps are commonly available.

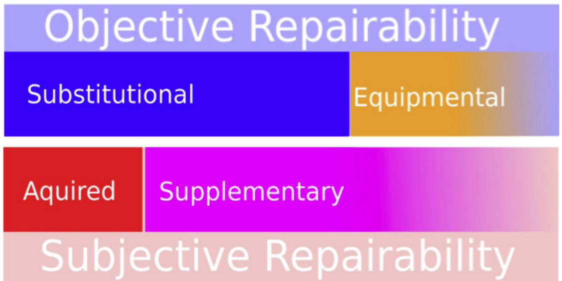

Figure 2. The two aspects of repairability and their two parts building on each other. Aquired subjective repairability (ASR, e.g. 'skill') in red and supplementary subjective repairability (SSR, e.g. 'repair instructions') in purple constitute subjective repairability, and equipmental objective repairability (EOR, e.g. 'tools') in orange, and substitutional objective repairability (SOR, e.g. 'spare parts') in blue constitute objective repairability. © Own work.

The dependency of objective repairability on certain tools or equipment can be termed equipmental objective repairability, whereas the dependency of objective repairability on the replaceability of parts and the spare parts themselves can be termed subsitutional objective repairability. A similar subdivision makes sense for the subjective repairability, in that a trained skill or otherwise gained experience in handling certain product is different to the content of a repair instruction sheet or manual. For the latter is not able to convey the fundamentals of a trade within its scope, e.g. mechanical construction fundamentals, and the experiences built on those. Hence, subjective repairability has to be distinguished further into an aquired subjective repairability on the one hand and an auxiliary or supplementary subjective repairability on the other hand. Supplementary subjective repairability in the form of an instructional sheet may still assist the aquired subjective repairability in easing and/or shortening the duration of a repair process in spite of not being essential to it.

However, supplementary subjective repairability is obviously an essential condition to repairability per se when it is the only available form of subjective repairability in case of an absence of aquired subjective repairability in that particular case. It was shown above that repairability is not just a property of a technical product. Although there is an objective repairability attributable to a technical product, repairability is not limited to that. The person performing the repair is contributing to repairability with technical understanding and practical experience. However, in the absence of all understanding about or instructions on repairing a broken product the best tools and spare parts are useless. Therefore subjective repairability needs to meet objective repairability for a repair to be possible. Tools and spare parts can be described as equipmental and substitutional objective repairability, EOR and SOR, respectively. Professional training and following repair instructions can be termed aquired and supplementary subjective repairability, ASR and SSR, respectively. EOR and SOR are equally necessary for a repair on the side of the object. Being knowledge, ASR outranks the mere information of SSR, yet only one of the two may be necessary for a repair on the side of the subject. However, a particular EOR may require a respective ASR, for example when considering the skills it takes to operate special tools.

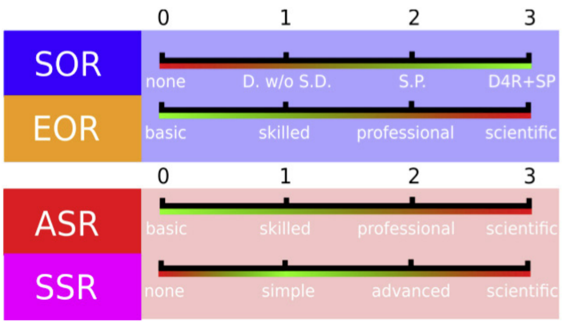

Figure 3. Contribution to overall product repairability by the four aspects on a scale from zero to three. Substitional objective repairability (SOR) scales from 'not repairable' (0) over 'disassembly without structural damage' (1) and 'availability of spare parts' (2) to 'designed for repair' (3). Explanations of this figure and the levels depicted can be found in the text, also for EOR, ASR and SSR. Green indicates potentially optimal repairability, yellow indicates conditional repairability, and red indicates difficult repairability. (ASR: e.g. 'skill', SSR: e.g. 'repair instructions', EOR: e.g. 'tools', SOR: e.g. 'spare parts'. © Own work.

Substitutional objective repairability, SOR

Substitutional objective repairability is the constructional readyness/ of a product for repairs without a degradation of the structural integrity of that product. This implies the availability of individual parts beyond the/active production process itself (then called spare parts) and the possibility of disassembly and, where applicable, disconnectable connections (mechanical or electrical). Probably the highest similitude to what is commonly refered to as the repairability of a product is, within this text, this substitutional objective repairability. This is correct in so far that an economically feasible repair ultimately depends on this type of repairability being frontloaded during the development of any product and, hence, predating the production of the first piece of that particular product. The SOR is necessarily a design feature and determined during the development of the product. Although all parts of a product are determined during the development of the product, the availability of spare parts is not a design feature but an organisational decision. Considering a scale of SOR having four levels, the lowest level is the complete lack of repairability of a product ('non-repairable products'). The second level of SOR is the first precondition of any repairability and that is the ability to disassemble a product without damaging its structural integrity ('disassembly without structural damage'). The third level includes the second level and indicates the availability of original or QUAGAN (see IEC 62309, *Utilisation of Used Components in New Electrical and Electronic Products*) and easy to obtain spare parts. The highest level, again, includes the lower levels (2nd and 3rd) and extends them in that products of this level are being actually developed to be repairable ('repairable by design' or 'developed for repair'). The highest level of SOR is also the one providing the best repairability. Without a damage-free disassembly and the availability of spare parts, there is no economically feasible subsitutional objective repairability of the product and the only objective repairability remaining as an option is/...

Equipmental objective repairability, EOR

Equipmental objective repairability summarises the equipment necessary to repair. This may range from a toothpick to a specially equipped laboratory. Lack of substitutional objective repairability can theoretically always be compensated with increased cost and effort on the equipmental objective repairability side. It is this repairability which can always be claimed to be the property of any product. When considering economical repairs, that is repairs which are cheaper than replacing the product with a new one, the EOR is cheapest when being kept to the absolute minimum. A minimal EOR depends on an optimised SOR, or in other words, a product developed to be ready for repairs. The EOR is a design feature and ultimately determined during the development of the product, too. Considering a scale of EOR having four levels, the lowest level of EOR is the most basic. The second level describes EOR by tools that need some skill to operate and are not to be assumed being publicly available. The third level indicates a demand for professional tools and equipment. The highest level of EOR is limited to scientific equipment and setups, like equipment found in specialised laboratories for example. In the case of EOR this scale indicates better repairability the lower the level is. This means, that the lowest level of EOR is also the one providing the easiest, hence, most economical repairability.

Aquired subjective repairability, ASR

Aquired subjective repairability is any technical understanding and practical experience or skill that enables a particular person to repair and was aquired by that person before that repair. ASR is always relative to a particular product and because ASR is ready and available before a repair is undertaken, it is somewhat related to the ability to develop, construct or at least assemble assemble a product from scratch following instructions. Whereas its supplementary counterpart is enabled exclusively for a particular repair, ASR, as it is understood here, is a broader understanding of technical principles rather than particular mechanisms. Again, considering a scale of ASR having four levels, the lowest level of ASR is the most basic. The second level describes ASR from some experience on the matter. The third level indicates professional experience, likely simultaneously with third level EOR experience. The highest level of ASR indicates a repair only being possible to someone with a scientific background.

In the case of ASR this scale indicates better repairability the lower the level is. This means that the lowest level of ASR is also the one providing the easiest and most economical repairability. The minimum ASR required to enable a repair may be, strictly speaking and hinting at the inclusive idea of 'everyone can repair', basic language skills which enable the access to repair instructions.

Supplementary subjective repairability, SSR

Supplementary subjective repairability is a persons ability to repair based on particular information supplementary to a particular product. Following repair instructions would be the simplest case of enabling SSR. When someone is skilled in repairing (has ASR) repair instructions may still allow that person to repair quicker, more accurate and safer. When a person with entry level ASR for the product in question, a successful repair may depend on the availability of SSR. Any lack of ASR can be theoretically compensated by increasing the SSR, similar to compensating a lack of SOR with EOR, however, again there is a practical limit beyond which someone may simply run out of time. This practical limit is a limit to the amount of content and thereby a limit to the bridgable 'distance' in terms of subjectively new knowledge which can be conveyed by a repair instruction without it turning into a study course. In other words, the scope of a repair instruction is very limited and therefore its content must be limited to the absolute minimum. For repair instructions to be accessible and feasible they depend ultimately on the repairable design determined during the development of the product. So there is a connection to the objective repairabilities. In theory the most competent issuer of repair instructions would be the manufacturer of a product because all information about the product is initially available there. However, there are many excellent examples of people and organisations who supply repair instructions independently of the manufacturer, further giving weight to the observation mentioned above that repairs are on the rise to become commonplace, if they aren't already at this point. Once more, considering a scale of SSR having four levels, the lowest level of SSR is 'no SSR', meaning no supplementary information or unavailable repair instructions in any way, shape or form. The second level of SSR is a simple repair instruction that only contains the necessary information.

The third level describes advanced technical information on the product and the fourth level describes a level of information on the product that may include e.g. measurements of voltage quality or other detailed documentation and at least resembles a reverse engineering effort or an open source documentation. For a repair to be accessible via SSR without a high level ASR, the best repairability is achieved on the second level in the case of SSR, with decreasing repairabilities below and above this second level. The reason for this is that below this second level the ASR needs to compensate the lack of SSR, and the levels above again need ASR for the information to be interpreted correctly towards the repair. This is because the necessary information on how to repair is implicit on the higher levels and needs to be extracted by a person familiar with these, implying third or fourth level ASR. However, if higher level SSR contains repair instructions that are easy to follow by everyone, this equally qualifies for the second level SSR repairability and therefore 'easy repairability'. The accessibility of SSR is optimally the same as the accessibility of the product itself.

All four aspects of repairability are summarised in Fig. 3 including the scales introduced in the sections before.

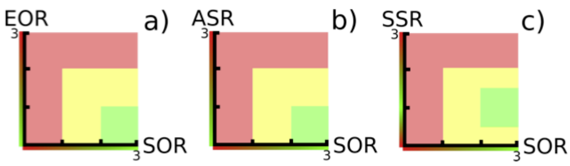

Figure 4. Color coded degree of repairability in relation to its four aspects. Green indicates the combination which enables optimal repairability, yellow indicates conditional repairability, and red indicates difficult repairability. See also Fig. 3 (ASR: e.g. 'skill', SSR: e.g. 'repair instructions', EOR: e.g. 'tools', SOR: e.g. 'spare parts'). © Own work.

Qualifying repairability

When qualifying a products repairability all of the four aspects of repairability have to be considered (see section above). Fig. 4 shows three diagrams with three degrees of repairability colour coded as green, yelow and red representing easy, conditional and difficult repairability respectively. Fig. 4 a shows the degree of repairability in dependence on SOR and EOR.

It is obvious from this figure that a high SOR level of 3 does not imply easy repairability per se, because in cases where a repair demands level 3 EOR this necessarily still qualifies for a difficult repair. The same repairability pattern is found in Fig. 4 b where ASR is shown in dependence on SOR. Similar to Fig. 4 a, only low ASR levels in combination with high SOR levels lead to easy repairability of the product. Last not least, Fig. 4 c shows SSR in relation to SOR. And in conjunction with the definition of SSR above, easiest repairability is given where level 1 SSR meets level 3 SOR and ease of repairability declines to all sides otherwise. All charts of Fig. 4 graphically relate to SOR because parts of the current debate on repairability of products seem to focus on SOR being repairability as such, a point highly questioned by the findings of this publication in that high SOR levels do not always lead to easy repairability. Only a product that satisfies the conditions for easy repairability on all three graphs - i.e. in all four aspects of repairability - can be considered easy and generally repairable. It is the understanding of the author that a product that is generally repairable is repairable by the majority of the population (see defintion of ASR in the section above for minimum requirements). This concludes the main points of this publication.

Conclusions

Generally, all technical products are repairable in the sense that their production process can be imitated given enough funds and time available. But today only very few products are 'generally repairable', i.e. repairable by almost every member of society.

This publication claims that the person repairing contributes significantly to the repairability of a product and, hence, must be considered when improving and establishing a products repairability. On the basis of the distinction between the repairability of the product itself (objective) and the repair-ability of the person repairing (subjective), two further subdivisions are established.

Objective repairability consists of Substitutional and Equipmental Objective Repairability, representing - grossly simplified in a few words - the design and spare part availability on the one side, and the toolset necessary for repairing on the other side. Subjective repairability consists of Aquired and Supplementary Subjective Repairability, representing, firstly, pre-repair knowledge and, secondly, specific repair instructions accompanying the product. The repairability of a technical product cannot be raised with the degree of technical detail of the Supplementary Subjective Repairability. It is found that optimal repairability is given when simple, yet sufficiently detailed and accessible repair information is supplied with the product, which does not require a high degree of Aquired Subjective Repairability for it to be accessible to the repairer.

This finding is contrary to open source hardware concepts, which claim that total technical information warrants for general repairability. This is shown to be not the case because total technical information requires a high degree of Aquired Subjective Repairability, which does not allow for inclusive repairability by everyone because not everyone has a high degree of Aquired Subjective Repairability.The fact that simple repair information is a precondition for optimal ease of repair, instead of the complete technical documentation of a product, can therefore be called the repair information optimum, or the SSR optimum. It is shown what 'easy to repair' translates to in all of the listed aspects on a scale from zero (0) to three (3). Products that are 'easy to repair' in all four aspects of repairability meet the requirements for 'generally repairable'.

This publication outlines a general method to qualify a products ease of repair and what requirements a product should meet to make its repairability accessible to everyone.

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Towards a Circular Photovoltaic Economy: The Role of Service-based Business Models

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Keywords: Photovoltaics, Circular Economy, Business Model, Product-service System.//

Abstract: Solar photovoltaics (PV) has experienced tremendous market growth and has large potential in the urgently needed transition towards a low-carbon energy system. The continued growth of the sector will, however, evoke new sustainability challenges with regard to efficient material use as well as end-of life management of PV products. The aim of this paper is to provide an overview of potential Circular Economy actions in the PV sector, and explore the present and potential future role of service-based business models in operationalizing these actions. Based on a review of academic and industry literature, the paper structures the circularity actions according to the ReSOLVE framework. The analysis also distinguishes between the role of product-oriented, use-oriented and result-oriented product-service systems (PSS). Results show that to result-oriented business models have primarily been implemented in order to facilitate the adoption of PV deployment. Product-oriented PSS are widespread with the service component involving maintenance, repair, insurance and warranties. The paper further explores opportunities of service-based business models to enhance additional circularity actions such as a sharing, optimisation and looping, which so far are mostly in a conceptual or pilot stage only. Expanding beyond current practices, the paper explores future pathways of service-based business models to catalyse a range of additional circular economy actions in the PV sector, and discusses some of the associated key challenges and gaps in knowledge.

Background

Amongst the various renewable energy technologies, solar photovoltaics (PV) is anticipated to become one of the fastest growing markets. Despite its significant potential in contributing to low-carbon electricity generation, the sector’s reliance on linear business model logics undermines its full sustainability potential. In particular, as PV markets will continue to expand, so will the volume of discarded PV products entering the waste stream. End-of-life PV module waste is projected to increase to over 60-78 million metric tons cumulatively by 2050 (IRENA, 2016). Although interest in the research and policy community towards more circular practices in the PV sector has gradually increased, implementation remains constrained by a bundle of policy, economic, social and market barriers. Specifically, lack of profitability, absence of regulatory incentives, weakly developed collection and recycling infrastructures, as well as missing coordination between market stakeholders, inhibit material flow looping in the PV sector (Salim et al. 2019). Hence, there is a great potential to develop circular business models for the solar industry that allow for closing and slowing resource loops, through strategies of repair, reuse, remanufacturing and recycling (Bocken et al., 2016).

Purpose

Innovative business models that rely on the principles of product-service-systems (PSS) have been proposed as a key enabler to catalyse the transition towards a circular economy (Tukker, 2015). In the PV sector, leasing and third-party ownership business models, have already been in use for over a decade and they have been effective in reducing customer-sited barriers to PV adoption (Horváth & Szabó, 2018). More recently, attention has also been directed towards the role that service-based business models could play in enabling circular material flows in the PV sector. The European H2020 project CIRCUSOL (“Circular Business Models for the

Solar Power Industry") aims to develop and validate the market viability of second-life PV products through a co-creative approach with end users and the entire value chain. Yet, a systematic analysis about the full potential of service-based business models as an enabler for a circular economy with focus on the photovoltaic sector is missing. For this rapidly expanding sector, a review of circular economy strategies such as optimization, repair, life-time extension and sharing, is lacking. As a first step towards a more comprehensive understanding, the objective of this paper is to provide a more holistic perspective on the opportunities for a circular economy in the PV sector through service-based business models.

Methods

We develop an overview of current and potential circular service business models for the solar industry, building on business model and solar photovoltaics literature, as well as initiatives observed in industry. Data collection comprised of a review of the academic and grey literature on industry practices in PV deployment, business models, operation, and end-of-life management. Furthermore, to gain insights into recent industry and R&D efforts towards CE in the PV sector, the data collection also involved a review of relevant R&D projects co-funded by the European Horizon 2020 programme during 2014 – 2019.
The analysis is structured according to the six dimensions of the ReSOLVE framework, used in circular business model literature before (e.g. Lewandowski, 2016), distinguishing between the business actions of (1) regeneration, (2) sharing, (3) optimization, (4) looping, (5) virtualizing, and (6) exchange (EMF, 2015). Secondly, the paper analyses how service-based business models can catalyse these business actions in the deployment, use-phase and end-of-life management of PV systems. In this analysis we distinguish between product-oriented, use-oriented and result-oriented services.

Results

Table 1 provides an overview of our preliminary analysis how the business actions of the ReSOLVE framework could be applied across the entire PV value chain (manufacturing, distribution, distribution and installation, use-phase, end-of-life management). Closing loops for PV products, components and materials will require the development of circular product management strategies, including the redesign of PV products for circularity and the development of quality management schemes for second-life components. Besides, optimisation of the PV system performance can be established through the deployment of high-quality planning, installation, monitoring and maintenance practices. The action of sharing refers to the supply of excess PV electricity to other users, amongst others. Furthermore, PV systems can deliver virtual value, for example by providing grid-supporting services as well as performance data through established ICT platforms. Building on the established ontology of the ReSOLVE framework, we propose to add the cross-cutting action category "facilitate" to the framework. Facilitate involves the reduction of customer-sited barriers for the adoption and use of circular PV-systems.
To date, service-based business models have already been widely used to operationalize a number of these aforementioned business actions. Result-oriented PSS – sometimes also referred to as fee-for-service models – have been instrumental in facilitating PV adoption in a number of geographies. Particularly, in low-income countries these models have catalysed rural off-grid electrification by removing the up-front cost barrier of PV (Muchunku et al., 2018). Similarly, they have catalysed the development of the U.S. solar market (Drury et al., 2012), as they enabled the adoption of PV with low consumer transaction costs, leading to immediate electricity bill savings, along with minimal technical risk during installation and operation (Strupeit & Palm, 2016). In terms of optimizing operation, PV systems deployed under result-oriented PSS were found to exhibit superior operational performance as compared to systems directly owned by the user (Guajardo, 2018). While this could indicate the prevalence of least-life cycle cost thinking on behalf of the solar service firm, empirical evidence that could confirm this hypothesis is scarce and inconclusive. In fact, it has been found that the performance of PV systems deployed by a major U.S. solar service firm is below market average, possibly due to the firms' rapid market expansion strategy that placed less emphasis on quality and operational efficiency (Wang, 2017).

	Description	Value chain stage			
		R&D and manufacturing	Distribution & installation	Use-phase	End-of-life
Regenerate	Shift to renewable energy and materials	Design PV products by making use of renewable materials (e.g. wood-made mounting structure)			
	Reclaim, retain and regenerate health of eco-systems		Use (industrial) wasteland for on-ground PV systems		Regenerate land used for on-ground PV systems
Share	Maximise utilisation of products by sharing them among users			Supply excess electricity to other users; facilitate demand side management/and sharing of storage/ capacity at community level	
	Prolong life through maintenance, repair and design for durability	Design of PV products for reparability and long life/	Ensure selection of high-quality PV products and high-quality PV installation/	Enable systematic monitoring & preventive maintenance	
Optimise	Increase performance/ efficiency of a product	Increase conversion efficiency of PV modules and inverters; develop building-integrated modules with multiple functions	Ensure high-quality PV installation	Enable preventive and high-quality maintenance; minimize PV system/ downtimes	
	Remove waste in production and the supply chain	Use PV products with secondary quality; reduce/ production scrap in cell manufacturing; / optimise/PV manufacturing/	Make efficient use of distribution infrastructure; minimize transport damage.		
	Leverage big data, automation, remote sensing and steering		Track and trace single PV components	Gather and analyse data of PV yield and performance	Track and trace single PV components
Loop	Product reuse or redistribution	Design PV products/ for easy disassembly	Use/PV products/for/ second-life applications		Enable appropriate disassembly, collection and refurbishment of PV products to facilitate reuse
	Product repair, refurbishment or remanufacture	Design PV products/ for easy disassembly/and repair	Remanufacture products disused in other sectors for use in PV applications (e.g. EV batteries)	Use second-hand products/ components/as spare parts	Enable appropriate disassembly, collection and refurbishment of PV products to facilitate reuse

	Product recycling	Design PV products/ for easy disassembly			Enable appropriate collection and recycling of PV products
Virtualise	Deliver utility virtually		Use IT for planning and/permitting of PV systems	Use IT for remote monitoring, fault detection, and yield optimization	Use IT for second-life product management
Exchange	Replace old materials with advanced non-renewable materials	Replace scarce materials (e.g. silver) with more abundant materials (e.g. copper)			
	Apply new technologies		Catalyse market introduction of/novel PV technologies		
Facilitate	Remove/// reduce customer-sited barriers for/ (circular) PV/ adoption		Reduce/user-sited/ transaction costs and risks/associated with planning and installation	Reduce/user-sited/ transaction costs and risks/associated with operation and maintenance	Reduce/user-sited/ transaction costs and risks/associated with end-of-life management
	Remove barriers to upfront finance		Provide financing for upfront investment		

Table 1. Overview of current and potential business actions towards a circular economy in the photovoltaic sector.

Note: Since not all CE actions are applicable to all value chain stages, certain table cells/remain blank.

Actions based on Adhya et al. (2016), Ahlgren Ode & Lagerstedt Wadin (2019); ApollonSolar (2019); Behrangrad (2015); BestRes (2019); Brenner & Adamovic (2017); CIRCUSOL (2018); Drews et al. (2007); Drury et al. (2012); EcoSolar (2017, 2018a, 2018b); Einhaus et al. (2018); Guajardo (2018); Hamwi & Lizarralde (2017); Horváth & Szabó (2018); IRENA (2017), Kim et al. (2019); Klise & Balfour (2015); Lam & Yu (2016), Muchunku et al. (2018); Müller & Welpe (2018); Peeters et al. (2018); PVADAPT (2019); Rogers (1999); Mukhopadhyay & Suryadevara (2014), Schmidt-Costa et al. (2019); Sharma et al. (2016); Sica et al. (2018); SolarPower Europe (2018); Strupeit & Palm (2016); SuperPV (2019); Tang et al. (2018); Rai et al. (2016); Rai & Sigrin (2013); Vanadzina et al. (2019); Wainstein et al. (2017), Wambach (2017); Wang (2017); Woyte et al. (2014); Xu et al. (2018).

While this set-up potentially could facilitate life-time extension or controlled collection and end-of-life management of PV systems, little empirical/ evidence exists, presumably due to the still relatively novel character of/ the business model. A variant of the result-oriented PSS model are use-oriented PSS, generally referred to as leasing models in which the property owner (as lessee) pays to use the equipment instead of purchasing the generated power. In the U.S., solar PV/leasing is often used in states that do not allow power-purchase agreements inherent to the result-oriented PSS (Ardani & Margolis, 2011).
Still, in most solar markets,/ product-oriented PSS are the dominant mechanism for PV deployment. In this model, solar firms, in addition to selling a PV system to users, also deliver a set of product-related services, such as maintenance, repair, insurance and warranties (Strupeit & Palm, 2016). In general, a key benefit of service-based business models is the opportunity to gather valuable data on performance and service needs on a large number of systems, thereby enabling incremental optimization of system design and operation (Rogers, 1999). It also allows for easier repair, reuse and recycling and other life cycle benefits (Tukker, 2015). In the market segment for commercial and utility-scale PV, systematic monitoring and preventive maintenance is fairly common, seeking to maximise PV yield and reduce system downtimes. Service contracts/ typically have some result-oriented elements such as minimum availability, guaranteed response

times and performance-based reimbursements (Klise & Balfour, 2015; SolarPower Europe, 2018). Despite its potential to optimize PV yield, systematic maintenance services in the residential PV market are much less widespread yet (Peeters et al., 2018), due to issues with data availability and quality, less favourable economics, and a different set of PV users who typically are not solar professionals (SolarPower Europe, 2018).
Across these market segments, a well-established type of maintenance service is the repair of high-value components of PV systems, in particular inverters, which are either repaired either repaired onsite (high wattage central inverters) or in a workshop at the original equipment manufacturer or at third-party firms (low wattage string inverters). Conversely, repair of defect modules is often financially not viable under present market conditions and the continued price reductions for newly manufactured modules. Still, a niche market for second-hand modules exist in the spare parts segment, in particular when a specific module type is not manufactured anymore but can be in high demand to replace a defect module of the same type.
Novel approaches to operationalize circular economy practices in the PV industry through service-based business models are currently investigated and tested. The CIRCUSOL research project aims to catalyse market development for (1) the reuse of PV modules for a second-life application and (2) the remanufacturing of disused electric vehicle batteries and their recirculation to the market in stationary PV systems. Here, the intended role of a service-based business model approach is to enable coordinated product management (collection, sorting, refurbishment, testing, certification) and mitigate user concerns about the reliability, performance and lifetime of second-life PV products.
Exploring opportunities beyond current practices, service-based PSS can potentially catalyse various other circular economy actions in the photovoltaic sector, thereby reducing the specific material footprint per kWh of solar electricity delivered. For example, opportunities exist in maximising the utilisation of PV systems, by sharing excess electricity with other users through micro-grids, aggregations service and trading platforms (BestRes, 2019; Wainstein et al., 2017), as well as by enabling the sharing of electric storage capacity at the community level (Müller & Welpe, 2018; Tang et al., 2018). Delivery of these actions would require the coordination of responsibilities across several partners of the value chain, a role that a solar service firm potentially can adopt.
Service-based business models could also catalyse the market introduction of novel product technologies with a lower environmental footprint, in particular by transferring the risks that users might associate with new product design towards the solar service firm. Examples of products might include novel module technologies that are designed for efficient and low-cost disassembly at the end of life (Einhaus et al., 2018), or mounting structures that make increased use of renewable materials (EcoSolar, 2018a).

Challenges and gaps in knowledge

Current efforts to repair, reuse or remanufacture PV modules are compounded by practical and economic difficulties. Firstly, at present the availability of modules to be refurbished for second-life use is fairly limited, although this is expected to change in the forthcoming decade with an increasing number of modules reaching an age of 20 years or more. Secondly, the market value of used PV modules remains unclear, in particular as new modules will be available at declining cost levels and competition from novel module technologies may emerge. Furthermore, the market acceptance and business viability of service-based models with a clear circularity focus remains to be further tested.
The review has identified various challenges and gaps in knowledge. Firstly, PV-systems are designed as a long-life product and trade-offs between optimisation and looping may exist. In particular, a better understanding is required whether and when the repowering of PV installations makes financial and environmental sense. Optimizing PV systems from a least-life-cycle cost perspective requires comprehensive data sets. Given the fragmented nature of the market and the relative long operational lifetime of PV systems, improving data resolution and quality is faced with significant challenges.
It is also important to recognized the limitations of service-based business models in operationalizing circularity actions in the PV sectors, and simultaneously acknowledge the need for complementary mechanisms and approaches. For example, implementing circularity in the upstream part of the value

chain economy is generally beyond the scope of more deployment-centred business models.

Contributions

Building on earlier research on the role of PSS as an instrument towards a resource-efficient, circular economy, the novel contribution of the paper is the investigation of service-based business models for a long-life product in distributed renewable energy production. The findings show how service-based business models could help integrate currently fragmented responsibilities and knowledge areas across the PV value chain and thereby remove split incentives, exploit least-life-cycle-cost thinking and benefit from scale and learning effects in circular product management. For practitioners in the PV sector, the paper aims to provide an overview to identify opportunities for circular service-based business concepts.

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How Do the Revisions of the Nordic and EU Ecolabel Criteria Reflect Circular Economy?

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Keywords: Circular Economy; Product-service-time Extension; Type 1 Eco-label Criteria; Durability; Reparability.

Abstract: In a Circular Economy, products maintain their potential to create value for as long as possible (EC 2019:3). The focus of this paper is on Type 1 eco-label as an existing policy instrument, in creating a pull towards product qualities that enhance Circular Economy. Durability, reparability, upgradability and multi-functionality contribute to extending product service times. Material circulation factors are also essential. The aim of this research was to assess the extent to which the ecolabel criteria that have been published during the period 2017-2019 reflect Circular Economy, with a focus on product service time extension and whether a strengthening of the relevant requirements can be observed. This research builds on previous research carried out in 2016: "Do ecolabels promote longer life times: a comparison of the Nordic Swan and EU ecolabel" (Suikkanen, J. and Nissinen A. (2017), PLATE Conference proceedings). The data for this analysis is new criteria and revisions of criteria of the Nordic Ecolabel and the EU Ecolabel dating from 2017, 2018 and 2019. We analysed the criteria and compared them to the results from the previous paper. We noted that the new criteria documents mention Circular Economy. However, in practice the requirements mainly reflect Circular Economy in packaging requirements. This is concluded to be line with the EU Plastics strategy and identified priority sectors. However, there is a need for more coherently and broadly include requirements that enhance in particular life time extending factors, such as reparability and upgradability to further address Circular Economy through ecolabelling.

Introduction

In recent years the Circular Economy (C.E) concept has gained momentum among policymakers, academia and industry (Geissdoerfer *et al.*: 2017) to meet the goals of sustainable development (Saidani, M. *et al.*: 2019). It has been viewed as a way to operationalize the concept of sustainable development for business (Ghisellini *et al.,* 2016 and Murray *et al.*, 2017 in Kirchherr *et al.* 2017: 127).

In a Circular Economy, products maintain their potential to create value for as long as possible (EC 2019:3-4). Literature points to longevity as an important factor in a circular economy (Franklin-Johnson *et al.* 2016: 132 and Beek *et al.* 2016:8). To extend the time during which a product is in use, the products can be designed to simply have a longer physical or use life time (Asif *et al.* 2016:1266).

The consumer role in a Circular Economy has been pointed out by some authors (Kirschherr *et al.*, 2017: 228, Ghisellini *et al.* 2016: 19, Lieder and Rashid 2016:45). Ecolabels are a means of guiding consumer choices towards products that have better environmental performance compared to other products in the product group. Kirschherr *et al.* (2017: 228) refer to Repo and Anttonen (2017) and Gallaud and Laperche 2016 in saying that consumer demand is needed for viable circular economy business models and that it is the consumer that is the "most central enabler" of them.

A recent European Commission document highlights the role of existing product policy instruments in pursuing the objectives of Circular Economy. Even when the instruments are pre-dating the Circular Economy Action Plan, they are seen to act towards the C.E. goals (EC 2019: 3-4).

The EU Ecolabel (Flower) and the Nordic Swan Ecolabel are ISO14024 Type 1 ecolabels. They are thus multi-criteria and based on scientific evidence and a life-cycle based approach, and are third party certified and revised regularly (EC 2019:10). Type I ecolabels, such as the Nordic Swan, or the EU Flower set a standard for environmentally preferable products, which are identified by considering the environmental impacts throughout the product life cycle (ISO14024:2018).

The EU Ecolabel targets the best 10-20% of products within a specific product group on the market and criteria have been established for 25 good and service groups (EC 2019:10,12). The Nordic Ecolabel targets the best 30% of the products within a particular product group and criteria have been developed for over 60 product and service groups.

For this paper we use the framework developed in Suikkanen & Nissinen (2017) "*Do ecolabels promote longer life times: a comparison of the Nordic Swan and EU ecolabel*" (Suikkanen, J. and Nissinen A. (2017), PLATE Conference proceedings). This framework considers that actions to maintain value could be divided into product service time extension (PSTE) and material circulation. Product service time is extendable by designing products are durable, repairable, and upgradable. We consider that multi-functionality of products intensify their use time and hence service time is extended. Material circulation considers the recyclability and secondary raw material and component use in the product as well as recycling in production and end-of-life.

In this article we focus on the factors that have the potential to extend product service: durability, reparability, upgradability, and multi-functionality. We also undertake a screening regarding material circulation. The analysis includes consumable products (e.g. detergents), which EC (2019) considers important to produce with the minimum impact on resources and consumed so as to leave as little waste as possible (EC, 2019: 3).

The aim of this research was to assess the extent to which the criteria that have been published in the reference period 2017-2019 reflect Circular Economy and whether there is an in the stringency compared to the older criteria. The comparison is done to our previous research. The former paper consisted of a review of the Nordic and EU ecolabel product group specific criteria documents for products that were valid at the time.

In our previous paper we observed that the Nordic and EU ecolabel criteria documents published before 2017 include durability requirements for a broad range of product groups but there was only one Nordic ecolabel product group (computers) and three EU ecolabel product groups (computers, televisions and mattresses) with requirements on upgradability and only one Nordic ecolabel product group with a requirement on multi-functionality (rechargeable batteries) (Nissinen and Suikkanen: 2017)

Results

EU Ecolabel

Of the EU Ecolabel criteria, those product groups belonging to the category "cleaning up" have been updated in 2017. These product groups include the following criteria: Hard Surface Cleaning Products, Detergents for Dishwashers, Industrial and Institutional Automatic Dishwasher Detergents, Hand Dishwashing Detergents, Laundry Detergents, Industrial and Institutional Detergents. For these product groups extending the service time of the product itself through durability requirements, reparability, upgradability and multi-functionality is not relevant, with the exception of durability in the sense of effectiveness.

However, in comparison with the former criteria versions, the "cleaning up" product groups include a requirement for design for recycling for packaging, which aims to improve separation and reprocessing of the material. The product groups continue to have an exemption within the Weight to Utility (WUR) calculation for those materials that are made of over 80% of recycled materials. According to the Technical Background report, it had been suggested to remove the exemption on the grounds of Circular Economy so as to ensure that there is no overuse of any kind of packaging (Boyano, and Wolf, 2016:93 & 277).

The new EC ecolabel product group "*Wood,-cork and bamboo- based floor coverings*" which dates from January 2017 has been designed so as to promote Circular Economy and to extend product life time (Boyano and

Wolf: 13, 52). Extended guarantee, design for repair and disassembly and consumer information on maintenance repairing have been introduced (Boyano and Wolf: 15, Criteria document C9). The lubricants criteria document (2018) states that the criteria should facilitate the transition to a more Circular Economy, and includes a 25% requirement of post-consumer plastic packaging (Lubricants, Criterion 5).

Nordic Ecolabel

For this analysis all the 44 product group specific criteria for the Nord Ecolabel were analysed. Of these, new generation criteria have been published in the reference period only for the product groups "Baby products with textile 1.0" (June 2017), "Cleaning products 6.0" (November 2018), "Primary batteries 5.0" (November 2018), "Rechargeable batteries and portable chargers 5.0" (June 2018) and "Disposables for food 4.0" (June 2017). For most of the other product groups the updated document concerned most often about extending the validity and minor adjustments that are considered non-relevant for the purpose of this study.

It is less easy to detect and to generalize a common unifying approach to Circular Economy within the criteria documents for these product groups, in comparison to the ones for the EU Ecolabel revised documents. The background document for the "Disposables for Food" product group states as one of the main points of the revision "*seeing what waste requirements can be set with regard to the circular economy and better use of resources*" (Nordic Ecolabel, 2017:4), and the criteria correspondingly state that disposables for food contain a high proportion of bio-based materials or recycled plastic and are designed to promote recycling. The scope of the "Cleaning Products" criteria document states that "*packaging requirements contribute to circular economy by addressing packaging design and material choices*". The scope of the "Rechargeable batteries and portable chargers" criteria document refers to the possibility of dismantling. For the new product group "Baby products with textile", there is an explanation under New Criteria that the focus has been on chemical requirements, but a generation 2 of the criteria, expected 2023, will assess how product design can support the circular economy (Nordic Ecolabelling, 2017: 100).

We did not note requirements addressing reparability or upgradability for any of these new generation criteria. We consider that the "Rechargeable batteries and portable chargers"- product group specific criteria continues be the only product group to address multi-functionality through the requirement O4 "*Battery charger must suit a minimum of two battery sizes*".

Durability requirements continue to be present in most Nordic Swan Ecolabel criteria, including the revisions. The new criteria for "Baby products with textile" includes a number of quality and function requirements for textiles, similar to the "Textiles, hides, skins and leather" criteria. The quality requirements include for example colour fastness to light, to washing and to rubbing (O69-O72), pilling requirements (O73), dimension changes during washing and drying (O74) and wearing strengths (O75). Both of the battery groups have requirements on the operation time of the batteries. The new generation (generation 5) of "Primary batteries" criteria has changed requirements regarding minimum average duration and a new requirement for test of battery shelf life (Background document O9 and O10). The new generation criteria (generation 5) of the "Rechargeable batteries and portable chargers" criteria document includes a revised requirement O9 on adjusted endurance cycles. Both of the battery product groups refer to quality in the scope description.

Some product groups have requirements on refills. For example the adjusted candles product group includes a new requirement on candle containers: "*Containers that are designed to be used multiple times for the same purpose should have two refills*" (O9).

While not the focus of this paper, we present some observations regarding material circulation. In the new generation criteria documents, strengthened requirements regarding recyclability were noted. Separability requirements for the product are included in the product groups "Baby products with textile" (O62), "Rechargeable batteries and portable chargers" (O15) and "Disposables for food" (O27) as well as for the packaging of the "Cleaning products" and "Primary batteries" product groups (O4). The “Cleaning products” criteria document (p.4) states that “*requirements have been set on packaging to increase possibility to recycle plastic so as to contribute to circular economy*”. The WUR formula of this requirement exempts from the calculation products that are supplied in packaging that are taken back, washed and refilled.

In most product-group-specific criteria there continue to be numerous requirements that may contribute to recyclability through non-toxic cycles that are addressed through chemical requirements. A different study should assess the extent to which the chemical requirements enhance recyclability. In particular many product groups have requirements that enhance the separability of materials and disassembly of products to facilitate recycling. In the “Office and Hobby Supplies” adjusted criteria there is a new requirement O5 on design for single packaging, which puts a 80% requirement on pre- or post-consumer recycled material and states “*when using single packaging the packaging must be designed in such a way that dismantling is possible for all individual parts for waste sorting without using any tools*”.

The section of the product-group-specific criteria called “New Criteria” or “Future Criteria” identifies topics that will be evaluated in the next criteria revision. The review of the text in these sections showed that in the future many evaluations of the criteria will assess the recycled content and the recyclability of materials.

Discussion

As many of the EU Ecolabel product-group-specific criteria that had been updated are fast moving consumer goods (paper products, cleaning liquids etc.) requirements relevant to product service time extension are not relevant. Therefore, for many product groups, contribution to the Circular Economy is reflected mainly in the packaging requirements where recyclability, recycled content and information on correct end-of-life recycling are included. Packaging is one of the priority sectors that have been identified by the EC and thus its systematic addressing can be considered relevant (EC 2019). On the other hand, recently some of the product groups that could have been interesting from a Circular Economy perspective have been discontinued due to low uptake. These include the product group “imaging equipment” and “computers” as well as some building related product groups (sanitary tapware, flushing toilets and urinals). Construction has been pointed as one of the priority sectors, but recently water based heaters and sanitary tapware have been discontinued. In addition to construction, other priority product categories that are currently be covered by the eco-labelling schemes are EEE and batteries, furniture, textiles, buildings and construction products and chemical products (EC 2019:1)

While almost all of the products-group-specific criteria for Nordic Swan ecolabelled product groups have been adjusted in the reference period, there were only five product groups that had gone through full revision, resulting in a new generation of criteria. In these product groups the aim of the ecolabel to contribute to circular economy is reflected in the wording and in requirements that reflect material choices and their end-of-life recyclability, including in packaging choices. The Cleaning Products criteria exempts refill packaging from the WUR calculation, perhaps implicitly encouraging refill systems. Based on this research, the role of design for packaging can be expected to strengthen in the future. It is also in line with the EC strategies and priority sectors (EC, 2019).

Of the revised criteria documents, there were only two product groups that are durable products (Rechargeable batteries and portable chargers and Baby products with textile). For these product groups reparability, upgradability and multi-functionality would be relevant to assess further in the future. Considering the entire set of product-group-specific criteria documents, there are requirements regarding warranties, guarantees and spare parts, but these requirements appeared not to be coherently applied across all product groups for which they could be seen as relevant.

If comparing the two Type 1 ecolabelling schemes, a movement towards integrating circular economy considerations is noted. From the perspective of longevity, proposed by Franklin-Johnson *et al*. and Figge *et al.* (2018:300), it is important to consider the initial use, product refurbishment and recycling.

While ensuring appropriate end-of-life considerations is important, more ambitious and coherent PSTE requirements in Type 1 ecolabels across product groups could create a pull for products that have a refurbished life.

Finally, as there is an important role for the ecolabels in creating consumer demand in general for sustainable products, the role of ecolabels in activating consumers for the circular economy should be more broadly exploited through setting the criteria accordingly.

Conclusions

The current European priorities point to the strengthening of the current policy instruments to more clearly support the Circular Economy. Ecolabels have a role in informing consumers about the environmental performance of products, but also encourage producers to meet a standard of environmental performance. Ecolabel requirements are a way to influence the design of products to be of excellent durability and to enhance product service time extension through reparability and upgradability.

Given that the validity period of the EU ecolabel criteria is long, in the considered period there have only been a few product groups which have undergone revisions that would allow contribution to Circular Economy. At the moment it is mainly reflected in the packaging requirements. The new EC ecolabel product group for “Wood-, cork-, and bamboo-based floorings” is an example that indicates a benchmark of a future ecolabel criteria that integrates requirements that help extend the product life time.

The Nordic Swan Ecolabel has been integrating requirements that support the Circular Economy, especially as it concerns material choices and separability. There is a need to continue to assess the potential to place requirements that extend product service times, in particular through repairable and upgradable product design, information to consumers, and availability of spare parts as well as long warranties.

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Design Competencies for a Circular Economy

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Keywords: Circular Economy; Product Design; Design Competencies.

Abstract: Limited research has been done on design competencies for a circular economy in practice. Yet, an overview of design competencies for a circular economy would be useful to understand which topics should be emphasized in both education and practice. This paper focuses on deriving circular economy competencies for product designers working in industry. The study consisted of three focus groups with twelve designers that are actively exploring circular economy opportunities in an industrial product design context. We derived six design competencies for a circular economy: (1) circular economy understanding, (2) circular economy storytelling (3) setting circular criteria, (4) assessing circular solutions, (5) connecting reverse logistics with users, and (6) design for multiple use cycles. These six competencies are presented and reflected upon by comparing them to competencies found in literature. Two of the competencies found (i.e., circular economy understanding and storytelling) are new compared to those mentioned in literature. The other four competencies found in this study overlap or further specify competencies mentioned in literature. Ultimately, the relevancy of each of the six competencies for an individual designer is determined by the role this designer has in a company.

Introduction

The increasing pressure on resources has become a growing concern. The circular economy, which is propagated by the Ellen McArthur Foundation (2013) as “restorative and regenerative by design”, offers a compelling alternative to our current resource intensive systems. The proposal to cycle material resources is not new, but because the circular economy makes it operationalizable (Ghisellini et al., 2016; Kirchherr et al., 2017; Murray et al., 2017) the concept has gained traction among companies that want to contribute to sustainable development (Kirchherr et al., 2017). Circular economy emphasizes high value and high-quality cycling of materials. By advocating sharing and reusing it also connects sustainable production and consumption (Korhonen et al., 2018). Product designers are seen as potential facilitators and even leaders of the transition towards a circular economy (Andrews, 2015, p.305), because they can design products and services that fit multiple lifecycles. While design for a circular economy can be seen as part of the larger design for sustainability landscape, its aims are more explicit. Design for sustainability is aimed at the broad concept of reducing environmental impact. The aim of design for a circular economy, based on its focus on resource efficiency and economically viable closed-loop systems, is more focused and aims to maintain product integrity as long as possible over multiple lifecycles (den Hollander, 2018).

Research has also suggested that the transition towards a circular economy requires acquiring new competencies and knowledge (EEA, 2016). This reflects the notion that the competencies designers need to operate in the sustainability landscape are changing. Yet, there is a lack of understanding regarding these changing competencies (de los Rios & Charnley, 2016; Sumter et al., 2018). Although limited, some research has been done specifically on design competencies for a circular economy. Often, these competencies are derived from case studies with companies that are exploring circular economy opportunities. They are related to “understanding product and service aspects of the circular offering” (de los Rios & Charnley, 2016), “assessing environmental impact of the circular solution”, “facilitating collaboration”, “anticipating how the circular offering will evolve”, and “integrating business model and product’s design” (Sumter, 2018). In addition, earlier research suggests that the role designers have in companies determines which “circular” design competencies are relevant (Sumter et al., 2017b; Sumter, 2018).

This paper derives circular economy competencies for product designers working in industry through a series of three focus groups. We use the following definition of a competency: “a functionally linked complex of knowledge, skills, and attitudes that enables successful task performance and problem solving” (Wiek et al., 2011, p.204). The focus is on those designers that work for medium and large companies. These are believed to have a wider reach than small companies when pursuing their sustainable or social activities goals (Hockerts & Wüstenhagen, 2010).

Methods

This study is part of a wider collaborative project (hereafter: co-project) titled *Circular Business Competencies Building: Business function specific knowledge and competencies for a circular economy*. This co-project was initiated by Philips and the University of Exeter and facilitated by the Ellen MacArthur Foundation. While the co-project focused on deriving wider competencies for a circular economy, this paper only presents and discusses the circular economy competencies relevant for product designers working in industry. The co-project offered the opportunity to gather perspectives from multiple designers who have a wide range of roles in companies that are actively exploring circular opportunities, and identify and validate gaps in the design competencies for a circular economy.

Data Collection

The full co-project ran from November 2018 until May 2019. Data was collected in three focus group calls and two surveys between March and April 2019. Table 1 shows the topics and the number of participants who took part in each step of the process. The principal researcher of this study facilitated the calls with the design practitioners in the co-project. A note taker from the Ellen MacArthur Foundation was present during each of the focus group calls to make minutes.

Data collection method (number of participants)	Topics
Survey 1: (8)	- Barriers and drivers in exploring circular opportunities
Call 1: (8)	- Barriers in exploring circular opportunities and design challenges - Enabling conditions
Call 2: (11)	- Challenges for product creation - Collaboration - Communication
Survey 2: (-)	- Company culture: supporting/hampering circular economy
Call 3: (7)	- Design for circular economy competencies - Resources needed to address identified competencies

Table 1. Data Collection Process and Participant.

Participant selection

Companies selected employees with circular economy knowledge and/or who were actively exploring circular economy opportunities in their daily work. The selected employees took part in a kick of call, which each of the participating companies organized separately. During these calls the co-project was introduced. Each of the five companies then put forward two or three employees who took part in the focus group calls. Table 2 gives an overview of the participants and their job titles.

Company	Job title
H&M Group	Team Responsible for Engineers
COS Brand	Product Architect
Tarkett	Design Manager
Tarkett	Senior Design Manager
Tarkett	Project Manager Sustainability
Tarkett	Team Manager Design
Essity	Global Brand Innovation Manager
Essity	Global Brand Innovation Manager
Essity	Regional Brand Director
Philips	Senior Product Manager
Philips	Product Designer
Coty	Manager R&D Packaging

Table 2. Participants Data.

Data Analysis

The first survey and call were used to explore the context the participants worked in. This resulted in a wide array of barriers and drivers. We used Covey's "concern-circle of influence model" (Covey, 2004) to separate the challenges that were within their circle of concern (e.g., key performance indicators that are hindering the implementation of circular initiatives) from the challenges that were within their circle of influence (e.g., how to determine the useful lifetime of components after take back). The challenges that were within the participants' circle of influence were the focus point in the second call. In the second analysis round, based on challenges that were discussed in the second call, we derived and formulated design competencies for circular economy competencies. These identified competencies were then validated in the third call, by asking the participants to comment on the importance of the competencies that were formulated.

Results

Based on the collected data six design competencies for a circular economy were derived from the calls with the product designers working in industry (see table 3).

1.	Circular economy understanding
2.	Circular economy storytelling
3.	Setting circular criteria
4.	Assessing circular solutions
5.	Connecting reverse logistics with users
6.	Designing for multiple use cycles

Table 3. Six design for circular economy competencies (validation).

1. Circular economy understanding

"Circular economy understanding" is about having a clear understanding of the circular economy concept as well as mastering the vocabulary to be able to communicate with others. This competency was classified as foundational. It was seen as a more general competency that forms the basis for further actions. A participant remarked: "circular economy is often equated with recycling, while this is the least preferred solution". In order to tackle the challenge of getting to higher order circular concepts, such as reuse, refurbishment and prolonged life, it is vital one masters the ideas behind the circular economy and is able to verbalize those.

2. Circular economy storytelling

To master "circular economy storytelling" means being able to engage internal and external stakeholders (e.g., consumers, suppliers and partners) in the circular story. Product designer should be able to interpret what the benefits of a circular economy are and what the consequences of "going circular" are for the company and for the department they are working in, and "sell" this to others in an engaging way. This reflects the need to create involvement and get commitment, which was mainly expressed by the design managers.

3. Setting circular criteria

Setting circular economy criteria relates to being able to determine the circularity of products. This competency is based on the challenge the participants faced when it comes to checking whether products under development are circular. They indicated that they were struggling to determine what they should consider and whether they were on the right track when they were developing circular solutions. Setting circular criteria could be useful in guiding the design process: participants working as design managers mentioned that they were implementing criteria in the form of 'circularity' checklists and product scores (e.g., modularity, ease of disassembly and recyclability of material) to transform the design process. In addition, the criteria for circular materials can also be used as a standard in procurement when searching for and buying materials.

4. Assessing circular solutions

"Assessing circular solutions", is about being able to make financial and environmental assessments of the circular products over multiple use cycles. This competency is required as it can help to assess the viability of proposed circular solutions for the company. Participants mentioned that being able to make a financial assessment is necessary, and should be a starting point, as it helps designers to estimate whether developing a circular solution makes business sense. The environmental component of this competency entails being able to estimate what the impact is over multiple use cycles. A design manager mentioned that current environmental assessment methods, such as Life Cycle Assessment, did not align with the circular solutions they were trying to assess.

5. Connecting reverse logistics with users

To master the competency "connecting reverse logistics with users" entails being able to engage users to participate in the reverse logistics that have to be set up to facilitate the take-back of circular products. Essentially this competency connects two topics: customer engagement and reverse logistics. Creating customer engagement is connected with the ability to determine what the implications are for reverse logistics (e.g., which logistics channels should be in place to facilitate, for example, take back?). Participants stated that consumers should be engaged to participate in circular business models: "for the consumer it should be very clear how to use the product, how to give it back, how it is designed […] what his benefits are and what environmental benefits are".

6. Designing for multiple use cycles

Being able to "design for multiple use-cycles", entails designing product-service systems that can serve multiple use cycles and/or users. In addition, it includes being able to set up a monitoring and tracking system to have an overview of where company resources are and the ability to determine in which state the products are upon take back. Participants found it important to be able to determine the remaining useful life of particular components upon takeback and to determine how often they could be reused.

Role dependency of competencies

During the validation call, participants emphasized that not all competencies were applicable to them because they were not involved in all phases of the design process. For example, a product engineer mentioned that he was not involved in initiating new product development. Therefore, it was less relevant for him to be able to do financial assessments of circular solution. Instead, it was important that he could "design for multiple use cycles". He added that product designers are not always in the "driver's seat" when it comes to initiating the development of new circular products or services. The business model is often set by marketing. Design choices then have to align with the scope of the business model as determined by marketing: "if it is a business model only relating to recycled contents, then you only focus on that, if it is refurbished content, then you focus on that."

Discussion

The six identified design competencies for a circular economy as indicated by the product designers working in industry range from being new to partially overlapping and further specifying competencies found in literature.

First, "circular economy understanding" was found to be a core competency that could serve as a foundation to develop other competencies such as "circular economy storytelling". Circular Economy understanding and storytelling are highly connected competencies and were not earlier mentioned in literature. When previous research mentioned management buy-in and support as important driver for implementing circular solutions (Sumter et al., 2018, p.12) it was seen as a general requirement for introducing change in companies. Yet, the industrial design practitioners who participated in this study shared that they struggled with engaging stakeholders inter alia due to the fact that they insufficiently mastered the circular economy vocabulary. Hence, these competencies were derived and formulated.

Second, within this study, it appeared that there is a need to develop a competency in doing financial and environmental assessments over multiple use cycles for circular solutions. When it comes to environmental assessment a related competency was mentioned in literature: “estimating the environmental impact on a systems level over multiple life cycles” (Sumter et al., 2018, p.12). Yet, while relevant according to industry when it comes to financial assessment literature does not mention related competencies. While both competencies reflect a need to be able to also “anticipate how the circular offering will evolve over multiple lifecycles” (Sumter et al., 2018, p.12), financial assessment is done on company level while the environmental assessment is done on system level.

Third, “connecting reverse logistics with users” reflects the expanding design domain in which customers should be engaged to participate in circular business models. Literature shows that this competency also means there is a need to understand that in the context of access-based models consumers are framed as users (de los Rios & Charnley, 2016) as they temporarily get access to products. Within this context, literature furthermore mentions the following competencies: “understanding factors of the use experience”, “understanding processes for reverse and re-manufacturing” and “understanding logistics and distribution processes” (de los Rios & Charnley, 2016, p. 118). This reflects an emphasis on the user within circular economy literature. Yet, industry is more concerned with how to set up of the (physical) reverse logistics system and connect it with the users.

Fourth, the identified competency “designing for multiple use cycles” corresponds strongly to three competencies mentioned in literature that are all related to understanding product and service aspects of the circular offering: “understanding the service experience and how to design services”, “understanding product wear by use”, and “understand failure mode and maintenance procedures” (De los Rios & Charnley, 2016, p.). Further, this competency relates to the competency to “anticipate how the circular offering will evolve over multiple life cycles” (Sumter et al., 2018, p.12). This challenges the current mindset of designers as it requires them to look further ahead predict how the product will be used, what the potential useful lifetime of product is and which value recovery strategy to apply.

Last, while the participants recognized the importance of certain competencies, they did not feel the need to acquire all the identified competencies. The perceived relevance seems to be dependent on the position that they are working in. For example, “setting circular criteria”, was a competency that was mainly reflected by the participants working in more strategic roles as they felt responsible for guiding colleagues in the design process. There is a need to keep exploring circular design competencies, as they help to understand how organizations learn and how design roles evolve in the context of a circular economy. Further research should lead to a comprehensive framework in which design competencies for a circular economy are allocated to the roles designers could have in sustainability transitions.

Conclusion

In this study we derived six design circular economy competencies for product designers working in industry: (1) circular economy understanding, (2) circular economy storytelling (3) setting circular criteria, (4) assessing circular solutions, (5) connecting reverse logistics with users, and (6) design for multiple use cycles. "Circular economy understanding” and “circular storytelling” are new compared to those mentioned in literature. In addition, when it comes to the competency “assessing circular solutions”, financial assessment was not mentioned before within literature. Furthermore, while literature focused on topics related to the changing role of consumers in circular economy, industry practitioners are more concerned in acquiring competencies that help them determine the implications for customer engagement on reverse logistics. This reflects that industry puts more emphasis on competencies to tackle short term barriers. The six competencies reflect the expanding role of product design needed to contribute to circular activities. Yet, the role designers have in these settings determines the relevancy of acquiring one of the six competencies. The insights following from these explorations can be used to shape and keep design education up to date.

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Consumers' Engagement in the Circular Economy: Results from a Large-scale Behavioural Experiment and Survey in the EU

A study for the European Commission, Specific Contract – No 2016 85 06 implementing Framework Contract – CHAFEA/2015/CP/01/LE

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Keywords: Circular Economy; Reparability; Durability; Behavioural Economics; Experiment.

Abstract: In recent years, the European Commission has shown interest in driving Europe towards a more Circular Economy (CE) and has adopted an ambitious Circular Economy Action Plan to achieve this. We were appointed by the European Commission to conduct a behavioural study on consumers' engagement in the Circular Economy to aid the implementation of this Action Plan. The study was conducted in two phases. Phase one comprised of a literature review, stakeholder consultations and consumer focus groups to understand current CE practices and consumer attitudes. Insights from this phase fed into phase two which consisted of a consumer survey and behavioural experiments. This quantitative research tested barriers and drivers of consumer engagement with CE practices. The study showed that consumers are generally willing to engage with CE practices. However, actual engagement was found to be low, likely due to a lack of information about CE characteristics of products. The study showed that providing consumers with information on durability and ease of repair shifted consumption towards products with better CE credentials. The behavioural experiment further showed that decisions on repairing products can easily be disrupted if repairing requires effort. To further enhance consumer engagement in the Circular Economy, this study recommends to: i) boost CE engagement by strengthening pro-environmental attitudes and awareness; ii) create financial incentives for manufacturers to produce products that last longer and are easier to repair; iii) make information on CE credentials (durability/reparability) available at the point-of-sale; iv) take steps to make repairing easier for consumers; and v) strengthen implementation of existing policies promoting the CE.
This paper is based on a report for the European Commission entitled 'Behavioural Study on Consumers' Engagement in the Circular Economy' (completed under Specific Contract – No 2016 85 06, implementing Framework Contract – CHAFEA/2015/CP/01/L), published in 2018. Reuse of this report is allowed under Article 6 of Commission Decision of 12 December 2011 on the reuse of Commission documents on the conditions that (a) the reuser to acknowledges the source of the documents, (b) the original meaning or message of the documents is not distorted and (c) the Commission is not liable for any consequence stemming from the reuse of the documents.[1]

Introduction

Circular Economy (CE) practices have a close connection with key EU policy priorities, including growth, climate and energy and the social agenda, and with a global effort on sustainable development (European Commission, 2015). CE practices were first promoted by the Commission in a Commission Communication *"Towards a Circular Economy"* (European Commission, 2014).

This was followed by a Circular Economy Package in December 2015, containing various stimuli to drive Europe's transition to a more sustainable use of resources, and a comprehensive action plan (European

[1] Available at: https://publications.europa.eu/en/publication-detail/-/publication/5de64de7-f9d3-11e8-a96d-01aa75ed71a1/language-en/format-PDF.

Commission, 2015). The package established a long-term vision to increase recycling and reduce landfill.

Against this backdrop, we were appointed by the European Commission to conduct a behavioural study on consumers' engagement in the Circular Economy. The objective was to provide policy-relevant insights to assist with the implementation of the EU Circular Economy Action Plan.

The study sought to:
1) identify barriers and trade-offs faced by consumers when deciding whether to engage in the CE, in particular whether to purchase a more or a less durable good, whether to have a good repaired, or to discard it and buy a replacement;
2) establish the relative importance of economic, social and psychological factors that govern the extent to which consumers engage in the CE, especially purchasing durable products and seeking to repair products instead of disposing of them; and
3) propose policy tools to enable and encourage consumers to engage in CE practices related to durability and reparability.

The remainder of this paper outlines the methodology of the study, presents results and findings, and concludes with a summary of policy recommendations arising from the study. This paper is based on a report prepared by the authors and others of our consortium for the European Commission in 2018 (European Commission, 2018).

Methodology

General approach

The study was conducted in two phases. The first phase consisted of a systematic literature review, stakeholder consultations and consumer focus groups. The insights obtained from this phase fed into the second phase: a consumer survey and behavioural experiments. In both phases, the study focused mainly on CE attitudes towards five products: vacuum cleaners, televisions, dishwashers, smart phones and clothes.[2]
The literature review covered academic and grey literature from the EU Member States, Norway, Iceland, Switzerland, Japan, Canada and the USA. It focused on CE product characteristics, CE-related consumer behaviour and existing CE business models. The review was complemented with stakeholder interviews across the EU covering business and consumer associations, NGOs, public authorities and academia. Further insights into consumer decision-making were obtained from consumer focus groups with different consumer groups including potentially vulnerable consumers[3].

The insights from the first phase of the study fed into the development of a consumer survey and two behavioural experiments. The consumer survey was conducted in 12 countries[4]. In six[5] of these 12 countries, the respondents also completed experiment tasks embedded in the survey. The survey and experiments were conducted with respectively 12,064 and 6,042 respondents, who were representative of the general population for each country in terms of age, gender and geographic region (see Table 1).

This mixed methods approach with uniquely wide sample coverage makes this likely the largest and most representative study on consumer attitudes towards the Circular Economy to date.

The survey collected information on consumers' experiences with CE practices, such as repairing, renting, leasing and purchasing second-hand products, and their reasoning behind engaging in the Circular Economy (or not). Furthermore, general socio-demographic characteristics and self-declared attitudes towards the Circular Economy were included.

The behavioural experiment contained two tasks: a purchasing and a repair experiment. Respondents repeated each task three times for different products, encompassing vacuum cleaners, televisions, dishwashers, smart phones and clothes. Task order and treatment assignment were fully randomised and tasks

[2] The survey regarded attitudes towards clothes in general. The experiments focused on "coats".

[3] People who struggle, or are in arrears, with bills, and are unemployed, retired, long-term sick or disabled, or single parents.
[4] Austria, Czech Republic, France, Germany, Hungary, Ireland, Latvia, the Netherlands, Portugal, Romania, Spain and Sweden.
[5] Czech Republic, Germany, Ireland, Romania, Spain and Sweden.

were financially incentivised for enhanced realism and external validity.

The purchasing experiment

The first experimental task, the 'purchasing experiment', focused on consumer decision-making regarding durability and reparability of products when purchasing new products. In a simulated e-commerce environment, respondents were asked to purchase a product using a given budget. Choices were incentivised such that consumers had an interest in purchasing products that last a long time while also maximising their remaining budget (i.e. purchasing cheaper products). Respondents had perfect information on prices and their budget and were given some information about product durability depending on their assigned treatment (see below). Figure 1 below shows the baseline experimental environment.

The purchasing experiment tested different forms of durability and reparability information, and their effects on consumers' product choices. The following treatments were tested:

- no information on durability and/or reparability of products (baseline)
- 'manufacturer warranties' and 'expected lifetime' claims[6];
- durability commitments and reparability rankings [7] embedded via icons within established EU labels (i.e. the EU Energy or Ecolabels); and,
- behaviourally motivated claims to 'nudge' respondents to take note of relevant information.

For the latter treatment, the claims used were: *"Products that last longer may save you money over time"* and *"A majority of people choose products that last longer and are easier to repair"*.

The repair experiment

The second experimental task, the 'repair experiment', focused on respondents' behaviour in relation to products they owned but broke down. This experiment contained two stages. In the first stage, respondents were told that a product they owned broke down and were asked whether they wished to replace the product or have it repaired (see Figure 2).

If a respondent decided to replace a product, they were directed to a second stage. At this stage, they had to make a decision between buying a brand-new product or buying a, cheaper, second hand model (see Figure 3).

The repair experiment tested the following treatments:

- a real effort task to be completed after either choosing to repair or replace a product;
- framing of repair prices as VAT exempt or not[8]; and,
- varying repair characteristics, especially whether repair was carried out by an independent shop or the manufacturer; and whether the repair was done using original parts only (or not).

[6] These carried lifetime indications in years or months, but the precise meaning of these claims was not further explained or defined in the experiment.

[7] Durability on EU labels was defined as: "The period in which the manufacturer promises to replace or repair the product free of charge".
Reparability on EU labels was defined as: "Ease-of-repair rating based on availability of repair manuals, spare parts and repair services".

[8] Note that across the experimental treatments, prices were not varied. Only the framing of prices was changed.

	Male	Female	Age 18-24	Age 35-54	Age 55+	Total (N)
Austria	51.8%	48.2%	24.0%	38.1%	37.9%	1,005
Czech Republic	50.7%	49.3%	25.2%	36.4%	38.4%	1,004
France	52.6%	47.4%	26.7%	34.4%	38.9%	1,002
Germany	50.7%	49.3%	22.3%	37.3%	40.4%	1,009
Hungary	53.2%	46.8%	25.9%	37.4%	36.7%	1,003
Ireland	50.6%	49.4%	29.4%	40.7%	29.9%	1,003
Latvia	55.1%	44.9%%	27.6%	34.0%	38.4%	1,005
The Netherlands	51.0%	49.0%	25.7%	36.7%	37.6%	1,002
Portugal	53.1%	46.9%	25.7%	37.7%	36.6%	1,005
Romania	53.1%	46.9%	32.0%	42.1%	25.9%	1,005
Spain	51.9%	48.1%	25.3%	38.8%	35.9%	1,020
Sweden	50.9%	49.1%	23.5%	34.4%	42.1%	1,001
All	*52.1%*	*47.9%*	*26.1%*	*37.3%*	*36.6%*	*12,064*

Table 1. Summary statistics.

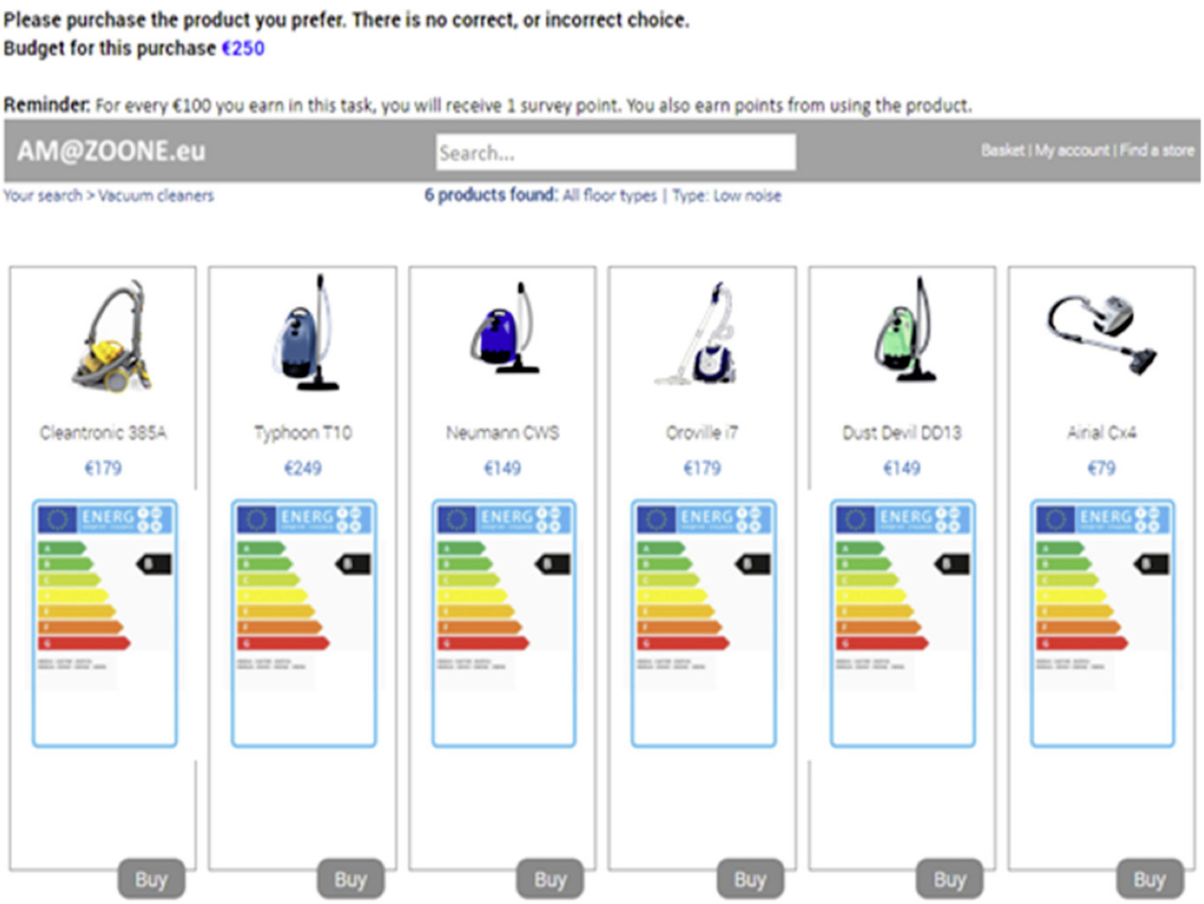

Figure 1. Environment of the baseline purchasing experiment.

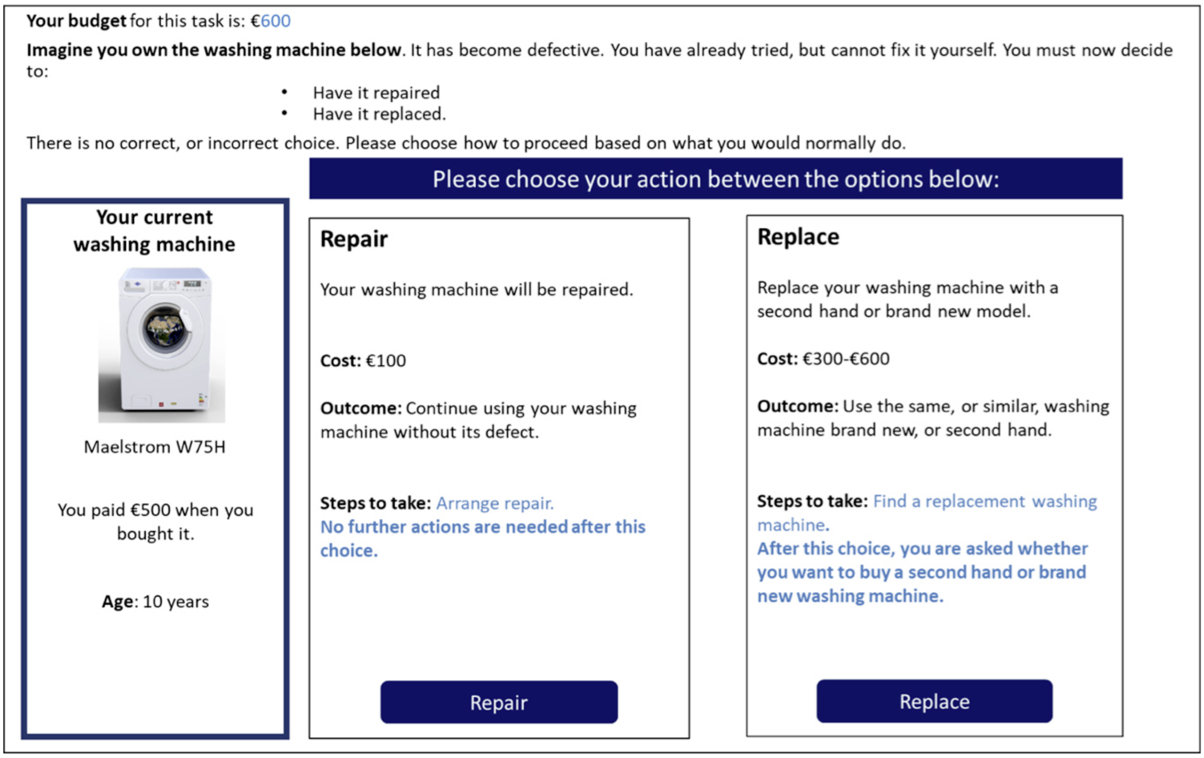

Figure 2. Environment of the repair experiment (stage 1).

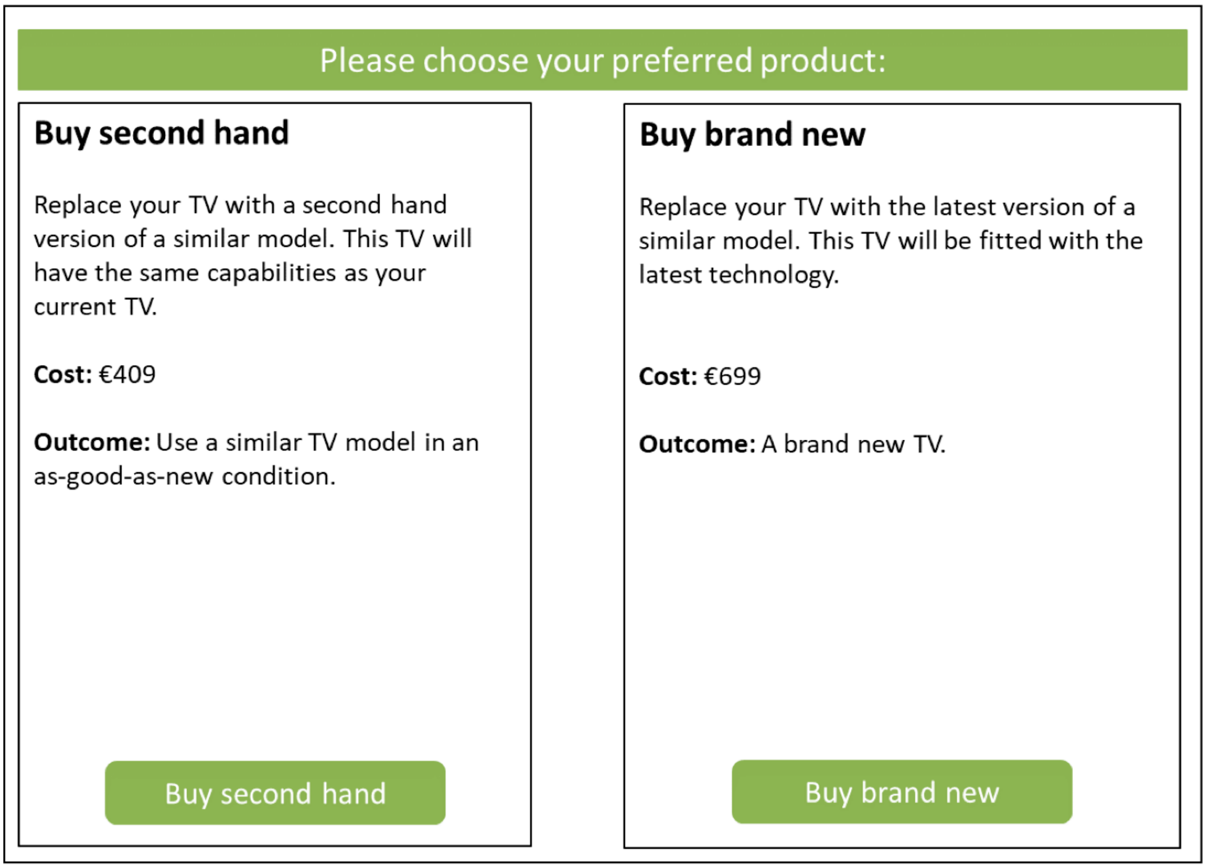

Figure 3. Environment of the repair experiment (stage 2).

Results

In brief, across the different strands of research the study did not find evidence of a 'throwaway economy'. Across the different product categories and countries, consumers commonly repair (or attempt to repair) their products. Similarly, product durability is important to consumers but information about the durability of products is often difficult to find. The study did, moreover, uncover that engagement with the Circular Economy can be increased by providing relevant information to consumers and by reducing barriers to repair products.

The impact of Circular Economy related product information on consumer decision-making

All strands of research found that consumers were generally willing to engage in CE practices, but actual engagement was low. In the survey, a substantial share indicated that they had not repaired products in the past (36%) and the vast majority (~90%) had no experience renting/leasing or buying second-hand. A reason for this low actual engagement in CE practices could be the lack of information regarding product durability and reparability.

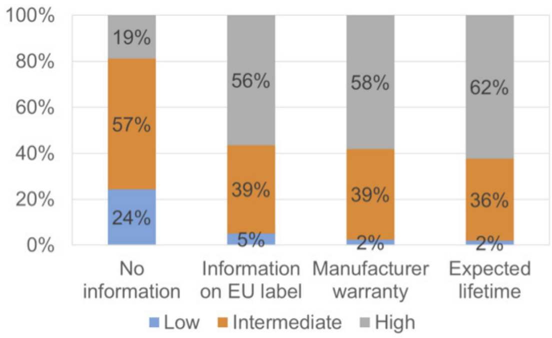

Figure 4. Share of respondents who selected products with low, intermediate and high levels of durability[9] by information treatment in the purchasing experiment.

In the behavioural experiment, the provision of such information was found to be highly effective. Figure 4 and Figure 5 show consumers' propensity to select products with low, intermediate and high levels of durability and reparability respectively under different information treatments. Compared to the baseline, when durability or reparability information was provided, consumers were almost three times as likely to choose products with the highest durability on offer, and more than twice as likely to choose products with the highest reparability ratings ($p < 0.01$ in a two sample z-test for proportions, comparing the proportions of respondents with a revealed preference for 'high' durability products, between the information treatments and the 'no information' baseline). This shift resulted from consumers turning away from low durability/reparability products in favour of those with better CE credentials.

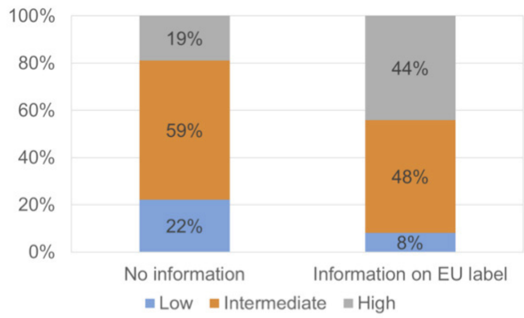

Figure 5. Share of respondents who selected products with low, intermediate and high levels of reparability[10] by information treatment in the purchasing experiment.

When durability and reparability information was shown together on the product label, individuals were most likely to purchase products which rated highly in both dimensions – durability and reparability. However, durability was clearly the more influential factor.

The experiment data also showed that consumers' have a significant willingness-to-pay (WTP) for better durability or reparability across product categories.[11] Depending on how information was presented, WTP for an additional year of durability ranged between €20-36 for vacuum cleaners and dishwashers,

[9] 'High' refers to consumers who mostly purchased highly durable products. 'Low' refers to consumers who mostly purchased relatively short-lived products. 'Intermediate' refers to consumers with a mixed consumption pattern across the three repetitions of the purchasing experiment.

[10] 'High' refers to consumers who mostly purchase products with relatively good reparability ratings. 'Low' refers to consumers who mostly purchase products with relatively poor reparability ratings. 'Intermediate' refers to consumers with a mixed consumption pattern.

[11] All WTP amounts presented here are significantly different from €0 at the 5% level (t-test for non-linear combinations).

€92-148 for TVs, €148-217 for smartphones[12], and €14-27 for coats. WTP for an improved reparability rating was around €29-54 for vacuum cleaners, €83-105 for dishwashers, €77-171 for TVs, €48-98 for smartphones and €10-30 for coats.

The claims aimed at nudging consumers towards more CE-friendly product choices by informing them of the benefits and social norms of buying durable or repairable products, increased the saliency of durability of products. This triggered a shift of consumer preferences away from short-lived products and towards more durable products. Fewer respondent showed a preference for short-lived products when shown a claim compared to the 'no claim' baseline ($p < 0.05$, two sample z-test for proportions). More respondents showed a preference for durable products when made aware of potential savings compared to the 'no claim' baseline ($p < 0.01$, two sample z-test for proportions). The claims did not affect preferences for reparability.

Barriers to repairing products

The survey found that repairing is popular but not ubiquitous. Some respondents, who chose not to repair, considered the act of repairing itself a barrier to repair. Some (5-10% depending on the product) felt they did not know how or where to repair products, and some respondents (8-14%) felt that repair would require too much effort.

In the behavioural experiment, 63-82% (depending on the product type; see Table 2) of respondents chose to repair rather than replace products. In line with the survey results, effort was confirmed as a barrier to repair. Decisions to repair became less frequent when additional effort was required to arrange the repair (see Figure 6). This was especially pronounced for consumers with a preference for new trends and technology.

However, imposing effort on replacing products did not affect the extent that respondents did so. These findings show that the effort barriers are not symmetric.

Product	Proportion choosing repair
Vacuum cleaner	67%
Dishwasher	82%
Television	67%
Smart phone	68%
Coat	63%

Table 2. Proportion of respondents choosing 'repair' in repair experiment by product.

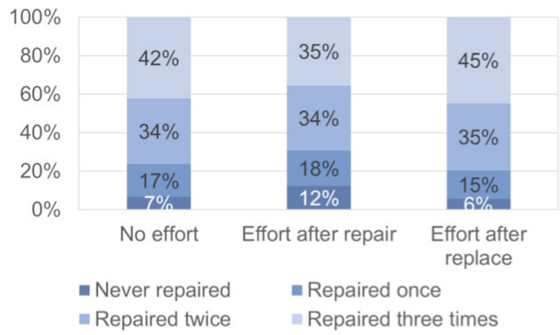

Figure 6. Proportion of respondents choosing 'repair' across all repetitions of the repair experiment by effort treatment[13].

Beyond convenience, framing repair prices as VAT exempt had only a limited effect on consumer decisions in the experiment. Moreover, consumers in the experiment were indifferent between using repair services offered by manufacturers or independent repair shops.

Conclusions and suggestions for future policy action

The study showed that consumers are willing to engage in CE activities, however actual engagement was found to be low. A possible explanation could be a lack of appropriate information about CE characteristics of products. Indeed, the study showed that appropriate information was often difficult to find.

The behavioural experiment clearly showed that providing information on product durability and reparability shifts purchasing decisions towards products with better CE credentials and away from products with poor CE

[12] Willingness-to-pay for additional durability of smartphones was measured in months and subsequently extrapolated to years. A linear relationship between time and willingness-to-pay was assumed (i.e. each extra month has the same value).

[13] The proportions of people who never or always (3 times) chose to repair are significantly different between the 'no effort' and 'effort after repair' treatments at the 1% level (two sample z-test for proportions). No significant results were observed for the 'effort after replace' treatment compared to the 'no effort' baseline.

credentials. Consumers also appear to be willing to pay significantly more for products which last longer and are easier to repair. Providing information on both durability and reparability proved to be most effective.

The study also showed an important barrier to repairing products. In the experiment, many respondents tried repairing before replacing products, but this decision was easily disrupted if arranging repair required effort.

Overall, the findings indicate that there is a large potential to close the gap between consumers' willingness to engage and their actual engagement.

The recommendations arising from the study to enhance consumer engagement with the Circular Economy are:

1) Boost engagement by strengthening pro-environmental attitudes and awareness;
2) Make repair easier;
3) Create financial incentives for reparability and durability;
4) Make durability and reparability information available at the point of sale; and,
5) Strengthen enforcement of legislation requiring the provision of accurate information to consumers.

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Diffusion of Access-based Product-service Systems: Adoption Barriers and How They Are Addressed in Practice

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Keywords: Business Model Innovation; Innovation Diffusion; Product-service System (PSS); Innovation Adoption; Sustainable Consumption.

Abstract: Access-based product-service systems are frequently suggested as innovative business models that could enable sustainable consumption, by allowing consumers to access products' functionalities without purchasing the products. This can reduce the number of idle products and incentivise the providing organisation to extend product lifetimes through maintenance and repair, as only 'functional' products generate revenue. However, consumer adoption of such offerings has been slow so far. In this study, we present barriers to consumer adoption of access-based product-service systems, ways in which they are addressed in practice, and examine them through an innovation management lens. We identify adoption barriers in literature and explore how they are addressed in practice through interviews with providers and users of access-based product-service systems for mobility such as bicycle sharing. We cluster the resulting data according to the innovation attributes of Rogers' (1995) innovation diffusion model. Many barriers relate to the benefits and hindrances perceived by consumers in access-based product-service systems compared to more traditional alternatives. We conclude that consumer adoption of access-based product-service systems is more complex than the diffusion of product innovations because access-based product-service systems are bundles of product, service, and infrastructure elements. Consumer adoption of these offerings can be enhanced by providing relevant benefits and by increasing the visibility of their consumption.

Introduction

During the last two decades, product-service systems have been proposed as circular and sustainable business models (Mont, 2002a; Stahel, 2010; Tukker, 2015, Vermunt et al., 2019). These business models combine product, service, and infrastructure elements to satisfy consumer needs (Mont, 2002a). For example, access-based product-service systems (AB-PSS) allow users to take advantage of products' functionalities for a fee, without owning them. This could disincentivise planned obsolescence and reduce idle products (Tukker, 2004; Bocken et al., 2016; Den Hollander, 2018), in other words, extend product lifetimes and increase product utilisation. The implementation of AB-PSS in organisations changes the way they conduct business and must be understood as business model innovation (Lewandowski, 2016; Bocken et al., 2016). Many innovative circular business models such as AB-PSS are emerging; however, some are more readily adopted by consumers than others (Edbring et al., 2016). These business models seem to evoke different or higher adoption barriers than innovative products that are directly *sold* to consumers (Mont, 2002b; Poppelaars et al., 2018; Cherry and Pidgeon, 2018).

Until today, AB-PSS are a niche mode of consumption. The aim of this study is to outline why consumers adopt or reject AB-PSS. We review adoption barriers in literature and extract ways to address them from widely adopted mobility AB-PSS through interviews. We then employ innovation diffusion theory to generate further insights into consumers adoption of AB-PSS that can guide designers to improve adoption.

Background

Consumer adoption of AB-PSS

In 2003 Mont and Plepys (2003) indicated that product-service systems have been successfully applied in the business-to-business context but have been less successful in consumer markets. In recent years, AB-PSS have been tested and implemented for many consumer products and mobility AB-PSS such as bicycle and car sharing schemes have been mushrooming in many cities. Studies have analysed the rental of high-quality baby products such as prams (ResCoM, 2019), and infant car seats (Catulli et al., 2017). These propositions are seen as financially beneficial by consumers due to the temporary need for the products. Recently, companies have increasingly started offering AB-PSS for products that consumers use for a longer time. For example, jeans and headphones can be accessed for several months or even years through AB-PSS (Weiguny, 2018; Gerrard Street, 2019). Consumers adopt the headphone AB-PSS because the included repair and replacement services eliminate the financial risk of headphones breaking after the warranty expires. The company MUD jeans is known for its jeans AB-PSS, yet only 25% of their jeans are used through their AB-PSS and 75% are still *bought* by consumers (Weiguny, 2018). This example shows that we need to better understand what consumers value in AB-PSS and why they adopt or reject them.

Can innovation diffusion models explain the adoption of AB-PSS?

Innovation diffusion models aim to explain the level of adoption of innovations in the market. Many innovations fail and never achieve wide market diffusion (Moore, 1991; Hall & Vredenburg, 2003; Feola & Nunes, 2014). Hall and Vredenburg (2003) argue that sustainable innovations face barriers additional to the general barriers that innovations entering the market encounter because of contradicting demands from a multitude of stakeholders. Rogers (1995) developed a seminal model to explain the diffusion of innovations in the 1960s. He reasoned that the diffusion of innovations is influenced by five innovation attributes, namely their *Relative advantage*, *Compatibility* with existing values, practices and habits, *Complexity*, *Trialability*, and *Observability*.

The early innovation management literature focused on product innovations but soon the models were also applied to services (Schrader, 1999; Mont & Plepys, 2003; Rexfelt & Hiort af Ornäs, 2009). Schrader (1999) applied Rogers' (1995) innovation attributes to outline consumers' perceived advantages and disadvantages of communal washing machines and car sharing. Rexfelt and Hiort af Ornäs (2009) also refer to Rogers' (1995) innovation attributes and conclude that many comments of the participants relate to them. Mont and Plepys (2003) briefly discuss the applicability of Rogers' (1995) framework to product-service systems. However, it appears that no study has systematically applied these attributes to analyse consumer adoption of AB-PSS. Therefore, it is still unclear how AB-PSS adoption differs from the diffusion of product innovations. In this paper, we aim to elucidate this by addressing the following research questions:

- What adoption barriers do AB-PSS face in the consumer market?
- What can we learn from innovation diffusion literature about AB-PSS adoption?
- How can AB-PSS achieve wider adoption in the consumer market?

Method

This study aims to provide insights to improve the consumer adoption of AB-PSS. We identify adoption barriers through a literature review as there is an extensive body of literature covering adoption hinderances. We complement them with insights into how these barriers are addressed in practice. We decided to study mobility AB-PSS that are widely adopted in practice, because previous literature has largely studied hypothetical AB-PSS (e.g. Rexfelt & Hiort af Ornäs, 2009; Catulli et al., 2013; Armstrong et al., 2015) or AB-PSS that are not (yet) widely adopted (e.g. Catulli et al., 2017a; Pedersen & Netter, 2015).

We revealed conducted barriers to consumer adoption of AB-PSS through a systematic literature review. We included the following keywords, their synonyms, and related concepts in the search query: product-service system, consumer, and adoption. The search query was run in SCOPUS on 26/06/2018 and resulted in 112 unique publications. We only included publications in our analysis that cover Business to Consumer AB-PSS involving tangible products. Further, we only used papers that address factors influencing the adoption or acceptance of AB-PSS. This led to an initial set of 18 publications. Publications were added using the snowballing technique (Wohlin, 2014) resulting in a total set of 34 publications. We identified nearly 200 AB-PSS adoption barriers. Multiple authors mentioned the same barriers and phrased them slightly differently. During two discussion and clustering sessions, three researchers condensed these to 17 barriers.

We employed eight semi-structured interviews with four mobility AB-PSS experts and four users to explore how adoption barriers are addressed in practice. Mobility AB-PSS can be considered successful in terms of consumer adoption; they are very common in the Netherlands and adopted by a significant share of consumers. These AB-PSS have the potential to reduce car use and encourage the use of public transport, thereby benefitting sustainability. The interviewed experts work in positions such as Marketeer and Innovation officer at mobility AB-PSS providers (e.g. bicycle or scooter sharing). The interviewed users have tried at least one mobility AB-PSS. The interviews were conducted in person, recorded, transcribed and coded, resulting in 20 aspects that influence mobility AB-PSS adoption in practice (Ryan & Bernard, 2003).

Finally, the identified AB-PSS adoption barriers and the insights from practice were clustered according to Rogers' (1995) innovation attributes. In this way, we determined whether they relate to innovation diffusion theory or are specific to AB-PSS. The five innovation attributes are *Relative advantage*, *Compatibility*, *Complexity*, *Trialability*, and *Observability*.

Findings

All identified barriers and ways in which they are addressed in practice could be clustered according to Rogers' (1995) innovation attributes. Most findings relate to the Relative advantage which comprises benefits that consumers perceive AB-PSS to have or lack compared to other modes of consumption, such as ownership.

Barriers to consumer adoption of AB-PSS based on literature

During the literature review AB-PSS adoption barriers were extracted. Not all papers used the term adoption barriers, some described acceptance barriers, consumer satisfaction, or factors for (non-) acceptance of AB-PSS. Contamination is a frequently mentioned barrier that results from consumers sequentially using products (e.g. Edbring et al., 2016; Baxter & Childs, 2017). Further, the lack of ownership in AB-PSS implies practical and psychological barriers, such as uncertainty regarding product availability, and a lack of intangible value (Armstrong et al., 2015; Tukker, 2015; Edbring et al., 2016; Tunn et al., 2019). We provide the clustered barriers in Table 1 with exemplary quotes from references. The table with all references is available upon request.

How are consumer adoption barriers addressed in practice?

The interviews revealed how successful mobility AB-PSS address adoption barriers and which barriers consumers perceive. Consumers value the convenience and flexibility that mobility AB-PSS provide. For example, convenience is frequently mentioned in literature; the interviews showed that some consumers find it convenient not to be responsible for repairs whereas others appreciated easy obtainment of the bicycles. An overview of the ways in which mobility AB-PSS address adoption barriers is provided in Table 2.

Adoption	Exemplary quotes from literature
Relative advantage	
Functional aspects	
Quality of product	"Consumers were concerned not only about whether the products were hygienic and in good condition, they also wanted them to be "shiny and new" " (Catulli, 2012, p. 787)
Specific product characteristics	"People have less positive attitudes towards using second-hand products made of soft materials like upholstery and fabrics than products made of hard materials, such as wood and metal." (Edbring et al., 2016, p. 13)
Additional effort required	"For many people, renting and especially sharing are associated with […] excessive costs of organising private life." (Mont, 2004, p. 149)
Intangible aspects:	
Lack of trust in others	"Lack of trust is often seen as a barrier for collaborative consumption" (Edbring et al., 2016, p. 12)
Desire to own	"Respondents saw the renting or leasing of such products associated with a social "stigma", a solution for poorer consumers." (Catulli, 2012, p. 787)
Lack of hedonic value	"We found that in contrast to the hedonic experiences with cars […], these experiences were not common in our data, as functionality is privileged in our context." (Bardhi & Eckhardt, 2012, p. 890)
Lack of intangible benefits	"So one can only substitute those goods with which consumers have a functional rather than an emotional relationship" (Schrader 1999, p. 113)
Financial aspects:	
Financial barriers, e.g. perception of high cost	"Products that are used over a long period of time are not seen as suitable for renting, since the cost of renting might be higher than purchasing new furniture." (Edbring et al., 2016, p. 13)
Perceived risks:	
Availability	"On the other hand, car pay-per-use adopters were inconvenienced due to product unavailability or the limited working area of car2go." (Poppelaars et al., 2018, p. 11)
Contamination and safety	"Access schemes and growing second-hand markets present consumers with objects with 'contamination' from previous use." (Baxter & Childs, 2017, pp. 391-392)
Having to treat the product carefully	"The majority of consumers feels a *greater need for carefully* handling the product in case of access as compared to ownership." (Baumeister & Wangenheim, 2014, p. 27)
Compatibility	
Lack of flexibility	"One has to make a deliberate decision to gain access to the use of a car, to plan car use and to make a reservation in advance." (Meijkamp, 1998, p. 241)
Change required	"Consumers also seem to more easily adopt a business model that does not require a dramatic change in their practices." (Antikainen et al. 2015, p. 13)
Complexity	
Complexity of offer	"It was not entirely transparent to participants what the real advantages would be, in light of their historical consumption habits." (Armstrong et al., 2015, p. 37)
Trialability	
Relevance of service	"One pattern across the different PSS was participants associating them with package-deals. In their view, added services were rarely relevant and often used to "scam" the customers for more money." (Rexfelt & Hiort af Ornäs, 2009, p. 679)
Reluctance to commit	"The participants did not want to commit to paying fixed costs" (Rexfelt & Hiort af Ornäs, 2009, p. 679)
Observability	
Lack of awareness or understanding	"Customers have a lack of knowledge and understanding about the S.PSS [sustainable product-service system] concept" (Vezzoli et al., 2015, p. 3)

Table 1. Barriers to consumer adoption of AB-PSS identified through a literature review.

Ways to address barriers	Exemplary quotes from the interviews
Relative advantage	
Product quality	U1: "For me, both [shared] bikes are pretty good and robust."
Effort savings	U2: "I just decided to go for it because it [the bicycle] looked as if it would always function smoothly, and if it would not, you could just give them a call or send them an app and then they simply fix it."
Time savings	U1: "The connection between the tram timetables or the public transport is poor, or it [cycling] is faster, because I do not have to wait for a bus to arrive."
Relieves burdens of ownership	U3: "Then I had to choose between a second-hand bike and a [leasing bike]. A big advantage of [the leasing bike company] is that you directly get a new bicycle if it gets stolen or if something breaks down they fix it quickly."
Financial benefits	E3: "The costs are 30 cent per minute, so it is very clear what you pay and there are no hidden costs."
Perceived control	U1: "Well, with a bus you never know whether it actually will arrive or maybe it has a delay. Thus, you have a bicycle *now* or very likely a bus, but not totally likely."
Temporary need	U3: "With [the leasing bike] I have the feeling that it can be a short-term solution for a month if you would want to change to another bicycle after that."
Provision of intangible benefits	U4: "Yeah, the [shared bike] looks silly. Yes, it really looks touristy."
Compatibility	
Flexibility	U1: "If you consider it from a relocating yourself perspective, at any moment you can say: „well, I am going to the other side of town" and the bicycle is within reach to do that now and you instantly go there."
Low level altering consumer's habits	U3: "I am used to cycling with gears, I personally consider that very pleasant."
Past experiences	U3: "I had thought about the possibility of it [the bicycle] getting stolen because of past experiences, but then I figured that a double lock would do the job."
Accessibility service providers	U1: "There is no service point or anything, and that I consider a disadvantage of [the bike sharing company], as you do not have a single point of contact anywhere."
Complexity	
Ease of use	U2: "I would like to add something that is really annoying me with [the leasing bike]. There are so many [similar looking leasing bikes] at Amsterdam Central Station that you really need to try three locks of three different bicycles before you find yours. Yeah, that is really crappy."
Archetypical product	E1: "The bicycle that we supply, the Dutch original bicycle, is a highly recognizable product for students. Everyone got that "granny" roadster bicycle model."
Trialability	
Context of use	U4: "I did not use the bicycle but public transport instead when it was raining cats and dogs."
Accessibility of products	U1: "Until a while ago, I used public transport and walked the final part, yet with the presence of so many types of bikeshares I am more aware of it that that possibility exists too and use it more often."
Low level of commitment	U1: "The "public transport" bicycle [available at several train stations] is a product for a day, for which you are only responsible that day."
Low price complexity	U3: "After twelve months this number became the monthly fee and after twenty-four months this number became the monthly fee, so it goes down the longer you have it [the lease product], while with [the leasing bike] the fee stays the same."
Observability	
Recognisable design	U3: "[The leasing bikes] I see all the time, and they stand out very much, which is very clever. Yeah, I see them every day when I arrive at my apartment."
Word of mouth	E4: "70%-90% had heard of [the leasing bike company] by word of mouth, either from someone working [there] or from a friend or family member with [leasing bike] experience, and that made them look into it."

Table 2. Summary of how adoption barriers are perceived and addressed in mobility AB-PSS with quotes from semi-structured interviews. (Translated from Dutch to English).

Discussion and Conclusions

This paper provides an up-to-date, structured overview of AB-PSS adoption barriers and how they are addressed in practice, based on a synthesis of 34 articles and insights from eight interviews. We clustered these findings according to Rogers' (1995) innovation attributes. The results show that many of the identified barriers are addressed in mobility AB-PSS. For example, the barrier Additional effort required has been addressed in one mobility AB-PSS by providing convenient maintenance and repair services thereby relieving burdens of ownership. This study facilitates the understanding of the current state of AB-PSS adoption in the consumer market and how they could achieve wider diffusion.

Furthermore, we found that consumers compare AB-PSS with standard consumption practices. Our findings correspond with Schrader's (1999) observation that consumers assess the relative advantage of AB-PSS and compare it with the available alternatives (e.g., purchasing the product). The relative advantage of AB-PSS consists of functional, intangible and financial aspects, and perceived risks. For example, consumers consider the quality of the product, how easy it is to obtain access, whether they perceive the AB-PSS as financially advantageous, and whether it can provide the desired hedonic and emotional value. It appears that the success of the analysed mobility AB-PSS is largely based on the convenience they provide.

AB-PSS adoption is influenced by the same innovation attributes as the diffusion of product innovations. The large number of identified adoption barriers and ways to address them mirrors the complexity of AB-PSS (e.g. Mont, 2002b; Rexfelt & Hiort af Ornäs, 2009; Armstrong et al., 2015). The bundling of product, service, and infrastructure elements (Mont, 2002a) makes them inherently complex. Any one of these elements can cause a consumer to reject an AB-PSS. Though most of the identified AB-PSS adoption barriers and ways to address them relate to the *Relative advantage*, some relate to the other innovation attributes. *Compatibility* describes how much or little consumers need to change in order to use the AB-PSS and *Complexity* how easy it is to use and understand. *Trialability* and *Observability* both comprise strategies that make AB-PSS consumption visible and reduce the perceived risks of adopting AB-PSS. To achieve wider adoption, AB-PSS need to provide a relative advantage to consumers, be visible in the consumptionscape, and allow for trial periods to build knowledge and trust. They should provide relevant benefits that make consumers perceive them as preferable over alternative offerings.

This study builds on previous research (e.g. Schrader 1999, Mont, 2002b; Poppelaars et al., 2018) and contributes to the understanding of AB-PSS adoption in the consumer market. We show that while AB-PSS adoption can be described with the same attributes as the diffusion of product innovations, it is inherently more complex. The findings can help AB-PSS designers to understand the complexity of AB-PSS implementation in the consumer market and the benefits that consumers value. Adoption barriers are likely to vary depending on the product placed in an AB-PSS (Schrader, 1999; Catulli, 2012; Edbring et al., 2016), we suggest to use our findings as an inspiration for AB-PSS development while designing them for the specific context, and with sustainability in mind (Kjaer et al., 2019). We concur with (Rexfelt and Hiort Af Ornäs, 2009, p. 678) who stated "As consumer acceptance of PSS is complex and case specific, there is a need for methods and tools which are easy to adapt to each individual project of designing PSS" and see a need for further research to translate these findings into actionable AB-PSS design guidelines and to test them in practice.

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Living Labs to Develop Reuse and Repair Workshops in Territories

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Keywords: Living Lab; Repair; Reuse; Repair Workshop.

Abstract: Current industrial practices, supported by an unsustainable economic growth and technological innovations, are leading to a "throwaway" era leading to inefficient use of natural resources and social inequity. The reuse and repair of products are priority strategies for a radical reduction of the environmental and social impact of our production and consumption. It consequently questions the paradigm of traditional economic growth. The transition to repair and re-use activities requires going beyond the technical aspect of waste management to embrace a citizen and territorial logic. In this paper, we submit the hypothesis that through "living labs", that is to say, citizen, collaborative and experimental workshops, it is possible to structure communities of practice and to improve the recognition of repair and reuse activities both for citizens, political and economic actors. On the one hand, the aim is to understand how to stimulate the collaboration of heterogeneous actors through experiments in the context of reuse / repair and upcycling oriented living labs. On the other hand, the objective is to collectively participate in the emergence of territorial repair networks, with the objectives of reducing environmental impacts while creating social links and questioning development models. For that, we expose the protocol developed to structure the living labs as well as the some qualitative results.

Introduction

Current industrial practices, supported by an unsustainable economic growth and technological innovation, are leading to a "throwaway" era leading to inefficient use of natural resources and social inequity. Even if European directive promotes a waste reduction approach, recycling is still the most developed solution. Such short-term and technical solution are counterproductive and create path dependencies, closing opportunities for real sustainable alternatives waste management and participating in a constant growth of waste production.

More particularly, current design approaches in terms of eco-design or circular economy are based on disassembly, upgradability, modularity, and are largely focused on large-scale business models, and on the search for technical solutions (Bridgens et al., 2018). Therefore, these alternative development models, supposedly less unsustainable, target the same objective of an economic “green” growth.

In parallel, new organizations from civil society have emerged in territories. These grassroots and social initiatives propose real alternatives both in social and environmental issues. Nevertheless, public actors and traditional business stakeholders still poorly consider them. Called, often indifferently, repair workshop, “ressourcerie”, "repair café", they are generally the result of collective movements, often very locally situated, with a social or environmental objective, and offer to develop second-life markets with reused, repaired or upcycled products. Therefore, these activities challenge our patterns of consumption and production, and consequently the current regime[1]. They are seen as a transitional stage towards a truly circular economy (Terzioglu, 2017). However, these niches are struggling to overcome an embryonic and economic unsustainable state.

This research is part of the RECYLUSE project in which a multidisciplinary team analyzes the technical, political, cultural, and societal barriers from the regime to the emergence, diffusion and viability of repair niches. The research presented in this communication

[1] (DeHaan, 2010) “If the regime embodies the powerful, yet conservative mainstream, then a niche is its innovative, avant-garde but not so powerful counterpart.”

aims at removing some of these barriers observed on the ground and literature.

In this paper, we submit the hypothesis that through "living labs", that is to say, citizen, collaborative and experimental workshops, it is possible to structure communities of practice and to improve the recognition of repair and reuse activities both for citizens, political and economic actors. This paper will expose how such living labs can help to structure a repair and reuse culture.

State of the art

The scientific literature largely mentions techniques to favor disassembly, upgradability, modularity (Pialot et al, 2012, Cooper, 2013). Repair is often mentioned as a strategy of the circular economy as a means of prolonging the life of products and of working in a closed loop (Terzioglu, 2017). These expert approaches integrate constraints from other stakeholders (for example the development of dismantling technics for recycling operators) and are focused in a closed design process, as they generally do not involve other relevant stakeholders (users, citizens and communities). In contrast, a phenomenon emerging in recent years, the living labs, allows the exchange of know-how between stakeholders and seem to be a modality to change representations and unlock some resistance and create space for discussion. Living labs are experimental environments in which end users are considered as co-designers (Ballon, 2005). They benefits from a European network (the ENoLL network), and are a user-centered research methodology for detecting, prototyping, validating and perfecting complex solutions in multiple and changing contexts of life real. A living lab is a process of thinking centered on uses, with a strong iterative design process. This type of approach encourages a more global reflection, extracting from the purely technological framework of product design, to a system level. It is a collaborative design space that allows prototyping new systems where all actors are considered experts. They allow the co-construction of innovative and local specific solutions and must encourage a better social acceptability (Gobert and Brullot, 2016) and economic territorial integration.
However, the cases of applications are rare on the theme of end-of-life products. We can note the works of Bridgens et al. (2018) but who are more interested in exploring the establishment of repair and upcycling space than in the co-construction of solutions. A second research, by Terzioglu (2017), focuses on developing and observing repair workshops, without being qualified by the author as living labs.

The main similar work comes from the recent research of Hirscher and Mazé (2018). They proposed to develop a framework to analyse the results from a ‘co-sewing café”. They adapted an analytic framework based on three main component: the stuff (i.e. the material used during the process), the skills used and developed and the images (i.e. the meaning of the workshop).They specifically underlined that participatory design process, such as living labs, questions the role of designer and users, as users are directly involved in the design process. Moreover, they underlined that workshops (as co-sewing workshops) allows participants (including professional designers or dressmakers) to share clothes-making techniques, to teach and learn these techniques. Participants can both use classical everyday tools (as a textile chisel) and more specific ones (such as a sewing machine).

Development of a repair-oriented living lab protocol

This paper aims to develop new understanding on how to implement a living lab focused on repair and reuse activities, towards both citizens, public actors and companies. As previously said, developing reuse and repair activities in territories requires a systemic thinking, covering not only product and process innovations but also dealing with user practices, markets, policies, regulations, cultures, or infrastructures (Gaziulusoy and Brezet, 2015).
Thus, this protocol has a threefold objective:

(1) To understand how the methodology of living labs promotes the culture of repair and reuse among the participants,
(2) To understand how the living lab fosters communication between the various actors involved in reuse and repair (designers, citizens, companies, public authorities, recyclerie user and employees),
(3) To analyse the relevance of this methodology to question the different systemic levels: product/workshop/ territory.

This section exposes the multi-level perspective of the protocol developed for the reuse and repair oriented living lab and then focuses on the product level approach.

The multi-level approach for reuse and repair living lab design

The protocol is based on a systemic approach to develop a reflection on the three levels of a territorial reuse and repair network.

(1) At the 'practical / product' level, the objective is both to support participants on learning on reuse/repair (i.e. basic knowledge on reuse and repair) and on practically experimenting how to implement reuse and repair everyday products;
(2) At the repair workshop level, the objective of this protocol is to collectively design a repair workshop regarding its missions and objectives, organisation (internal and external logistic, skills and knowledge acquisition and transmission), business models;
(3) At the 'territorial' level, the aim is to model and discuss the tangible and intangible metabolism of territorial repair networks, to identify new synergies and to strengthen or diversify collaborations.

At this state of the research, the protocol to support the territorial level is under construction and only one living lab at workshop level was tested. This communication focuses on the product level living labs protocol and the observation of four workshops.

Product-level living lab

The different steps of the living labs, the different objectives as well as the deliverables are described in table 1. The protocol draws two main parts: the individual diagnostic of discarded/failed products and secondly, the designing and prototyping of solutions to extend these discarded products' lifetime. Two templates to support the participant's work were designed but are not detailed here. Between these two parts, facilitators present the stakes of the sector and some examples of existing initiatives to counter negative effects of these activities.

In addition to the deliverables completed by the participants, facilitators captured specific events (ideas generation, prototype development, presentation of results, etc.) on video and researchers in design and social sciences made direct observations. Few days

First part : Individual diagnostic of the products
Objectives
- Identification of the product and of its characteristic (nature, perceived quality, risks, current state of the product) - Description of the problem: broken, damaged or failed part of the product - Description of the domestic practice of the participants facing this problem.
Deliverable : Discovery template
- Description of the product - Description of the failed part of the product - Description of first solution ideas
Break : information – inspiration
- Social, environmental and economic challenges in the sector - Presentation of inspiring solutions from invited professionals
Second part : Design and prototype
Objectives
- Group must collectively find solutions: - Describe the problems identified during the product analysis step - Describe / Draw the different solutions - Realize a prototype
Deliverable : Concept template
- Description of the concept (words and schemas) - Description of the process (steps, tools, material) - Listing of difficulties and constraints (skills, tools, …)
Collective restitution and discussions

Table 1. Protocol for product level living labs.

after the living labs, participants received an online survey to have feedbacks on the workshop.

Implementation of product-level living labs

To remain accessible, living labs have been adapted to all kind of participants (industrial, repair and public actors, and citizens), whether they are experts or not of the sector, sensitized or not. Three 'co-sewing café' were organized with the support of two members of a sewer collective (Orratzetik Hari), in three cities of the Agglomeration Pays Basque (Southwest of France) and gathered 46 participants. A living lab on furniture was realized with the designer and carpenter of Api'R bois, a furniture upcycling workshop. Table 2 summarizes some characteristics of these living labs.

Place	Characteristics	Nb.
Bayonne	Main city of the Pays Basque conurbation	14
Cambo	Peripheral city of Bayonne	19
Mauléon	City located in the interior of the Pays Basque conurbation	13
Saint-Pierre-d'Albigny	Rural city in the Coeur de Savoie conurbation	15

Table 2. Participants in the living lab.

The analysis of the deliverables is not yet performed but some results of the surveys are presented below.

Analysis of the post workshop surveys

Twenty-three persons (over forty-six) respond for the textile living labs and five (over fifteen) for the furniture.

First questions are a qualitative self-evaluation of the participants' level regarding sewing or carpentering, product design and their general knowledge about repair workshops. A Lickert scale enables the self-evaluation: null, fair, average, good, excellent. Only one participant considers himself as a true beginner in sewing or carpentering. Their knowledge on repair workshops is disparate but there is not 'expert' level participants. An outstanding result is that participant evaluates their selves with a fair or null level in product design (56-60%). 60% have never been in a repair workshop, 28% have already experienced self-repair or repair in a repair workshop for the sewing living labs, no one for the furniture. Workshop participants have basic or advanced knowledge or practical skills on the topic of the workshop.

The first phase of the living lab is considered quite useful (textile: 88%; furniture: 75%). The objectives, instructions and the 'discovery sheet' were clear and the products presented were similar to what participants have at home.

During the second phase, and even if their initial design level was quite poor, participants did not face strong issues to design their solutions. Regarding the prototyping of textile solutions, participants consider that they did not have great difficulties (82%). The initial sewing level has an impact on the ease of designing and prototyping products (same repartition in self-evaluation of sewing level and impact of this on the design/prototyping).

Advices and supports from facilitators and inspiration boards were considered useful and sufficient by the participants. However, we observed that co-learning within teams during the living labs and teamwork appears as a strong strength for the success of these living labs.

82% of the participants for the textile living lab and 40% for the furniture living lab consider that living labs provides new knowledge on environmental and social issues in the sector considered. 70% (textile) and 100% (furniture) consider that they do not acquire new knowledge on sewing or woodworking. Textile living labs had positive influence on the perception of repair workshops (77%), repair and reuse activity (82%). The workshops also encouraged participants to be engaged in repair and reuse activities (88%). Furniture living lab had mitigated impacts on the perception of repair, reuse activities or in the perception of repair workshops. Nevertheless, it encourages participants engaging in these activities (80%).

Every participant to the textile living labs consider that they respond to their expectations but this is equally distributed for the furniture living lab. Twenty over twenty-one respondents have a fun and good time and would recommend these living labs.

Discussion and conclusion

In this paper, we have presented a multilevel protocol for living labs with the objective to promote repair and reuse culture and to foster the communication between stakeholders of the reuse and repair activities. First, participants acquired new knowledge on the sector and they highlighted importance of group work and peer-to-peer knowledge transmission from group members or facilitators. They also largely want to be engaged in repair-reuse community of practice. However, we have also to consider the lack of representativeness of the "concerned" actors within the participants. For the industrial sector, even if some professional actors (e.g. textile designers, wood sellers) shows some interests about the topic, no one participate to the living labs. Public actors participate in Coeur de Savoie as they are part of a repair workshop project, but there was no representative of the public actors in the Pays Basque. Participants were mainly non-professional practitioners or students in textile for the textile living labs. It questions the representation of these actors embedded in the regime and it was an

interesting illustration of the gap between stakeholder of the mainstream economy and social economy.
A strong result of the living labs was that there was only little technical learning. Indeed, even if everyone participate to the design of the solution, participants who do not have an expertise only learnt a little from their peers and expert facilitators. Moreover, we saw than some of them missed the basic vocabulary to describe physical or conceptual notions. Moreover, even if there is a demand for physical supports or models instead of pictures (it was the case for the first part of the furniture living lab), no one use model material during the furniture living lab (cardboard, glue, painting etc.).
Another objective was to analyse the relevance of this methodology to question the different systemic levels: product / workshop / territory. It appears difficult for the participants to project on other system levels and to imagine the consequences of their current decisions on another system. Consequently, there is a need to stimulate the consideration of the interfaces between levels to integrate external disturbances to the system under consideration.

One next step of this research will consist on analyzing the different prototypes developed by the groups with professional sewers to understand the feasibility to develop these concepts. Moreover, another step will be to analyze the living labs develop for other levels (repair workshop and territory levels) in order to better understand how each level (product, repair workshop, territory) can promote the culture of repair and reuse among the participants.

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PLATE
Product Lifetimes And The Environment

Developing Hybrid Business Models in the Reuse and Repair Sector: a Case Study

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Keywords: Ecosystem; Governance; Economic Model; Reuse.

Abstract: The on-going race towards innovation and growth, continuously sustained by new products, has shaped a “throwaway era” overwhelmed by waste. To overcome this logic, various repair workshops are developed in order to support citizens in giving a second life to products through a reuse or repair strategy. These repair workshops are generally small structures, with few employees and do not reach a critical size to develop a reuse and repair culture in territories. This paper relies on a practical case study, the development of the IKOS reuse, repair and recycling ecosystem in Bordeaux. IKOS is a collective composed of five partners with different economic and legal models (social companies, NGOs, etc.) on different core sectors (textile, furniture, books, building). Through this case study, the paper raises the question of understanding how to support the development of an ecosystem with various organizations and consequently the development of a new economic, social, and governance models, which respond to economic imperatives, and social or environmental demands. This paper presents the first steps of this research action project.

Introduction

In a context of circular economy, reuse and repair issues are fundamental levers for the European Parliament to reinforce social economy sector and develop a sustainability policy. Similarly, many actions are now implemented to promote the extension of the life of products: development of reuse and repair networks (RESTART in England, RREUSE in Belgium, “le réseau des ressourceries” in France), development of the French NGO HOP to fight against planned obsolescence or development of a reparability index, etc.

In line with these actions, repair and reuse workshops are amongst the main opportunities for promoting circular economy and local resources. They offer the possibility to value territorial resources, while creating local jobs. In other words, they can be considered as promising models in order to make the circular economy attractive and promote local resources (resources, skills, means of production, training).

Nevertheless, there are still many obstacles to effectively promote this sector, above all in the early stage of the project development: development of specific supports by public actors, waste policies, land use in city centers, funding, lack of knowledge and negative perception by consumers. Moreover, their economic models are often economically unsustainable and consequently, a diversification of the stakeholders’ network, of their objectives, and an increased pooling of resources is necessary.

The purpose of this paper is to describe the process to support the early stage development of a reuse and repair ecosystem – IKOS - taking into account the external events (political events, modification of the aim of the project, etc.). First, we propose a short state of the art about reuse and repair ecosystems, sustainable business models and repair issues. Secondly, the context of development of the IKOS ecosystem is described. The third section focuses on the design process developed to support the IKOS project. Finally, some feedbacks and perspective are drawn.

Literature background

The development of a reuse and repair ecosystem requires a systems-level change and a strong collaborative value creation. Fontell and Heikkilä (2017) define ecosystem according to Moore’s definition (1993) as “an economic community supported by a foundation of interacting organizations and individuals […]. The economic community produces goods and services of value to customers, who are themselves members of the ecosystem. The member organisms also include suppliers, lead producers, competitors, and other stakeholders. Over time, they coevolve their capabilities and roles, and tend to align themselves with the directions set by one or more central companies." Therefore, in line with Gorissen et al. (2016), the development of such an ecosystem requires to mobilize networks and to explore "future roles, collaborations and new organizational arrangements" (Gorissen et al., 2016).

In terms of the organizational model development of re-use / repair ecosystems, a large and recent literature has shown how the introduction of new economic and social models can accelerate the transition of organizations (Boons and Luedeke-Freund, 2013, Bocken et al, 2014). Many sustainable economic models have been identified (Bocken et al., 2014), some incorporating the principle of reuse and repair. Urbinati et al. (2017) classify circular business models, underlying that these business models require a high cooperation with the different stakeholders of the supply chain, in particular between companies and customers themselves.as well as a new way to perceive the buying process.
Moreover, the implementation of an ecosystem (of reuse and reuse) can generate specific practices and skills (Le Boterf, 2005) that have been previously ignored. Thus, such ecosystem can both stimulate organizational innovation (in terms of the development of a pooling of resources, of a change of employees' workstations ...), technical and social innovation for designers (exchanges on reuse practices) and institutional innovation (potential modification of local waste management policies). The construction of such business models and governance is therefore complex in a "volatile and uncertain context" (Gorissen et al., 2016) and it raises the question of how territorial stakeholders networks can benefit from this ecosystem.

Some methodological tools to support the implementation of new economic and social models (Joyce and Pacquin, 2016), or to support the integration of stakeholders' networks in the innovation phase (Tyl et al., 2015) have been developed. However, in line with Gorissen et al. (2016), our research reveals that organizations have still difficulties to implement these models, especially when it comes to hybridizing them to create a collaborative model anchored in the territory. Consequently, few cases illustrate how to implement collaborative and hybridized business models at a systemic level, above all in repair and reuse activities.

Through the case study of the development of a reuse and repair ecosystem (IKOS), this paper will present some issues to support such development.

Description of the reuse and repair ecosystem IKOS

This section aims at describing the IKOS project as well as its context with some geographical and political issues.

IKOS description

Five project holders develop the IKOS ecosystem project: Le Relais Gironde (textile sorting), L'atelier d'éco Solidaire (a creative repair workshop), R3 (platform of sorting), les Compagnons Batisseurs Nouvelle-Aquitaine (a structure dedicated to the building improvement and a mutual aid network) and Le livre vert (company dedicated to the reuse of books). The ambition of the IKOS ecosystem project is to bring together the different activities of its members within the same place: production (sorting and processing center), sales (re-use and repair of products), pedagogical (behavior change) and to develop new activities such as the development of a research activity dedicated to repair and reuse.

Context of development of the IKOS ecosystem

The city of Bordeaux is the ninth largest city in France with 249,712 inhabitants, but its agglomeration is ranked seventh with 904,359 inhabitants in 2015. Bordeaux benefits from a strong power of attractiveness and is at the top of the list of cities in the world to visit in 2017 according to the ranking of the guide editor Lonely Planet.

The IKOS project was first integrated into the A.I.R.E. operation which aimed to develop 10 sites of the Bordeaux metropolis. The site chosen to take IKOS' land requirement into account was finally recalibrated due to a

serious problem of soil pollution, thus making the land non-compliant with the intended use.
Therefore, the services of Bordeaux metropolis proposed a plan of withdrawal by reassigning the project on the metropolitan urbanization operation of the district of Jallère, a site of 95 hectares in the north of the ring road composed today by (1) half of private land tenure hosting more than 3,800 tertiary jobs (large headquarters in the areas of public administration, health, social action, finance, insurance, real estate (2) half of land owned by Bordeaux Métropole. The entire site, while maintaining a strong economic orientation, is destined to become a mixed neighborhood whose environmental wealth of the sector (Jalles Park in the North, Lake Bordeaux upgraded, 13 hectares of wetlands on site) will be preserved and strengthened.

The problem of this site is that it concerns the last wetland of Bordeaux. A symbolic and political outcry was therefore organized against this project and materialized through the creation of an alternative project led by the Ecologist politics group.
Bordeaux Métropole's online public consultation and the scope of the Ecologist alternative project have pushed for the project to be modified. The new orientation goes towards a project that should be exemplary in terms of eco-responsibility. It also have to be considered as a demonstrator of the best practice that a public authority can do in a responsible urban planning project reconciling the ecological with the social and the economic.
Thus, the territorial and political context around IKOS leads us to identify two points that make the project sensitive: (1) The status of IKOS in the project changes and gives much more visibility and highlighting to the collective who becomes the central actor of the project, guarantor of the eco-responsibility approach of the overall project. (2) The political context is that this urban planning project will be the first project of the new mayor in a territory otherwise accustomed to be administered by a national-sized city councilor.

The early stage of the IKOS' development process

The analysis of IKOS was performed through a participatory research action, as the two authors are deeply involved in the development process. The process was designed to support a collaborative process between project's holders to answer to three main questions: (1) What are the new activities/synergies that can be created through the development of IKOS? (2) What is the IKOS's stakeholder network, to favor a strong territorial anchoring of the ecosystem?, and (3) What is the economic and social business model of IKOS, with a specific focus on the governance of the project?
The front end of this collaborative process can be split into three main stages (see table 1). Each step corresponded to a specific external event, leading to new needs from the project holders and consequently the introduction of some design tools to help the team to answer to these needs. It consisted in five sessions of 2h30 with the different project holders (i.e. around 5/6 people).

In the first phase the process answers to the initial need of the project holders, i.e to specify the main activities and to link them to the different external stakeholders. To do so, a discovery matrix was introduced. Developed by Abraham Mole, it helps to stimulate the design team by developing relationships between two sets of problem variables. In this specific case, the first set describes the activities of the ecosystem (collect, valorization, sensitization, learning, research) and the second set describes the different stakeholders identified for the IKOS ecosystem (visitors, students, NGO, public actors, environments society, employees, etc).

In a second stage, the project holders were informed that the IKOS project could be located in the heart of a future district (La Jallère). Therefore, it was imposed to open the system to new external stakeholders (such as inhabitants, neighbor companies, etc.) and to identify the added value of this project for the community. To do so, we introduced the Value Mapping Tool, developed by Bocken et al. (2013). This tool proposes to consider and identify the different forms of value for a high variety of stakeholders (value captured; value missed, destroyed or wasted; and value opportunity) (Bocken et al., 2013).

In a third stage, external organizations were invited to candidate to integrate the project as projects holder of the IKOS project.
Due to divergence between initial project holders, it was proposed to develop a set of common criteria to be fulfilled by candidates.

To do so, the impact canvas tool developed by Saari et al. (2017) was used to identify such criteria. This tool is an early-phase tool which aims to support the involvement and the collaboration between many stakeholders through various issues: the vision of the system, the customers, the solution proposed by the project, the competition (alternative solutions), the initial resources, the involvement of key stakeholders and the team.

The following table summarizes the first three steps of the design process, according to the external events, the resulting need and the tool used to answer to the need.

Event	Needs	Tools
Initial demand of project holders	Support the development of IKOS	Discover matrix to identify the different activities proposed by the project holders according to the main stakeholders
Identification of a new location for the ecosystem IKOS, in the heart of a a new district	Need to open the system to new external stakeholders (such as inhabitants, companies, etc.)	Value Mapping tool to identify the potential created value and destroyed value by IKOS for all the stakeholders
Proposal to integrate new project holder in the IKOS project	Need to develop criteria to select relevant project holders who fit with IKOS's value	Impact canvas tool to identify common value shared by the initial project holders

Table 1. Overview of the first stages in the development of the IKOS ecosystem.

Feedbacks: a dialogical approach

There are many factors why the development of a business ecosystem (specifically in the reuse/repair sector) may success or fail. We propose to classify some feedbacks of our research-action project following a dialogical approach, i.e. a set of antagonistic but complementary issues (Morin, 2007).

The first strong issue is the difficulty to develop a collaborative project and to go beyond individual organizations. Each project holders has their own business models or activities, with different statutes (form NGO to companies), and presents difficulties to identify which activities can be mutualized, shared, commonly developed and until which point each project holders can be "dissolved" in the IKOS project. Some explanation can be drawn. Firstly, some project holders are part of a national network and therefore there is a contradiction between a local project and a national perspective. Secondly, this IKOS project was developed with a time pressure, because of the need of some project holders to quickly enlarge their area of production. Therefore, they did not take time to identify common values and a common view of the project.
The second issue is the position of each project holders in the reuse/repair value chain. Some project holders are only business to business oriented, without any kind or interaction with customers and citizens, where other are only customer-oriented. This antagonism raises the question of a common understanding of the value of the IKOS ecosystem and of the interest of some project holders to be part of such an ecosystem. The hybridization of the different business model is consequently more complex and uncertain.
To finish, a last issue, well known in the repair sector, is the difficulty to mix public actors point of views with private point of views. This project is strongly dependent of local policies, in particular concerning the access to land. Policies can bring new constraints, in potential opposition to the project holder's view. In the project IKOS, local public actors want to create a new district in the city with IKOS in its heart. Consequently, IKOS becomes a real living area and new stakeholders must be integrated (citizens, neighbors, etc.).

Conclusion

This paper is an early stage research and exposes some feedbacks identified during the first step of the development process. It must be considered as a description of a case study – IKOS – within a research action project, and as the identification of challenges to overcome in the future.

This paper is the initial step of a future 2 years research project, TERROIR, founded by the French environmental agency (ADEME), which will question the development and the modification of local stakeholders' network, and the territorial anchoring of the implementation of a reuse/repair ecosystem (IKOS) in a territory. In parallel, this project will propose an operational design process to support the development of such an ecosystem.
To do so, three scale of analysis will be mobilized to understand the development and the deployment of this ecosystem: (1) the project holders scale, (2) the future district scale and (3) the metropolis and its stakeholder network scale.

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Building a Sustainable Wardrobe: Quality over Quantity? – Survey of Students Wardrobes and Consumption Habits

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Keywords: Wardrobe; Wardrobe Building; Clothing Quantity; Consumption Habits; Sustainable Clothing Consumption.

Abstract: The aim of this study was to understand the kinds of thoughts and possible conflicts students experienced regarding their clothing purchases and how their consumption habits reflected on clothing quantity data. The objectives were to increase knowledge about the complexity of clothing consumption and develop new solutions for consumers' wardrobe building challenges. In this study "wardrobe" was examined as a vast entity, including daily clothing usage and consumption practices and aspects of self-expression. Sustainable clothing consumption and its challenges were also examined in the wardrobe context. Research material was collected by Räisänen between 2010 and 2016. Respondents (N= 395) were students at the University of Helsinki and the Open University of Helsinki who participated in a course *Textiles, consumption and sustainability* (2–3 ECTS). Responses contained wardrobe inventories (quantitative) and open questions (qualitative data) in which respondents were asked to describe their clothing consumption habits. A mixed methods approach was used to gain a diverse picture of the phenomenon. Clothes were meaningful for most of the respondents and it was important that clothes reflected one's personal style. Results showed that a significant number of students thought they had too many clothes and discontent seemed to have increased during recent years. One of the more important findings was related to the respondents who were content with their clothing quantity. This group was notably uniform: they were rational with their purchases, quality-oriented and loyal to their own style. Consumer education and clothing consultancy services could utilize the findings when building strategies for guiding consumers towards more sustainable deeds.

Introduction

Clothing consumption and clothing quantity are complex themes for research. To understand how and why clothes are being consumed, both physical and intangible aspects of clothing should be studied. Physical aspects refer to clothes as a necessity – we need a certain amount of clothing to protect us and keep us warm. Intangible aspects focus on the emotional side of clothing, the feelings we attach to them and how we express our personality through clothing.

The objectives of this study were to understand the consumers' relationships with their clothes, their clothing consumption habits and what would aid individuals in building a more satisfactory wardrobe. The theme of a sustainable wardrobe was studied from the consumer's viewpoint to understand the options but also the obstacles that prevent consumers committing to sustainable clothing practices.

Clothes as a necessity

It has been estimated that Finnish consumers dispose over 10 kg of textiles to waste annually (Dahlbo et al., 2015). Even though new and efficient textile reuse technologies are being developed rapidly, changes should also occur in clothing consumption habits (Niinimäki, 2018). Clothing purchases are influenced by many factors. Different life situations, personal preferences, lifestyles, culture, age and socio-economic status have effect on one's need of clothes, not to mention the weather and changing seasons (Anttila, 2003). Also, consumers' shopping motivations and decision-making processes vary – sometimes purchases are rational, sometimes based only on emotions (Evans, Jamal & Foxall, 2009; Engel, Blackwell & Miniard, 1995).

Clothes can be acquired from a range of sources. Clothes can be bought second hand or new, but garments can also be self-made, received as a gift, inherited, swapped or even borrowed (Winakor, 1969). When something new is acquired, at some point some clothes are also disposed of. Typically, clothes are being disposed of because there are challenges with the fit, garments are worn out or are no longer fashionable, the consumer has a desire for variation or has too little storage space (Laitala, 2014).

The Centre for Consumer Society Research of the University of Helsinki has calculated a reference budget for clothing that has suggested the number of garments for a reasonable minimum standard of living. The latest 2018 budget suggested 104 items of clothing, accessories and shoes for a woman and 88 items for a man (Lehtinen & Aalto, 2018). These numbers have been used as a reference point for our clothing inventory data. Clothing inventories have been confirmed to increase knowledge about one's clothing consumption habits, which therefore can be utilized in consumer education (Räisänen, 2014; Parker, 2017).

Intangible aspects of clothing

The intangible aspects of clothing is important when clothing consumption is being discussed. Niinimäki (2011) has studied the factors that enable attachments to be formed towards an item of clothing. In a nutshell, the better a piece of clothing covers consumer's needs in design, style and quality, the stronger will be the attachment formed. Also, clothes that have specific sentimental value are often treasured. Furthermore, it has been noted that in cases when clothing purchases lean on one's personal style, they tend to be more timeless and longer lasting (Cho, Gupta & Kim, 2015).

Consumers often have clothes in their wardrobe that they seldom or never use. Clothes can be saved if they are currently the wrong size, if they were expensive or carry important memories – even if those garments might never be worn again (Bye & McKinney, 2007). A consumer's appreciation and attachment to a garment can therefore prolong its life cycle considerably (Aakko, 2012).

Sustainable wardrobe and clothing consumption

Good intentions do not guarantee change in action when it comes to clothing consumption (Sumner, 2018; Berberyan, Jastram & Friedman, 2018). Consumers are often aware of the importance of their clothing consumption habits but if they value variety and self-expression, they might not be willing to choose sustainable alternatives over fast fashion (McNeill & Moore, 2015). Concepts of ecological and ethical clothing consumption can also be themes that are too complex for an individual to master – then it can be easier to choose a product by its physical appearance (Harris, Roby & Dibb, 2016).

Higher price might sometimes prevent consumers from buying sustainable apparel (Cowan & Kinley, 2014). Sustainably manufactured clothes could still be a realistic alternative for fast fashion, because it is not inevitable that more money will be spent. If sustainable clothes are also manufactured from high-quality materials, they will most likely last longer (Aakko, 2012). Additionally, more expensive clothes are often acquired thoughtfully, maintained with care and even used for longer (Niinimäki, 2007).

Use-oriented clothing solutions, such as clothing consultancy, clothing swaps and renting, have been studied from the consumer perspective (Armstrong, Niinimäki, Lang & Kujala, 2016). They are valuable tools that can significantly extend and add variation to one's wardrobe without new purchases. This is important, because consumers often have pressure to update their wardrobes continuously (Harris et al., 2016).

Daily clothing-related practices, such as washing and mending, are also important when following a sustainable lifestyle. Washing and drying clothes needs significant amounts of energy, so consumers should be encouraged to wash their clothes in lower temperatures and use line drying instead of tumble drying (Fletcher & Grose, 2012). In addition, airing and brushing can sometimes help to refresh garment without washing (Aalto, 1998). It is also obvious that good clothing repair skills increase the tendency to mend one's clothing (Norum, 2013).

Materials and methods

The research material was collected by Räisänen using an e-enquiry method during the period from 2010 to 2016. Respondents were students of textile and craft studies at the University of Helsinki and the Open University of Helsinki, Finland, who participated in a course entitled *Textiles, consumption and sustainability* (2–3 ECTS). The 395 respondents of which 392 were female and three men, were participants in 11 study groups.

Students' responses contained wardrobe inventories (quantitative data) and answers to five open questions (qualitative data) which surveyed their perceptions about themselves as textile buyers and consumers. Age and gender were the background information collected. Respondents were also asked to estimate the amount of clothing they had on a scale 'too much', 'a reasonable amount', 'too little', 'something too much or few' or 'I can't say'. A mixed methods approach was used to gain a diverse picture of the phenomenon.

Qualitative and quantitative data analysis

Qualitative data were analysed using ATLAS.ti software (ATLAS.ti Scientific Software Development, Version 8.4.2). All respondents had their own profile in the system and responses were read once as whole. The analysis method was theory-based content analysis. Data were coded to several code groups of specific themes and concepts, such as clothing acquisition habits, clothing quantity, self-expression and sustainable clothing consumption. New codes were added when something repetitive was noticed in the responses.

Quantitative data were analysed using Microsoft Excel (Microsoft Excel, Version 16.26). Data from different respondent groups (e.g. respondent groups in Table 1 and estimated amount of clothing in Figure 1.) were compared, and minimum, maximum and average amounts of clothing were calculated. The data were also analysed in comparison with qualitative data.

Results and discussion

The wardrobe inventory showed that the amounts of clothing in different garment groups were more than the double the amounts indicated in the Centre for Consumer Society Research reference budget amounts (Lehtinen & Aalto, 2018) and the variation between the maximum and minimum amounts was considerable. Results indicate that even if respondents had vast knowledge about their clothing consumption due to their studies, most of them considered their wardrobes to be far from ideal. Respondents' discontent with their wardrobe seemed to have increased in recent years, which could be a consequence of popular trends of wardrobe decluttering and a general atmospheric change regarding one's possessions (Korkman & Greene, 2017). All in all, respondents progressively considered that they had too many clothes. Average numbers of different types of garment and average, minimum and maximum numbers of items are presented in Table 1.

Respondents to this study acquired their clothes from a range of sources including clothing stores, supermarkets, web stores and flea markets. Some items were also ordered from seamstress or made by the respondents. Over half of respondents (52%) bought garments second hand which is comprehendible since most of the respondents were students with low incomes. Some respondents still stated that they wouldn't buy pre-owned socks, stockings or underwear for reasons of hygiene. Also, tight-fitting clothes, such as trousers, were often bought new.

The concept of need was discussed widely among the respondents. Many respondents claimed that they would buy new, full-priced clothes for 'real need', when an old garment had come to its end or when their clothing size had changed. Trousers were a garment group that was usually worn out, but clothes were also bought for pleasure when longing for something new and special. Impulsive buying was common among sale and second-hand purchases.

Clothes were meaningful for most of the respondents and it was important that clothes reflected the owner's personal style. The most important items of clothing were the ones carrying an important story or memories. This kind of attachment could prolong a garment's life, which has also been argued by Aakko (2012) and Niinimäki (2011).

Clothing maintenance skills were mentioned in many responses. Care labels were studied carefully, and daily wear was especially required to be easily washed in a washing machine. This is in accordance with the current study of Miilunpalo and Räisänen (2019) about the laundry habits of Finnish consumers. Clothes that required professional laundering

Respondent group	N=number of respondents	Lingerie	Nightwear	Socks, tights, leggings	Shirts, blouses	Skirts	Dresses	Trousers, shorts	Sportswear (in and outdoors)	Coats, jackets, blazers	Accessories (belts and scarfs)	Average	Min.	Max.
OA2016	34	40	8	57	71	9	16	18	21	13	22	275	51	556
US2016	32	40	7	48	76	9	23	17	19	14	23	275	57	837
OA2015	36	44	8	63	85	14	16	20	24	15	27	314	68	880
US2015	27	34	6	52	59	9	18	15	17	11	25	245	69	508
UA2014	42	45	9	60	75	12	18	17	16	13	26	290	37	756
OS2014	22	39	6	48	68	8	13	16	16	12	26	251	97	681
OS2013	23	36	6	46	60	13	12	20	10	13	29	245	62	814
UA2012	65	40	9	58	72	11	17	15	16	11	28	277	49	650
UA2011	45	42	8	54	78	11	17	17	17	10	24	278	69	739
UA2010	35	43	9	63	67	11	16	16	18	11	27	280	66	847
US2010	34	35	7	41	65	12	12	12	9	10	26	228	93	553

Notes: The letter before year stands for respondents of University (U) and Open University of Helsinki (O). Spring (S) and Autumn (A) data collections are also separated with letter.

Table 1. The average number of garments in each respondent group.

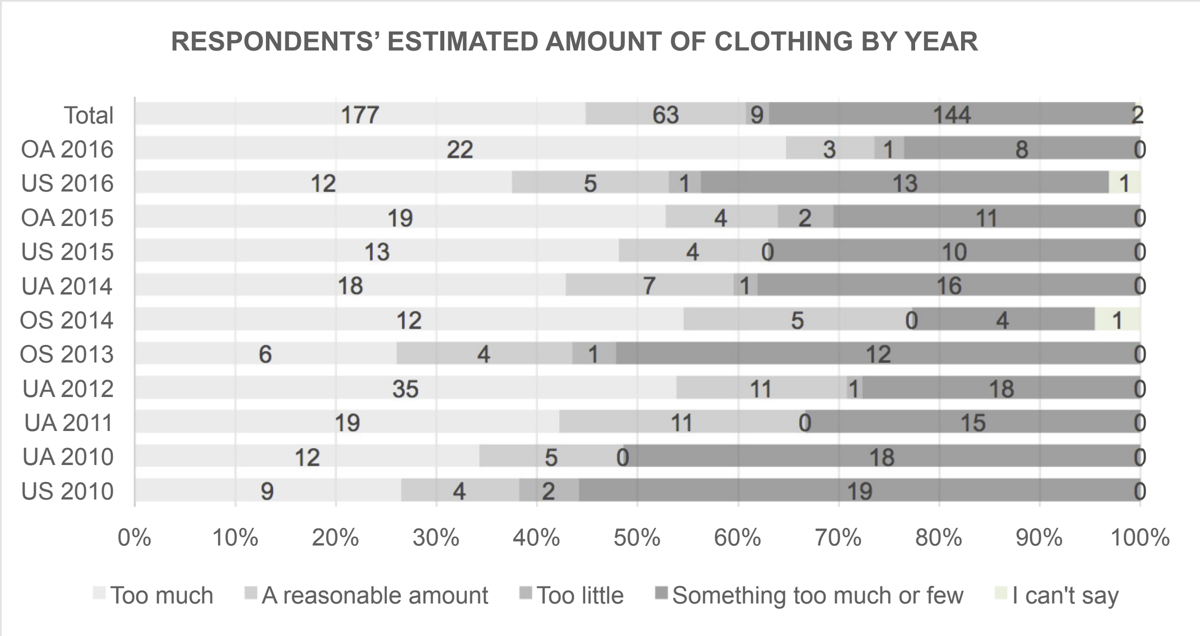
were not often bought. Garments were mended and altered diligently. In textile fibres, many respondents preferred natural materials and synthetic materials, especially acrylic, were avoided.

Respondents' clothing disposal habits were versatile. Clothes were often used to the very end. When clothes began to appear slightly worn out, garments were first downgraded to home wear, then as renovation clothes and after that they could still be used at the summer cottage. When clothes were not worn anymore, they could be utilized as cleaning rags or they could be turned into traditional rag rugs. Placing textiles in the rubbish was the last option. Clothes were also recycled via flea markets and donations.

Respondents discussed widely their active and passive wardrobes (Winakor, 1969; Anttila, 2003). The active wardrobe was usually a very compact collection of one's favourite clothes, whereas the passive wardrobe included several kinds of clothes, e.g. in many cases, clothes were the wrong size, or garments needed to be mended or altered. One specific passive wardrobe garment group was sentimental clothing such as wedding dresses or inherited clothes.

When asked about a reasonable number of clothing in general, respondents stated that one should have enough clothes that there is something to wear between laundry days. Another definition was that clothes should fit in the storage space available. Some variation in outfits was also desired, therefore a little extra should be calculated on top of the bare minimum. Also, a more extensive wardrobe was justified by the fact that individual garments wouldn't wear out as quickly if used less often.

Respondents were asked to estimate amount of clothing they had after the clothing inventory (Figure 1). Many respondents considered that they had too many clothes and only nine respondents reported having too few. One respondent group (n=63) was especially interesting: those who said that they had a reasonable amount of clothing. These respondents seemed notably uniform on how they related to their clothes. They were rational with their purchases and 'less was more' for them. Their relationship with their clothes was straightforward – they knew their own style and didn't buy other kinds of clothes (Armstrong & Lang, 2018). In this group, the average amounts of clothing didn't differ much from the



Notes: The letter before year stands for respondents of University (U) and Open University of Helsinki (O). Spring (S) and Autumn (A) data collections are also separated with letters.

Figure 1. Respondents' estimated amount of clothing by year.

average of all respondents, but variation was great. The smallest clothing quantity reported was 37 items and the largest 742 items. Two of the three male respondents belonged to this group and therefore it would be interesting to compare male and female respondents' answers with more a generalizable sample.

The respondents had vast knowledge about clothing sustainability but still many found sustainability issues challenging. The most common sustainable clothing purchase alternative was second-hand clothing. Still, second-hand shopping wasn't the solution for

everyone. Some respondents explained that it was hard to find right-sized clothes from flea markets, that the quality wasn't guaranteed, and that second-hand shopping would require too much time when attempting to find something specific.

Ecological and ethical clothes were perceived as being expensive (Cowan & Kinley, 2014). The price and style of the garment was usually more important than the product's ecological and ethical background. Some mistrust was also expressed towards brands' own sustainability information. Nevertheless, consuming fast fashion often caused guilt and anxiety if there did not seem to be an option for economic reasons.

Conclusions

Respondents were aware of the problematic nature of clothing consumption. Since most of the respondents were students, their clothing purchases were economic and ecological. Many of them acquired second-hand clothes, mended their clothes and even made their own clothes. Nevertheless, many respondents stated that their clothing purchases were often made impulsively and emotionally instead of them being acquired rationally according to one's needs (Evans et al., 2009).
One of the more interesting findings of this study was related to one specific consumer group – those who felt that they had reasonable amount of clothing in their wardrobe, neither too much nor too little. Those respondents clearly differed from others on how they related to their clothes: they seemed to be rational buyers, quality-oriented and loyal to their own style. They also wore most of their clothes and their "passive wardrobe", storage of currently unused clothing, was lighter. Clothing quantity and age did not explain the difference compared to the other respondent groups (cf. estimated amount of clothing). Personal style could have a quite significant role in sustainable clothing

consumption, which has also been argued in previous research (Armstrong & Lang, 2018).

In conclusion, strong personal style and rational clothing purchases could result in one's clothing quantity being more satisfactory, which is compatible with previous research (Cho et al., 2015; Armstrong & Lang, 2018). Therefore, some consumers could benefit from clothing consultancy services or renting when learning to find their own style (Armstrong et al., 2016). It was also an interesting result that having large amount of clothing didn't automatically mean dissatisfaction or vice versa. It would seem that quality overrules quantity.

Ethical and ecological issues often caused discontent and even frustration because it was hard to obtain information about items production and supply chain. This suggests that consumers might need some kind of "wardrobe manager" to change their consumption habits. Clothing ethics, ecological issues, clothing maintenance and personal preferences can be challenging for a consumer to master – even if textiles were one's main field of study (Harris et al., 2016). It is intended to tackle this problem by developing an application for consumer's empowerment in the future research.

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Co-creating Circular Product-service Systems for Long-lasting Washing Machines

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Keywords: Co-creation; Product-service Systems; Circular Product Design; Washing Machines; Circular Economy.

Abstract: This paper presents the result of a co-creation and context mapping study amongst seventeen washing machines users. The users had widely varying experiences with products offered through alternative ownership models, including three who were active users of a washing machine with pay-per-use or monthly subscription model. Through the co-creation process, user's needs, concerns and desires were identified and translated into potential opportunities and barriers concerning the acceptance of circular product-service-systems for washing machines. The paper details the method used in the co-creation process and consecutively highlights six key benefits of using co-creation in the development of circular product-service systems and exemplify them with citations from users. Examples of these benefits are the added value that the product-service systems can give over classic ownership models, the value propositions that can form an entry point for users to be interested in the service, as well as how pricing and feedback schemes could accommodate different users and their needs and desires. In closing, the paper addresses the implications of these benefits, relate them to past literature, but also raise a number of questions and considerations in the application of co-creation for the development of circular product-service propositions.

Introduction

Access models are seen as a key factor in successfully closing loops in a circular economy (MacArthur, 2013). However, for the circular economy to become truly successful, it is crucial that people actually start using circular products and services on a sufficiently large scale. As Selvefors et al., (2019) state, "it is essential to increase the understanding of what circular consumption entails for people in everyday life". To achieve this, it is imperative to understand people's aspirations, ideas, fears and dreams, so that these future circular propositions are optimally aligned with user's needs. This is where co-creation comes in. Co-creation methods enable users and other relevant stakeholders to participate in the design process of new service and product offerings (Holmlid et al., 2015; Sanders & Stappers, 2008). By taking this bottom-up approach, the chances of success on the market are increased because the resulting services and products better fit the way they will actually be used in people's own lives, and are therefore more attractive. To date, this approach has received limited attention within the circular economy community (Lofthouse & Prendeville, 2018; Selvefors et al., 2019) while Cherry and Pidgeon (2018) argue there is an "urgent need for research that explicitly explores the concept of Results-oriented services and how these new business models may be perceived."

This paper details the method used in a co-creation process amongst washing machines users to develop new laundry services. Consecutively, it highlights the benefits of using co-creation in the development of circular product-service systems (PSS) based on the outcomes of the case study. This study is part of a large-scale white goods demonstrator, implementing circular economy in practice within the EU project ReCiPSS (2018). The aim of the demonstrator is to develop and pilot a product-service system that incorporates long-lasting washing machines offered through an access model. As a key first step, co-creation sessions were held with users to identify their needs and to translate these into potential opportunities and barriers concerning the acceptance of circular washing machine business models. This is part of a larger co-creation process where users will be actively involved during strategic stages of the demonstrator to ensure a meaningful match between users and the PSS being developed.

Method/approach

Seventeen washing machine users participated in the co-creation study. The users had widely varying experiences with products offered through access models, including three who were active users of a washing machine with pay-per-use (PPU) or monthly subscription model. Others had no experience with access models whatsoever.
The study was conducted in two countries, the Netherlands and Slovenia, to verify if the same needs, concerns and opportunities were valid in different cultural contexts. The Dutch and Slovenian context was chosen as a representation of the North- and South-European context.
The study consisted of filling in a sensitizer booklet about their current washing machine practices beforehand and participating in a co-creation workshop.
The sensitizer was used as a basis for the discussion in the workshop. By using a sensitizer beforehand, users are able to reflect on their laundry experiences (Visser et al., 2005).
The co-creation workshop itself was split into two parts. The first half delved into user's laundry experiences based on what they had written in the sensitizer. In the Dutch session, mixing users who used a PPU washing machine with 'normal washing machine' users provoked a natural dialogue in which users exchanged their laundry experiences and, in the process, unsurfaced underlying desires and needs. In the second half participants were asked to design their ideal laundry service in pairs of two. A slightly different setup was chosen for the second half of the Slovenian session. There, the ideas from the Dutch session were presented to elicit reactions from the Slovenian participants, who were less familiar with (washing machine) access models, about what Dutch participants said.

Data analysis

The goal of the co-creation session was to inspire and engage the project team and create empathy for the users. (Sleeswijk Visser et al., 2007). Therefore, a medium needed to be chosen that affords presenting rich and in-depth information about the user in an accessible way for designers to work with and delve into. An infographic poster can give an extensive graphic summary of the data while retaining the personal identity of the users in the process. Infographic were made of each of the participants to be able to present the data in a manner that was easily accessible by the washing machine design team.
To be able to extract relevant data for the infographics, we first familiarized ourselves with the data by repeatedly listening to the recordings. Through this processed we reviewed what each participant had said to gain a better understanding of their key characteristics, needs, and concerns as well as their similarities and differences. During several analysis sessions, open coding was then used to identify key characteristics to include in the infographic. These included key and noteworthy facts about each participant and their washing rituals, how they viewed their washing machine, and their likes and dislikes.
By analyzing this data, four additional themes were identified that gave relevant insights for the development of new circular washing machine services. These were: 1.) user's (innate) needs, frustrations, and desires, 2.) their issues surrounding repairs, 3.) the underlying concerns, and 4.) underlying opportunity spaces that emanated from what participants said during the session.
Additionally, a list of similarities and differences between participants was compiled and then narrowed down. This was done by iteratively identifying and testing key contrasts that were applicable across the sample and were capable of being placed against each other on a scale. These were implemented in the infographics to give a quick overview of key differences between participants and included: their emotions towards different steps of the laundry practice, who in their household did the laundry, whether they were more focused on the function the washing machine delivers or (owning) the washing machine itself, where they based their decision to do laundry on (convenience or capacity), smartness and division of control between themselves and the washing machine, and whether they found the feedback on the costs in pay-per-use models confrontational or helpful.
Consecutively the first author went through the recordings again to select transcribed quotes to include in the infographics. Two examples of the infographics can be found in figure 1.

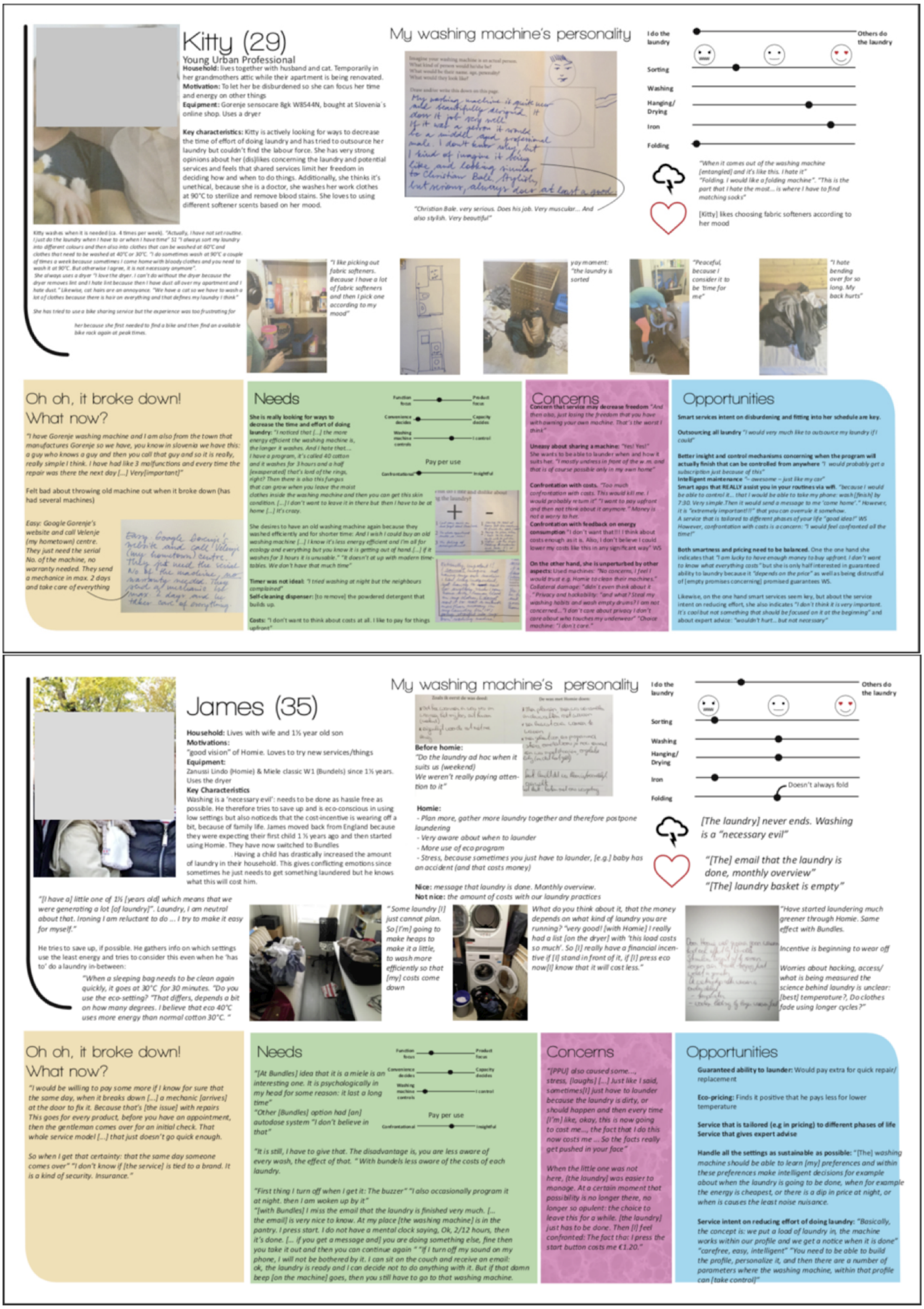

Figure 1. Infographics.

These infographics where then presented to the design team at the company. To initiate the design process, a first workshop was held together with the design team and all partners of the ReCiPSS project. During the workshop, each team, consisting of 4 people, selected an infographic. During 15 minutes, they brainstormed on new services for the person portrayed in the infographic, after which they rotated. The process of developing new PSS ideas was then continued by the design team in the following months.

Results: benefits of using co-creation

This following section will explain the key benefits of using co-creation for the development of circular PSS's and exemplify them with citations from users. These were extracted from the co-creation process and the subsequent data analysis.

Benefit 1: creating added value for PSS

Offering products-as-a-service or access models rather than traditional ownership models gives unique opportunities to provide services that would otherwise not be possible. It does require significant changes in the behavior of users and therefore needs have benefits in comparison to the current situation for users to gain interest in it (Selvefors et al., 2019). In this study, the use of co-creation revealed several areas that can make such a service relevant to users.

One example is in the area of service and repairs, where the quickness of repairs or even complete replacements could be part of the service package. As one participant stated: "I would be willing to pay some more if I know for sure that the same day, when it breaks down, a mechanic arrives at the door to fix it. Because that's the issue with repairs... Before you have an appointment, then the gentleman comes over for an initial check. That whole service model that just doesn't go quick enough. So, when I get that certainty: that the same day someone comes over... It is a kind of security. Insurance."

Another example is the opportunity PSS's give to provide relevant and timely information and feedback: "I miss the email that the laundry is finished very much. [the email] is very nice to know. At my place [the washing machine] is in the pantry. I press start. I do not have a mental clock saying, Ok, 2/12 hours, then it's done."

Benefit 2: Ability to develop attractive payment and contract options

A long-lasting washing machine is a durable good that can (potentially) have a lifespan of 20 or even 30 years. While durability in itself may be attractive, the length of time can give a certain rigidity that may not be attractive to (younger) users who value flexibility. One PPU-user described the appeal of PPU as follows: "Not having to pay upfront costs. You don't need to pay for a washing machine. You are not stuck to it. For example, if you move to another country, you aren't left with a washing machine that you need to get rid of". The lifespan of the washing machine may also mean that a classic ownership model is less suitable than an access-model which can be adapted or tailored to phases of life, e.g. in the size of the machine, payment options and flexibility of contracts: "When the little one was not here, the laundry was easier to manage. At a certain moment that possibility is no longer there, no longer so opulent: the choice to leave the laundry for a while. It just has to be done. Then I feel confronted: The fact that I press the start button costs me €1.20." Or, as a second parent said about the extra laundry loads that are sometimes inherent to having children: "I would feel hindered when having to pay per wash… "I would think every time ka-ching, ka-ching… Possession in itself is not important, but the freedom it offers."

Benefit 3: Finding unique value propositions

For companies it is essential to find unique value propositions for the proposed circular PSS, particularly when they are not the first on the market to offer access models. Co-creation can identify opportunities to differentiate themselves from competitors. For example, the value proposition could be in providing washing machines with smart technology that is desired by users but would otherwise be financially out of their reach, like providing wi-fi enabled intelligent maintenance or remote access to information and control mechanisms concerning when the program will actually finish. As a user explained: "I would probably get a subscription just because of this"

Benefit 4: Identifying potential user concerns

The co-creation session intentionally combined users with a pay-per-use washing machine and users with a classic ownership-model washing machine. This approach brought to light certain reservation that users might have including issues surrounding freedom, control, privacy, distrust, and (hygiene) perceptions. An example of this is several users who were very aware of hygiene issues and therefore (very) wary of (re)used and shared washing machines: "because my sister is studying biology, microbiology and she scared the shit out of me... there was a study that the bacteria actually that live in the washing machine can actually be harmful to you" Another example was lack of choice "I would want to choose, what [the washing machine] looks like, what it can do. I find it important that it can open, so that I can add forgotten socks, after the program has started… I would have real problems with 'oh, you get this concept and this is the machine. Then I would think hmmmm…"

Benefit 5: Assist company with internal shift from product- to service-orientated

Shifting towards circular economy strategies requires significant changes within companies and co-creation can be beneficial in this process to bring different departments on board. The design team was very positive in hindsight about the co-creation process and saw clear benefits for their company. They stated that it "greatly exceeded their expectations" and that they were now pursuing new ideas and avenues that they would otherwise never have considered.

Benefit 6: Identify cultural differences

Holding co-creation sessions in different cultural settings, and particularly using a first session as input for a second session in a different culture, can identify cultural differences. One example of this is that Slovenian participants seemed more prone to question guarantees and be wary of 'empty promises': "I would probably go for the cheapest one just because I don't know how they can guarantee that that one is really going to last so much longer."

Discussion

While there are clear benefits to implementing co-creation within circular product development it also raises a number of questions. A key question is whether the suggested opportunities and barriers also contribute to a prolonged lifetime of the product?

Furthermore, in these two cultural contexts there seemed to be little interest in (long-term) shared-services for washing machines. This begs the question: What would it take to normalize this model in other cultures and what are the underlying cultural values that impede this process? In Scandinavia this model is far more common and Mont (2004) suggests several factors that are at play including regulatory and normative institutional arrangements, the design and application of the PSS and societal socio-cultural background.

Likewise, in how far are perceived barriers going to be actual barriers? Hygiene seems to be a key barrier to several classic business model users. Nonetheless, some of these same users seemed not to be aware that the washing machines that came with their (rental) apartment was likely used by a previous tenant and therefore prone to the same issues.

A further consideration is how to implement the results from the co-creation sessions. A logical approach to hygiene concerns might be to provide a certificate of cleanliness guaranteeing the washing machine is 'as good as new'. However, previous research suggests that this could be counterproductive saying: "Reassurances that it is as 'good as new' just lead to more processing of the fact that it is contaminated." (Ackerman & Hu, 2017). Positive marketing communications (e.g. 'as good as new') on used or remanufactured products tend to make consumers *less* -rather than more- favorable towards these products (Ackerman & Hu, 2017; Mugge et al., 2018). Care should therefore be taken how to apply the results.

Conclusions

This case study shows that there are clear benefits to co-creating circular PSS's. It is an advantageous approach that merits more use within the field of circular economy. However, the results should be implemented with careful consideration to avoid having counterproductive effects, e.g. with regards to hygiene. Furthermore, the ideas generated within this process need to be weighed as to their effect on the overall sustainability of the product.

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PLATE
Product Lifetimes And The Environment

Sustainable Product Lifecycles: A Systemic Approach to the Regulation of E-Waste

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Keywords: Agbogbloshie, Cable Burning, Electronic Waste; Ghana, Regulatory Ecology.

Abstract: International, regional, and national laws have failed to control the transportation and management of electronic waste. This study focuses on Agbogbloshie, a scrap metal yard in Accra, Ghana, which has received worldwide attention for its unsustainable recycling practices. The social and environmental impacts as a result of these practices are well-documented. This paper proposes a polycentric perspective on regulation, in which the state is not seen as the sole locus of authority. This approach enables a broader perspective on who or what regulates and how these modes of regulation interact. We discuss our systemic approach with the concept of regulatory ecology, in which the interactions between law, social norms, markets, and architecture are explored to provide a better understanding of why unsustainable behavior continues. This approach is explored in the mapping of the regulatory ecology of the burning of cables in Agbogbloshie, a fast and cheap method used for extracting copper. This practice continues even though more sustainable options, such as cable-stripping machines, are available in the scrap metal yard. A systemic approach to regulation brings a deeper understanding to regulatory ineffectiveness. We conclude that legislation that doesn't address the interaction of hazardous waste and marginalization, will fail to deliver the social and environmental gains it pursues.

Introduction

Waste from electrical and electronic equipment (WEEE or e-waste) is the fasted growing stream of hazardous waste (Asante, Amoyaw-Osei, & Agusa, 2019; Awasthi, Li, Koh, & Ogunseitan, 2019; Lucier & Gareau, 2019). In 2016, almost 50 million tons of e-waste was generated globally, but only 20% was recycled via appropriate channels. Four percent of e-waste was sent to landfill sites. What happened with the other 76% is unknown (Baldé, Forti, Gray, Kuehr, & Stegmann, 2017).

At least some of that e-waste will have ended up at Agbogbloshie, a neighborhood of Accra, Ghana. Agbogbloshie has become synonymous with e-waste, not least as a result of various media reports and documentaries.[1]

[1] E.g., https://www.vice.com/en_us/article/4x3emg/inside-the-worlds-biggest-e-waste-dump; https://www.theguardian.com/environment/gallery/2014/feb/27/agbogbloshie-worlds-largest-e-waste-dump-in-pictures; http://www.welcome-to-sodom.com/. For a critique, see https://africasacountry.com/2019/03/six-myths-about-electronic-waste-in-agbogbloshie-ghana.

In fact, Agbogbloshie consists of a food market (see Figure 1); an industrial area; a large slum called Old-Fadama, housing about 100.000 people; a household waste dump; and a scrap metal yard. The Odaw river passes through between the slum and the scrap yard. A large part of the household waste dump is located on a wetland, the Korle Lagoon.

Most of the e-waste handled at Agbogbloshie arrives at the scrap yard, which is the focus of our study. It is relatively small in size, covering about 0.5 km^2, and employing about 4-6000 people, mostly young men. At the scrap yard, cars, buses, bicycles, and e-waste, such as air conditioners, computers, fans, televisions, and mobile phones are recycled. E-waste is brought in by scavengers going around the city looking for scrap. The majority of scrap is generated domestically (Schluep et al., 2012). Another source of scrap is imported used electrical and electronic equipment (UEEE) that is not functioning and not repairable

(Amoyaw-Osei, 2011; Odeyingbo, Nnorom, & Deuzer, 2018).[2]

Figure 1. Agbogbloshie. © SMART/Maja van der Velden.

The activities in and around Old-Fadama, the scrap yard, and the household waste dump have resulted in severe pollution of land and water and has seriously affected the health of communities living and working in the area (Asamoah, Essumang, Muff, Kucheryavskiy, & Søgaard, 2018; Chama, Amankwa, & Oteng-Ababio, 2014; Tue et al., 2016; van der Velden & Taylor, 2017). The pollution of the Korle Lagoon and its surroundings started long before the arrival of e-waste, but is exacerbated by e-waste recycling (Grant, 2006; Karikari, Asante, & A. Biney, 2009). The burning of car tires for the extraction of steel wire and cables and coils for the extraction of copper, on the outskirts of the scrap yard, is a particularly visible manifestation of unsustainable recycling practices (see Figure 2).

Initiatives to address this situation have resulted in a range of measures, from new e-waste legislation (Republic of Ghana, 2016), development programs,[3] and even the eviction of residents of Old-Fadama. (Akese & Little, 2018) . Most of these initiatives have sought to solve symptoms of the e-waste challenge to sustainability, without considering the regulatory difficulties arising from the complexity of local conditions or from the product lifecycles of electronics (Hoffman, 2017). Few, if any, have taken a systemic approach to the regulation of e-waste.

Figure 2. Burning cables. © SMART/Maja van der Velden.

This study has sought to approach the problem of e-waste recycling based on ethnographic fieldwork in Agbogbloshie and a systems approach to regulation. Fieldwork in Agbogbloshie has been implemented over several years, with the last visit taking place in September 2017. During fieldwork we observed electronics end-of-life (EoL) activities in Accra (repair, disassembling, burning, weighing, and storing) and implemented short ethnographic interviews (Pink & Morgan, 2013) with people involved in EoL activities, such as repairers, disassemblers, cable burners, as well as some of the organizations governing these activities, such as the Greater Accra Scrap Metal Association and the Environmental Protection Agency (EPA).

The data gathered forms the basis for considering attempts at regulation from a systems perspective. Critical systems thinking (Jackson, 1991) encourages socioecological awareness and human and non-human

[2] WEEE stands for Waste Electrical and Electronic Equipment and is in this paper used interchangeably with e-waste, which stands for electronic waste. The transportation and management of WEEE is covered by national and international legislation. UEEE or Used Electrical and Electronic Equipment is not a formal term. In this paper, it refers to both second-hand EEE as well as EEE that is collected as WEEE in one jurisdiction, but often still functioning, and exported as UEEE to another jurisdiction. It is estimated that 10-30% of UEEE imports in Ghana are non-functional (Amoyaw-Osei, 2011; Odeyingbo, Nnorom, & Deuzer, 2018).

[3] E.g. https://accra.diplo.de/gh-en/botschaft/themen/ewaste-project-launch/1164856

emancipation; it enables an analysis of complex societal and environmental problems and can propose interventions in support of addressing such problems (Stephens, Taket, & Gagliano, 2019) In this paper we take a critical systems approach to regulation in order to facilitate a different perspective on cause and effect, on who or what can regulate (the subjects and objects of regulation), as well as on interactions between different modes of regulation.

Regulation can be defined as the "act or process of controlling by rule or restriction." (Garner, Newman, & Jackson, 2011). A critical system approach to regulation builds forth on a polycentric approach to regulation, in which the power to regulate lies not solely the state, but arises from a system of constraints. As such, regulatory systems show system characteristics, such as non-linearity, emergence, and self-organization. Our approach is informed by the work of Lessig (1998), who describes four modes of regulation and their direct and indirect interactions: law, social norms, markets, and architecture. Architecture, encompassing nature, materials, and design, is a non-human actor with sometimes strong regulatory effects, constraining both directly and indirectly the regulatory effectiveness of national and international laws. The mapping of this polycentric system of regulation results in a so-called regulatory ecology (Sjåfjell & Taylor, 2015; van der Velden, 2016), which is intended to facilitate perspectives in the development of policy and law that are better adapted to the social and material complexities of product lifecycles.

Recycling e-waste in Agbogbloshie

The recycling of e-waste in Agbogbloshie consists of different phases. Scavengers collect e-waste from households, offices, and UEEE dealers, etc. in Accra and its surroundings. The work of the scavengers is highly efficient, with a collection rate of around 95% (Grant & Oteng-Ababio, 2016). The e-waste is brought into the yard on pushcarts and motorized three-wheelers, where it is disassembled into parts that can be sold to scrap metal dealers or to repairers. Disassembling takes place in open-air workplaces and shacks. Cherry-picking particular parts and materials, such as printed circuit boards, aluminum, copper, and batteries, is very common (Amoyaw-Osei, 2011).

Recycled materials leave the yard in several ways. Small pieces are collected in bags. Dealers weigh these bags and pay the worker. The bags are stored and leave the yard in trucks once enough bulk is collected. Large pieces of metals are stored and then loaded on trucks. Many materials remain on the yard. Some get a new purpose, such as chest freezers used for the storage of tools. Others, such as plastic computer monitor casings, are stored, waiting for a buyer, or used as fuel for the cable-burning fires (Figure 2 and 3).

Figure 3. Stored computer monitors and freezer boxes. © SMART/Maja van der Velden.

Recyclers use rudimentary tools to disassemble e-waste. We observed the same size chisel and hammer used for the dismantling of air conditioners as for mobile phones. None of the recyclers used health and safety equipment, such as steel-nosed boots, helmets, gloves or mouth/nose/ear protectors. The scrap yard also houses a container with two cable stripping machines, which we didn't see being operated during our fieldwork.

Cable burning

Copper is one of the most sought-after materials by the scavengers. They bundle the plastic-covered copper cables together in balls up to twice the size of a football (see Figure 2). Young men throw the cables in very hot fires, fueled by plastic materials from e-waste, such as insulation from fridges or computer monitor casings. The fire melts the plastic from the copper within a few minutes. The cables are then taken out of the fire for cooling down (Figure 2 and 4).

Conversations with young men during the burning of cables disclosed the hazardousness of their work. They were severely affected by the smoke of the fires (eyes, lungs), they had burns (legs and arms), and experienced nausea, coughs, and headaches. They continued their burning practices, because their daily earnings were too low to practice other ways of extracting copper from cables. Burning cables is much faster and cheaper than using the cable stripping machines (Figure 5; see below "Persistence of Cable Burning").

Figure 4. Burned cables. © SMART/Maja van der Velden.

The burning of cables is part of a much larger ecosystem of activities in which young migrant workers find income and community (Oteng-Ababio et al., 2018). It is a rather dynamic community. Some young men remain cable burners for years, while others move on to other recycling work. We interviewed a young man who, as an orphaned youth from the North, started with burning cables in Agbogbloshie and later became a disassembler of e-waste. Working with e-waste enabled him to pay for his education and livelihood. At the time of the interview, he was just finishing his bachelor degree at a community college.

Regulating hazardous waste

Ghana has ratified the *Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal* (1992), an international treaty designed to reduce the movements of hazardous waste between nations, and specifically to prevent transfer of hazardous waste from high-income to low-income countries.[4] Its intention is to decrease the amount of hazardous wastes generated as well as to safeguard the sustainable management of hazardous materials – as closely as possible to where the waste is generated. Ghana has also ratified the *Montreal Protocol on Substances that Deplete the Ozone Layer* (Montreal Protocol), an international treaty designed to protect the ozone layer, which came into force in 1989; and the *Stockholm Convention on Persistent Organic Pollutants* eliminates or restricts the production and use of persistent organic pollutants (POPs), which came into effect in May 2004. Especially polychlorinated biphenyls (PCBs) are found in electronics and are released during the burning or landfilling of electronics (Liu, Ma, Li, Yu, & An, 2019).

Figure 5. One of the cable-stripping machines. © SMART/Maja van der Velden.

In addition, Ghana has ratified the Bamako Convention and Malabo Protocol. The failure of the Basel Convention to prevent the export of hazardous waste to low-income countries prompted the Bamako Convention. The *Bamako Convention on the Ban on the Import into Africa and the Control of Transboundary Movement and Management of Hazardous Wastes within Africa*[5] of 1991 prohibits African nations to import hazardous wastes. The Convention is stronger in its prohibition than the Basel Agreement. In 2013, the African Union adopted the *Malabo Protocol*, which

[4] The Basel Convention (United Nations): http://treaties.un.org/Pages/ViewDetails.aspx?src=TREATY&mtdsg_no=XXVII-3&chapter=27&lang=en

[5] Bamako Convention: https://au.int/en/treaties/bamako-convention-ban-import-africa-and-control-transboundary-movement-and-management

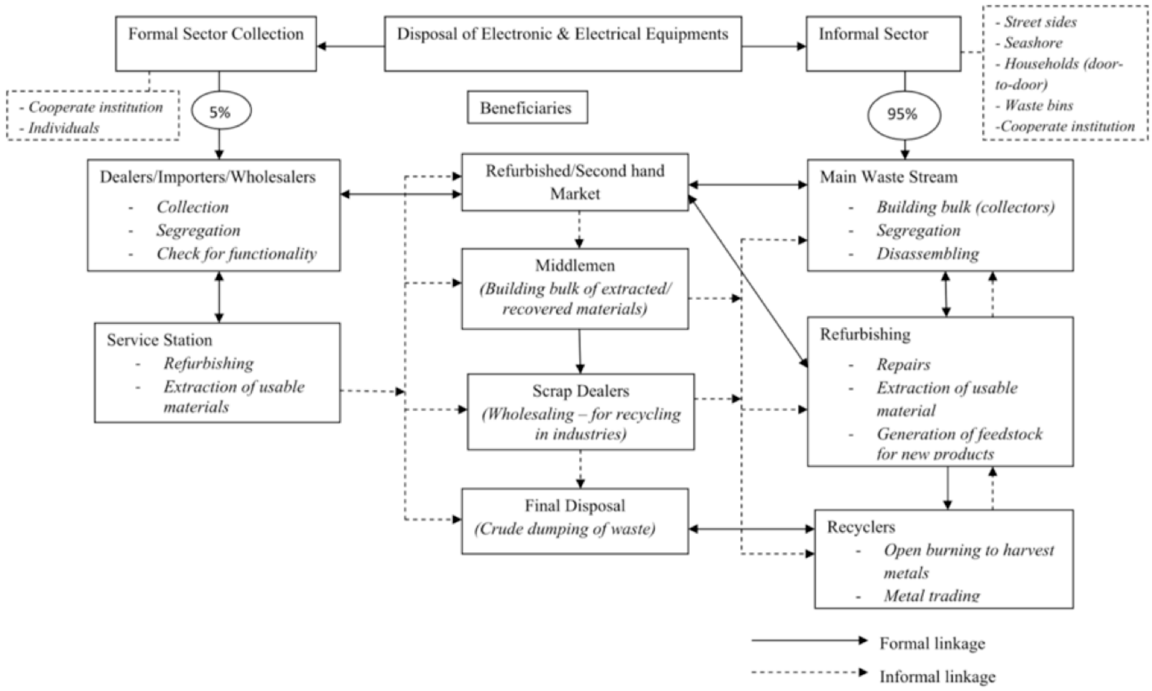

Figure 6. Formal and informal e-waste management in Ghana (Oteng-Ababio, 2012).

criminalizes the trafficking of hazardous waste and opens up for the creation of a tribunal.[6]

Ghana's Environmental Protection Agency (EPA) implemented in 1991 a National Environmental Action Plan, providing a framework for the control and management of potentially toxic substances (Atiemo et al., 2016). Specific regulation of e-waste and hazardous materials goes back to 2008, with the adoption of the Energy Efficiency Regulations (L.I.1932), prohibiting the manufacture, sale or import of incandescent filament lamps and used refrigerators, freezers, and air conditioners. This Act made it a criminal offence to transport or offer for sale such an appliance (ibid.). Opposition from scrap dealers delayed the implementation of the Act until 2013, but the Act seems not to be enforced as imported UEEE fridges are openly traded on markets.

In 2016, the *Hazardous and Electronic Waste Control and Management Act* (Act 917) and its accompanying *Hazardous and Electronic Waste Control and Management Regulations* (LI 2250), were passed in the Ghanaian parliament. The implementation of Act 917 is based on the formalization of the e-waste sector and a ban on burning e-waste. The Act prohibits the import, export, trade, storage, and transport of hazardous waste and other wastes. Exemptions are based on the Basel Convention and need approval from the EPA. Part II of Act 917 deals specifically with electronic waste. Among others, Part II sets provisions for an e-waste recycling plant and the obligation to a manufacturer, distributor or wholesaler of EEE or UEEE to take-back used or discarded EEE for recycling purposes. It also stipulates that the disposal and recycling of e-waste should be carried out in an environmentally sound manner.

The persistence of cable burning

Understanding how the four modes of regulation, *architecture*, *market*, *social norms*, and *law*, interact, can explain why cable burning persists within the current legal framework.

[6] Malabo Protocol hasn't come into force yet, because it hasn't received enough ratifications:https://au.int/en/treaties/protocol-amendments-protocol-statute-african-court-justice-and-human-rights

Architecture constrains the implementation of the *law* in several ways. Generally, the design of electrical and electronic equipment doesn't take the end-of-life of products in consideration by designing for recycling. For example, the unsustainable practice of cable burning continues in part because other methods are made less efficient by the functional design of the cables. A research project comparing the burning of cables and the stripping of cables with tools was implemented with workers at Agbogbloshie. It found that the burning of 40 lb mixed cables took on average 10 minutes, while the stripping of 40lb mixed cables took on average 185 mins (GreenAd, 2012). As a follow-up, stripping machines were installed (Figure 5). There is however a mismatch between the design of the cable-stripping machines and the size and shape of the most common cables recycled in Agbogbloshie. The cables are too warped to run smoothly through the machines or they are too thin to fit in the machine.

The health impacts of cable burning are obvious enough to those doing the work. An alternative method for stripping cables – even a slower one - would normally be preferred, but low copper prices paid to the e-waste workers constrain the use of more sustainable forms of cable stripping. The price of copper fluctuates daily and is set by scrap metal dealers, who are mainly from Nigeria. These dealers have captured a certain position in the market, which gives them control over local copper prices and thus the wages of the local cable burners. Another economic incentive is set by the steady stream of foreign media, attracted by the striking images of tire and cable burning in Agbogbloshie. Some of the young men feature in several photo reports and documentaries and have mastered the spectacular burning of car tires using large amounts of lighter fluid. [7,8, 9]

This simple example illustrates the point that a particular architecture, originating from a product design decision made at the start of the product life-cycle, interacts with the market dynamics operating at the end-of-life of that product. Together, these architectural and market-based realities constrain the effectiveness of the law, in this case Ghana's attempts to regulate e-waste sustainability in a manner that meets its international treaty obligations. In short, legislation that seeks to ban informal recycling at the end of life of products is unlikely to be effective where the architecture of the product and the market dynamics of recycling are mutually reinforcing.

It is important to note that there are structural aspects of making a livelihood in Agbogbloshie, which constitute important factors in shaping recycling activities. Briefly, recycling in Agbogbloshie is shaped by several aspects of social and economic marginalization;

i) Labour in the e-waste sector is based almost exclusively on informal work (Figure 6) (Oteng-Ababio, 2012). Poverty and widespread labour market informality combine to keep wages low and workers impoverished.

ii) Recycling work is dominated by migrants from the North of Ghana, affected by local conflicts and climate change (Oteng-Ababio, 2012). These migrant laborers are more vulnerable to exploitation and harassment by city authorities (Imoro, 2017), and they have less opportunities for safe and decent work (Yeboah, 2017).

iii) There is a gendered division of labor in e-waste recycling: men burn cables or disassemble e-waste, while women work as *kayayei*, selling food and water to the men (Agyei, Kumi, & Yeboah, 2016);

The result is that recycling in Agbogbloshie is precarious work[10]; it is extremely low paid,

[7] "Photojournalism is Agbogbloshie's biggest import": https://www.linkedin.com/pulse/victimhood-jujitsu-vs-compassionate-capitalism-robin-ingenthron/

[8] Awal Muhammed in action for the documentary "Welcome to Sodom": https://www.deutschlandfunk.de/film-der-woche-welcome-to-sodom-die-schattenseite-der.807.de.html?dram:article_id=424290

[9] http://retroworks.blogspot.com/2018/07/nuance-delivery-2-awal-is.html

[10] People in precarious work generally "…lack job security and generally have lower salaries, limited social protection, and few, if any, benefits. Precarious workers face more difficulties to exercise their rights, notably to join a union and bargain collectively for better wages and working conditions. Injury rates are higher for precarious workers… People in precarious work have little or no choice in determining their working hours and pay…" (IndustriALL, 2018)

dangerous, and insecure. It has a significant impact on the environment. At the same time, it provides the basis for livelihoods of several thousand people and is a key part of Accra's recycling system.

Concluding remarks

Our systemic approach to regulation, in the form of the regulatory ecology of cable burning, brings out the complex reality in which this unsustainable activity is entangled. Efforts to ban the activity through legislation will not be effective, because the law doesn't address the marginalization of workers and the design of e-waste. This becomes especially clear in the technical guidelines for the implementation of Ghana's Act 917 (EPA & SRI, 2018), which focuses on materials, not on people (workers) or products (design). Its focus on the formalization of the e-waste recycling sector results in the imposition of collection standards and materials standards that are almost impossible to fulfil for low-income migrant laborers. Similar license-based approaches in India and China have shown not to work (Shinkuma & Managi, 2010).

Alternative interventions are based on creating interactions between the informal and formal sector recycling activities (Davis & Garb, 2015). Most known are Best-of-2-Worlds (Bo2W) initiatives, in which informal workers are doing the manual dismantling and recycling takes place in formal recycling facilities. The main critique on the Bo2W approach is that while it can make their work less hazardous, it doesn't address the marginalization of e-waste workers (Lepawsky, Araujo, Davis, & Kahhat, 2017). Based on a study of cable burning in an e-waste recycling area on the West Bank, Davis and Garb (2015, 2019) therefore call for interventions based on a synergetic and deeper engagement between the informal and formal sector than proposed by the Bo2W approach. Ignoring the precarious social and legal status of informal e-waste workers will just move cable burning to less visible places.

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Test Strategy for Thermo-Mechanical Ageing Effects in Polymeric Materials

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Keywords: Material Characterization; Polymer Ageing; Reliability, Lifetime.

Abstract: The use of polymeric materials in (micro-) electronic applications is growing steadily since many years. They provide a multitude of functions, such as protection against environmental conditions (temperature, humidity, dust, etc.), mechanical stability and electrical isolation. However, during the lifetime of these electronic components, polymers can change their properties significantly, which can lead to premature failure. Therefore, it is of great importance to understand the behavior of these materials throughout its expected lifetime, considering the assumed use-profile, e.g. temperature, humidity, UV light, shocks/vibrations, etc. By means of numerical methods such as finite element simulations, the physical behavior of electronic components can be predicted. However, ageing effects are scarcely considered, and often materials are characterized only in their initial state. Appropriate material models, taking into account ageing effects over the lifetime are desired but not yet common or incompletely present in the literature. This paper describes an approach on how to test the ageing behavior of polymeric materials in order to develop such material models for numerical simulations.

Introduction

Since the year 1868, when J.W. Hyatt invented the first commercial plastic celluloid, the use and production of polymers has grown massively. Besides the many advantages of this class of materials (price, process-ability, freedom of design, etc.) there are also many disadvantages including the pollution of the environment.

In order to prevent electronic components to fail before their desired lifetime due to ageing effects of polymers, accelerated experiments can be performed on both product and material level. Product level experiments provide primarily information about the combination of used materials, e.g. interfaces between two different materials, and information on the total behavior of the specific product. Material level experiments provide a much deeper understanding of each material, independently of the final product.

This paper discusses an approach for performing material characterization tests of polymeric materials in order to determine the ageing effects.

Theoretical part

Classification

Polymers can be categorized into two main groups, thermoplastics and thermoset (Brinson, Brinson, 2008). The difference between the two is that thermoplastics only have secondary bonds between molecule chains, whereas thermosets exhibit both primary and secondary bonds, cf. Figure 1.

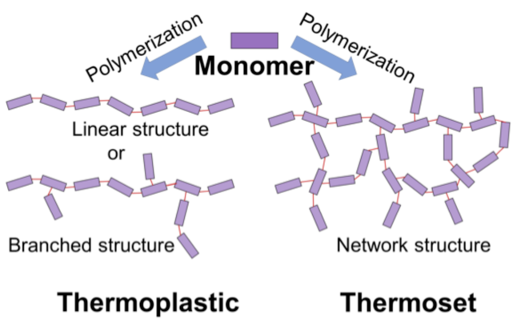

Figure 1. Polymer structure for thermoplastics and thermosets.

One characteristic for thermoplastics is that they can be heated until they melt and become solid again when cooled down. Both thermoplastics and thermoset materials are used in electronic applications, having different purposes and functions. Thermoplastics are used for insulation, housing and sometimes for encapsulation (Patterson, Boyer, Shiozawa, 1995). Thermoset materials are used mainly for encapsulation purposes (Thomas et al., 2014). In order to improve the properties of these polymers, often filler particles (i.e. flakes, fibers or spheres), made from various materials like glass, metals and their oxides and ceramics are added to it. This results, amongst others, in an increasing stiffness and strength, better thermal conductivity and a lower coefficient of thermal expansion.

Purpose of Polymers in Electronic Applications

A dominant material in electronic applications is the thermoset polymer. In general, it can be said that these polymers are used to protect the fragile electrical components against all kinds of (harsh) conditions (dust, humidity, electric current, etc.). Maintaining this protection is of key importance, since they define the reliability and lifetime. If the reliability increases, it can have a positive environmental impact, since less components need to be produced, which means less waste and less carbon emissions during production. Knowing the material parameters of thermosets and its degradation behavior over its lifetime is necessary to assess the expected lifetime in a correct manner.

Ageing effects of thermoset polymers

Although other material properties are affected by ageing effects (such as electrical, radio frequency and optical properties), this paper focusses on the mechanical properties.
The mechanical properties of thermoset polymers are determined by three characteristic mechanisms. The *crosslink density* is a measure for the amount of bonds between different polymer chains. Increasing the crosslink density results in a more rigid behavior. The *free volume* is a measure for the amount of space not being occupied by molecule mass (Brinson, Brinson, 2008) within a polymer. The third mechanism is the *flexibility of the chains*. If sufficient space is present within a flexible polymer, allowing for large scale movements, the behavior will be rubberlike. When reducing the temperature, the free volume reduces such that these large scale movements are not possible anymore, and the polymer will behave glasslike (Budd, 2015). The temperature at which the transition between rubberlike and glasslike state takes place is called the glass transition temperature (T_g). One characteristic for this glass transition temperature is that the coefficient of thermal expansion (CTE) changes significantly, having a much lower value in the glassy state. Also the stiffness experiences a pronounced change around this temperature. A measurement curve for both stiffness and CTE of a typical thermoset polymer is shown in Figure 2.

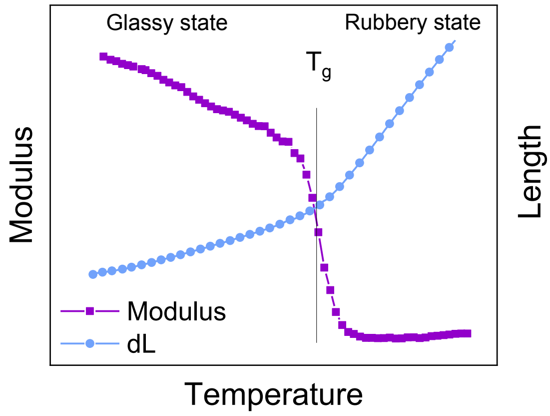

Figure 2. Glass transition temperature visible in modulus and CTE (own measurement).

Polymer ageing effects can be divided in three main mechanisms, namely chemical-, physical-, and mechanical ageing (Gates, 2008). Figure 3 shows examples for these three ageing mechanism. Ageing effects are accompanied by changes in the microstructure. Let us take thermo-oxidative ageing as an example: first, the oxygen molecules need to be able to diffuse in the polymer (depending on the free volume and crosslink density), after which it needs to find either a free branch in order to form a bond or interfere with an existing bond. Due to these additional oxygen molecules, it is possible that the flexibility of the chain is affected.

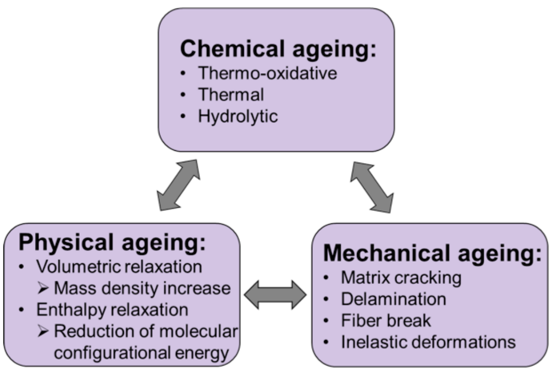

Figure 3. Classification of ageing effects.

Figure 3 shows also that the different ageing effects have an influence on each other. Considering the example from above, thermo-oxidative ageing might lead to relaxation or degradation of the interface between polymer and substrate.

Characterization of ageing effects

Measurement techniques

In order to identify the kinetics and severity of ageing effects, repeated material characterization can be used. Established techniques include the *Thermomechanical Analysis* (TMA, determination of coefficient of thermal expansion and glass transition temperature), and the *Dynamic Mechanical Analysis* (DMA, determination of stiffness over frequency and temperature).

Due to ageing effects mass and density of polymers change. The density can be determined with an Archimedes measurement method, wherein the weight of a sample in air and in a known liquid (e.g. distilled water) are determined. Due to the buoyancy force applied by the liquid, the difference in weight allows for determining the density.

On a molecular level, ageing effects caused by humidity uptake or oxygen accumulation can also be determined by measurements with *Fourier Transform Infrared Spectroscopy* (FTIR) or with *Raman spectroscopy*. In both techniques, which are non-destructive, a sample is exposed to a laser light or an infrared light. The light waves excite the vibration modes of the molecules, which results in an absorption / desorption of the signal. For FTIR the absorbed photons are measured, whereas for Raman spectroscopy, the scattering of photons is measured. Typically, the uptake of humidity or oxygen is characterized, which causes a change in the recorded spectrum. Detailed information about these measurement techniques can be found in (Hollas, 1995) and (Ferraro, Nakamoto, Brown, 2003).

On macroscopic level*, Differential Scanning Calorimetry* (DSC) measurements provide information about the curing behavior and the glass transition temperature. For these measurements, the amount of heat is registered that is necessary to increase the temperature of a sample compared to a reference. For polymers, the heat capacity below T_g is typically higher than above, showing a clear change at T_g.

Accelerated testing

Since ageing effects are a gradual process over time, it is desired to accelerate the effects in order to reduce the time to gather all data. Many ageing processes are thermally activated, which can be described by the Arrhenius equation:

$$k = Ae^{\frac{-E_a}{RT}} \qquad (1)$$

In this equation, k stands for the reaction rate, A is a reaction constant, E_a the activation energy, R the universal gas constant and T the temperature (in Kelvin). The reaction rate increases exponentially with temperature, meaning that the ageing effect can be accelerated by increasing the temperature. When doing accelerated testing, it is important that the desired ageing effect is triggered, without triggering other major effects. For example, if a polymeric material is thermally aged, elevated temperature will accelerate this process. However, if the temperature is too high, the material will burn or melt.

In a study by de Vreugd (De Vreugd et al., 2009), the effects of thermo-oxidative ageing are investigated in detail. It can be seen clearly that the storage modulus (stiffness) increases with increasing ageing time. As discussed before, the reason for this effect is that oxygen molecules diffuse in the polymer mold compound, starting to form oxygen bridges, which causes the crosslink density to increase. A higher crosslink density results in a more compact material with higher stiffness, which is especially visible in the rubbery region (cf. Figure 2, above T_g). Additional experiments with samples stored in a vacuum oven show almost no change in mechanical properties, meaning that temperature alone does not cause ageing effects. The exposure time in the oven was up to two weeks at 175°C, which is initially well above T_g. Due to the increase of crosslink density, the T_g also increases. From these measurements, the kinetic of ageing could possibly be determined. However, to translate this ageing kinetic into temperatures at which the polymers are exposed to during their lifetime, information about the temperature dependency is missing.

Similar results are obtained in the study of Zhang (Zhang et al., 2016), where additionally, by cross section images, the thickness of the oxidation layer is recorded for different ageing times. The thickness of this oxidation layer is used in numerical simulations, where two distinct areas are defined: initial material properties and aged material properties. The simulation results indicate a large difference in stress distribution before and after ageing takes place.

Ageing effects, causing the stiffness to increase, especially above T_g, will result in higher stresses on for example solder joint connections or wire bonds, which can consequently lead to early failure (Hölck et al., 2016), (Manoharan, Patel, Dunford, Morillo, McCluskey, 2018).

For different environmental conditions (temperature, humidity, additional stress factors), different empirical models, such as Arrhenius, Coffin-Manson, Eyring and Peck, to correlate product load and lifetime can be found in the literature (Escobar, Meeker, 2006). These models relate accelerated lifetime experiments to field conditions. However, these models are only able to relate the time of failure and do not provide the state of degradation.

Test strategy

In order to be able to capture the mechanical material properties, as a function of ageing time and ageing conditions, repeated experiments should be performed for samples stored at different accelerated ageing conditions (time and intensity). The goal is to improve numerical simulation models, which can include degradation behavior based on thermal and humidity loading. This requires a change of material properties based on their degradation, as function of time and load (humidity and temperature). This approach is different from the state-of-the-art, where usually only one ageing condition is considered. It is important, that if the polymer in its lifetime is used above T_g, than it is possible to perform accelerated ageing tests above T_g. If this is not the case, performing accelerated ageing experiments above the T_g does not provide sufficient information. An extrapolation between field conditions (what the component experiences during the lifetime) and the accelerated experiments cannot be made. Moreover, at least three different intensities of load conditions should be considered, in order to be able to adequately make an extrapolation to use-case conditions.

A schematical representation of the workflow for taking polymer ageing into consideration in the development process is depicted in Figure 4. As can be seen here, after processing the test samples, a pre-conditioning is proposed, which is necessary for the samples to have a comparable and defined starting state.

Furthermore, the shape of the test samples is of importance. Thin samples should be chosen, such that ageing effects affect the whole sample and exposure time at accelerated conditions can be kept to a minimum. As mentioned before, intermittent experiments should be performed in order to record the rate of change of the polymer. Observations made in pre-studies with thermoset encapsulation materials revealed that ageing times up to 1000 hours failed to reach an equilibrium state of the material. Furthermore, the rate of change was not constant. Therefore, it is recommend to perform ageing tests for longer exposure times such that a constant rate or equilibrium state is reached.

The measurement data should then be transferred to a material model, which can consider ageing effects, depending on the intensity and time the material is exposed to external loadings (e.g. temperature, humidity). Ideally, the change of material properties can be correlated to a physical and/or chemical effect, such as change of crosslink density and flexibility and change of free volume.

This material model should then be transferred to a numerical simulation environment, where components can be analyzed in a cost efficient way.

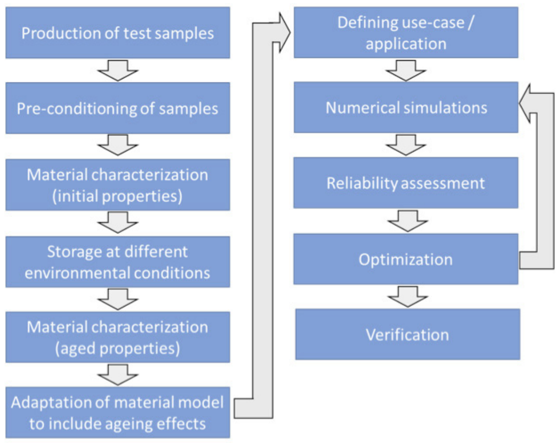

Figure 4. Workflow diagram for consideration of ageing effects in reliability assessment.

Up till now, ageing effects are discussed at material level but not at component level. Finally, it is recommended to include a verification between numerical simulation results and experimental results of the final product.

Conclusions

Knowing the behavior of materials and the change of behavior under various conditions is of key importance for developing reliable products. In the field of electronics, polymers are widely used for multiple purposes. However, the behavior of this material class is mostly obtained and considered in its initial state only. Temperature, humidity and other environmental effects can cause ageing effects in these materials, which can potentially lead to early failure.

Numerical simulation models that can take ageing effects into account can improve the reliability of components, increasing the lifetime of the product, reducing waste and carbon emissions. Since these models are not yet state-of-the-art, this paper aims at clarifying what effect ageing has on polymers, and how these effects can be measured.

Future steps include the characterization of typical polymers used in electronic devices, followed by the development of a numerical workflow which considers ageing effects.

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Can Refurbished Products Feel Like Antiques? The Role of the Neo-retro Design Style on Consumers' Evaluation of Refurbished Products

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Keywords: Refurbishment; Neo-retro Design Style; Antiques; Consumer Response; Circular Economy.

Abstract: This research explores a new pathway to improve consumer acceptance of refurbished products that is inspired by the positive evocations of other used products, such as antique products. Currently, the prior use and age of refurbished products make them a less desirable option because they are perceived to be of lower quality, to have a reduced performance and to be out of fashion more quickly than new products. In contrast, antiques are associated with durability, uniqueness and timelessness despite their prior use and considerable age. In 21 in-depth interviews with consumers, we compared refurbished products with antiques and explored whether refurbished products with a design style evoking the past – the neo-retro style – can lead to more positive associations than refurbished products with a prototypical design style. Our findings provided preliminary support for the value of a neo-retro design style for improving consumers' evaluations of refurbished products. Refurbished products and antiques differ in age, technology and the purpose of having them. Antiques have an emotional value and are kept because of the story and historic values, the appearance and/or durability; refurbished products are kept for purely functional reasons. Similar to antiques, refurbished products following a neo-retro design style do not only evoke more positive associations with old products, such as feelings of nostalgia but can also decrease risks associated with refurbished products as they are perceived to be of higher quality and more durable than refurbished products following a prototypical design style.

Introduction

Refurbished products are second-hand products that were recollected after their first use, subsequently tested and restored into an acceptable state before they are resold (Pigosso et al., 2010). Even though refurbished products are already on the market, they have not yet become a popular consumer choice. Prior research indicates that refurbished products are often perceived as being old, used, and having reduced performance (van Weelden, Mugge, & Bakker, 2016). Although environmental and financial benefits, as well as warranties, offer *rational* reasons to buy refurbished products (Sharma et al., 2016; van Weelden et al., 2016), these incentives are not sufficient for many consumers.

While prior research has identified reasons why consumers do not buy refurbished products, research on how to improve the negative perceptions of refurbished products is sparse (Mugge, 2017). We aim to contribute to the current literature by exploring a new pathway to improve consumer acceptance of refurbished products that is inspired by the positive associations of other used products – antique products. In particular, we explore whether refurbished products with a design style evoking the past – the neo-retro style – can lead to similar positive associations as antiques. Designing the first version of a product in a neo-retro style could potentially create an opportunity for designers to enhance consumer acceptance of future refurbished products by giving consumers additional benefits, such as associating products with a story, high durability and having a timeless design.

Currently, the prior use and age of refurbished products make them undesirable because they are perceived to be a riskier choice than new products (Hamzaoui Essoussi & Linton, 2010; 2014; Harms & Linton, 2015; Michaud &

Llerena, 2011; Debo, Toktay, & Van Wassenhove, 2005). Participants perceive them to break down more quickly, to have reduced performance and to be out of fashion more quickly than new products (van Weelden et al., 2016). Wear and tear signs, signalling prior use, negatively influence consumers' evaluation as well (Mugge et al., 2018). Furthermore, prior use can evoke associations of contamination, the "aversion that one has towards engaging with used objects" (Baxter et al., 2016, p. 2181).

Antiques are, in contrast, products from an earlier period that are considered valuable because they are beautiful, rare, old, and of high quality (Cambridge University Press, 2008; Zolfagharian, & Cortes, 2011). Even though antique products have been used by multiple consumers and look old, most people have little negative associations with them and show positive affective responses (Grayson & Martinec, 2004; Baker, 2012). Antiques evoke feelings of nostalgia, are valuable, and are associated with high durability, a rich history and symbolic meaning.

To evoke positive historic associations with new products, designers can use a neo-retro design style. According to Brown (2001), neo-retro products are technologically up-to-date but show significant design characteristics from the past that evoke feelings of nostalgia (Figure 1). For example, the neo-retro radio Figure 1 has an old wooden frame which antique radios often have, but the display indicates that the radio is modern. We investigate if embodying refurbished products in a neo-retro design style can transfer some of the positive associations of antiques to refurbished products and thereby improve consumer evaluations.

Figure 1. Example stimuli in neo-retro (left) and prototypical (right) design styles.

Method

Participants and Procedure

The principal investigator visited participants (*N*=21) at home to conduct audio-recorded semi-structured interviews. All participants were selected from a university-based research panel. The interviews took place at participants' homes, which enabled participants to show and discuss their refurbished and antique products.

The participants were first interviewed on their initial perceptions towards refurbished products. Second, they were shown 18 stimuli pictures of products belonging to three product categories (coffeemakers, headphones, and radios) that varied in their design style (neo-retro, minimalistic and prototypical). We explained that these products were refurbished, after which participants were asked questions about their perceptions of these products. We compared refurbished products following a neo-retro style to prototypical and minimalistic ones to assess differences between the neo-retro style and other design styles. All stimuli were selected based on a pretest to evaluate their design style. Fifty-four designers and design students (2-34 years of design experience, M=7.34 years, 52% female) rated 45 images of the product categories coffee makers, headphones and radios (see appendix for selected stimuli). The participants rated the degree to which the stimuli show design characteristics that are neo-retro, minimalistic, or prototypical of the product category on a 7-point scale (1 = completely disagree; 7 = completely agree).

Last, we explored the difference between refurbished products and antiques with themes, such as "*Some people think that in antiques, there are some positive qualities, do you see similar positive qualities in refurbished products as well?* ".

Participants received a small compensation (10 euros voucher) for their participation.

Data processing

All interviews were audio-recorded and transcribed by the principal investigator. Subsequently, the transcriptions were analyzed. Codes emerged during two coding rounds, which were inductive. The first five interviews were analyzed in a collaborative session of all authors, which resulted in 144 codes. The remaining 16 interviews were analyzed by the principal investigator and resulted in a total number of 259 codes in the second coding round. The first-order codes were discussed in the research team, adapted and summarized into 88 second-order codes that were sorted into 29 themes (see Table 1 for an example theme). These first- and second-order codes and themes were discussed and agreed upon by the full research team.

Theme	**Second-order code**	**First-order code**
Differences in wear- and tear between refurbished products and antiques	Wear- and tear can be acceptable or even desirable in antiques	Antiques need to have wear- and tear signs
		Small functional defects are nice for antiques (squeaking wheel)
		Signs of repair make antiques more desirable

Table 1. Coding structure.

Results

Differences between antiques and refurbished products

Refurbished products differ in age, technology and purpose.

Furthermore, refurbished products are generally not associated with a story and a historic value because they are younger and more modern than antiques. Additionally, the story of refurbished products is often unknown, while for antiques, it is not. Antiques were also described as being timeless because they are beautiful even though they are old. This is not the case for refurbished products.

Wear and tear in refurbished products were seen as more negative compared to antiques. While in antiques wear and tear signs were expected or even desired, wear and tear signs in refurbished products were tolerated but not desirable. The prior use of refurbished products is associated with a reduced quality and performance rather than making the product more unique and alive as described in antiques.

Role of the neo-retro design style in the evaluation of refurbished products

The design style can determine whether people choose, keep and care about their refurbished products as stated by one of our participants. With respect to the effects of different design styles, our findings provided preliminary support for the value of a neo-retro design style for improving consumers' evaluations of refurbished products.

Neo-retro products evoke associations with old products in terms of looks and usability. Several participants mentioned that neo-retro products reminded them of antiques, Artdeco, vintage or old products.

> Participant 12: *"I think it is an unconscious choice, but I would choose (coffee machine) 1 or 2 because they have an antique appearance and with that comes some sort of eternal value."*

Others said that neo-retro products could appear inauthentic.

> Participant 11: *"Radio 13 and 14 are products that look old, but they are actually not. That's a bit fake."*

Participants also expected neo-retro products to have old functional features, such as mechanistic buttons or wheels and preferred the old-fashioned wheels to newer ones. For example, in the neo-retro radios 9 and 10, participants expected the wheels to make squeaking sounds or to be rickety.

> Participant 6: *"Yes, 9 and 10. We had such a radio in the past. My association with is that the wheel is squeaking. It appears to be old. It could be really modern from the*

> *inside, but you cannot see this from the outside.'*

Neo-retro products reminded people of the 'good old times' and evoked feelings of nostalgia. Multiple participants said that the neo-retro coffee machines 1 and 2 evoked nostalgic feelings about the American sixties (coffee machine 1) or an Italian espresso bar (coffee machine 2).

> Participant 10: *'I would choose this one (coffee machine 2) because I've always liked this one. It's not a real argument, more a form of nostalgia. It reminds me of my vacation in Italy before they used these espresso machines here in the Netherlands.'.*

While some participants said that the feelings of nostalgia also determined participants' product choice for the neo-retro products, others said that nostalgia was good but that the quality of the object was still more important. Neo-retro products looked more durable, solid, robust and reminded them of the good quality of the past. The quality of the past was said to be decreased if wear and tear signs would be present on the object but wear-and-tear was more acceptable in neo-retro products than on products following a prototypical design style. The quality of the neo-retro product also made participants trust and care for it.

> Participant 8: *'I think that the quality is more or less the same for all products but that (coffee maker) 1 and 2 are better than number 5 because they (1 and 2) are classic models like they were built in the past. In the past, everything was built so that it would last for as long as possible. At the moment for just 3 years because otherwise, they don't earn enough money anymore. So, I think that 1 and 2 could be more durable.'*

Some participants said that products following a neo-retro style evoke associations with the products having a story.

> Participant 14: *'I think that some refurbished products have a story. Not all, of course. […]. It depends on your own interpretation. (coffee machine) 1, really has a story, and the other ones don't have that at all. I think it is an unconscious choice. A so-called unconscious choice that is probably related to my memories. The weird thing is that I have no memories of it because I had not been born in that time yet.'*

Other participants, however, said that the design of the product did not make them believe that the product had a story.

Participants said that neo-retro products, because of their old appearance, looked unique, prominent, extravagant, beautiful and more attractive than other products. Neo-retro products were also described as more charming. One participant also said that making the product look old gives the refurbished product an extra value because its appearance is more attractive. Participants like the use of wood in radio 9 and thought that the metallic parts of headphone 6 and coffee maker 1 and 2 made the products more robust.

> Participant 2: *'It looks like an old-fashioned radio (radio 9). And that wooden cover, not plastic. I think that is just more beautiful. That is the reason why I would choose that one.'*

Plastic was described to be less desirable than wood and aluminium and to become dirty quickly. Metal and brushed aluminium were deemed desirable because of two reasons: First of all, because metal products were perceived to be more repairable than plastic products and it was easier to determine whether products are in a good state. Wood was associated with warm feelings and the product having a story.

	Antiques	Prototypical refurbished	Neo-retro refurbished
Story	Have a story which is related to prior life of the product.	The story of refurbished products is unknown and not considered interesting.	Neo-retro products are more likely to have a story.
Historic value	Antiques have an historic value because they are from another time and design style.	Refurbished products do not have a special historic value yet.	Neo-retro products remind people of the past (e.g. 50s and 60s).
Emotional value	Antiques have an emotional value even if not used anymore. They also have a high financial value.	Value is determined by functionality of product and not by an emotional value.	Neo-retro products have more emotional value because they evoke memories and feelings of nostalgia.
Quality	Associations with high quality of the past.	Associations with lower performance and quality. The high quality of refurbished products is essential.	Neo-retro products are perceived to be more durable and evoke associations of the quality of the past similar to antiques.
Wear and tear	Wear and tear signs are acceptable or even desired in antique products.	Refurbished products should not have wear and tear.	Wear and tear signs are more acceptable on neo-retro because of the use of wood and metal.
Unique design	Antiques have a special design because of their design period and because they are rare.	Most refurbished products to not have a special design because they are still in mass production.	Neo-retro products were described as unique, prominent, extravagant, and beautiful.
Timelessness	Antiques are from a prior period but still considered beautiful.	Refurbished products are often perceived to be out of fashion in the near future.	Neo-retro products are described as being timeless.

Table 2. Differences between Antiques, prototypical refurbished products, and neo-retro products.

Participants also mentioned that neo-retro products could have a timeless design because the neo-retro design style is less vulnerable to trends.

> Participant 4: *'I think I would choose number 6 (to be beautiful for the longest time) because it just seems more timeless.'*

Discussion

This research explores how refurbished products and antiques differ and whether the positive associations that people have of antiques can be translated into the design of refurbished products, in particular, by employing a neo-retro design style.

While refurbished products and antiques generally differ in use, age and durability, a neo-retro design can potentially have a positive influence on people's perception of refurbished products. While the prior use in antique products is usually seen as something positive because of the historic value, uniqueness and high quality of antiques (Grayson & Martinec, 2004; Baker, 2012), the prior use of refurbished products is seen as negative (Mugge et al., 2018); refurbished products are often perceived to have a lower quality and durability than new products (Michaud & Llerena, 2011; Debo et al., 2005). Prior research has demonstrated that new products following the retro design style remind people of old products and can evoke feelings of nostalgia (Brown, 2001). Our findings indicated that refurbished products in the neo-retro design style do not only evoke positive associations with old products, such as feelings of nostalgia but can also decrease risks associated with refurbished products. Refurbished products following a neo-retro design style are perceived to be of high quality and more durable than those following a prototypical design style. Creating refurbished products with a neo-retro design style could potentially increase the consumer acceptance of refurbished products.

Even though refurbished products in the neo-retro design style evoke positive associations with antiques, the neo-retro design style is not everyone's cup of tea and may not be a good strategy to enhance the consumer acceptance for all consumer groups. Mugge et al. (2017) demonstrated that different consumer groups have different consumer preferences for design styles. Hence, it is necessary to provide refurbished products that are desirable for different consumer groups.

Whether designing a product in a neo-retro style is a good design strategy to enhance the consumer acceptance of refurbished products is also a question of the product category of the refurbished product. Product categories that are not highly technological, such as coffee machines and water kettles could benefit from the positive effects of the neo-retro design style. For products that are continuously advancing in terms of technology, making a product look old might not be beneficial.

However, for products that are circulating among multiple users, such as in sharing systems, the neo-retro design style might not be a good strategy if the product is only accessed briefly for functional reasons (Tunn et al., 2019). Other design styles could offer similar benefits as it is not sensitive to fashion cycles (Mugge et al., 2005) and need to be subject to future research.

Future research needs to be conducted to translate and further validate our findings into design guidelines for designers. Additionally, it needs to be explored what makes some neo-retro products attractive whereas others are considered inauthentic and which design characteristics of neo-retro products evoke the desired associations with antiques; is it the choice of materials, the form or design characteristics of the past?

Potential other ways to stimulate affective reactions towards refurbished products next to design styles should also be addressed in future research.

A limitation of our research is that we did not investigate choice settings in which participants compared refurbished neo-retro products with new ones. In real life, this is the choice that consumers make in a purchase setting.

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Appendices

1

Neo-retro	Minimalistic	Prototypical
MEAN	MEAN	MEAN
6.47	2.67	4.33

2

Neo-retro	Minimalistic	Prototypical
MEAN	MEAN	MEAN
6.13	2.67	4.20

3

Neo-retro	Minimalistic	Prototypical
MEAN	MEAN	MEAN
4.40	3.93	4.60

4

Neo-retro	Minimalistic	Prototypical
MEAN	MEAN	MEAN
2.67	3.35	4.40

5

Neo-retro MEAN	Minimalistic MEAN	Prototypical MEAN
6.0	3.14	3.86

6

Neo-retro MEAN	Minimalistic MEAN	Prototypical MEAN
5.93	1.64	2.93

7

Neo-retro MEAN	Minimalistic MEAN	Prototypical MEAN
3.29	4.79	5.57

8

Neo-retro MEAN	Minimalistic MEAN	Prototypical MEAN
2.79	3.64	4.14

9

Neo-retro	Minimalistic	Prototypical
MEAN	MEAN	MEAN
6.15	4.0	5.38

10

Neo-retro	Minimalistic	Prototypical
MEAN	MEAN	MEAN
5.62	4.00	5.38

11

Neo-retro	Minimalistic	Prototypical
MEAN	MEAN	MEAN
3.23	2.62	5.23

12

Neo-retro	Minimalistic	Prototypical
MEAN	MEAN	MEAN
3.86	3.36	4.86

A Comparative and Exploratory Study of Toy Products in the Circular Economy

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Keywords: Circular Economy; Toys; Lifetimes; LCA; Product Design.

Abstract: This paper concerns relatively unexplored research concerning the environmental impact of children's toys. This segment represents a challenge in the circular economy, a priority area concerned with the EU´s ambition of drastically reducing the use of petroleum-based plastics in Europe, along with the optimisation of waste as valuable resources for design. The paper discusses the methodological approaches used in an ongoing explorative study analysis of sixteen toy product cases through empirical research concerning the life cycle impact, and specifically, the end of life implications of children's toys, focusing on eight distinct toy categories spanning an age range of six months to eight years old. A mixed methods approach was used, with three distinct stages: Individual component level life cycle analysis, the use of Circular Product Design assessment and improvement tools, and semi-structured interviews of three key stakeholders to evaluate the toys, complemented by the analysis of the economic depreciation of the toy's value. Following this analysis, designers sought to improve the circularity of the products using one of four circular product design approaches, designing for: "slowing the loop", "closing the loop", "bio-based loop" or "bio-inspired loop" (Mestre & Cooper, 2017). The preliminary findings of the research show that higher value branded items significantly outperformed their less expensive counterparts in both the LCA and stakeholder research, due to higher value and their recognition in the second hand market leading to 2nd or 3rd lives, slowing the loop. Opportunities for improvement were identified to further improve toy circularity and close the loops through enhanced product attachment and circular business opportunities. Opportunities for bio-based solutions were also identified for lower value products, linking lower cost and shorter intended life to bio-based solutions, particularly in the craft and outdoor toys examples.

Introduction

There is little information available on the prevalence of toy waste and end of life prospects, and few publications concerning the outcomes of life cycle analysis of toys, and those that do exist are typically limited to singular examples (Muñoz, Gazulla, Bala, Puig, & Fullana, 2009). The toys industry represents an important socio-economic contribution to the European Union, which exported 1.91 Billion toys in 2016 (Toy Industries of Europe, 2017), whilst globally, toy sales reached $27.4 billion (US/$) between January and September 2018, with an annual growth rate of 1.5% (NPD Group, 2018). Such large scale has significant implications for the circular economy.

Children's toys have short initial lifetimes due to child development cycles, so the initial user will typically outgrow them more quickly than other consumer products. The nature and the mode of use typically also means that children's toys are often constructed to be highly durable and non-toxic, and therefore of higher quality materials and material intensive. Additionally, a growing number of digital toys also have energy use implications due to embedded electronics, which only further complicates the end of life strategies. The toy sector involves a diversity of product consumer typologies, representing a multiplicity of design solutions, and thus the use of different types of materials, processes and technologies. Meanwhile, research states that approximately 80% of a product's environmental impact can be determined within the design phase (McAloone, T. C., & Bey, N. 2009); it is therefore important that the key factors, which affect product life, and lead to end of life implications and/or a lack of circularity are understood by designers.

Methodology

This paper presents an exploratory study, comprising threefold mixed methods approach, including quantitative and qualitative methods.
First, a quantitative research involving a component-level simplified LCA was conducted using the EcoAudit tool in the Cambridge Engineering Selector (CES) (Ashby et al. 2012) at level 3 (the highest level) to ensure that the greatest range of materials and processes were considered. The CES software package uses a database of over 3000 materials (Mustafa, A et al, 2014), enabling users to access the impact of material choices and the associated embodied energy within the five key life cycle stages, material processing, manufacture, transportation, use and end of life (EOL). Whilst this tool would not be considered a full LCA, rather a simplified LCA tool it was selected for its intensive material driven database, the simplicity of the interface and ease of use for non-material specialist product designers.
The tool permits materials and processes to be quickly selected with a mass being entered for each component to build up a list of components with associated embodied energy and CO2 footprints. The user is asked to specify a lifespan duration and any energy or resource use also specified and calculated. The ability to build a product up from components in this manner also permits components with higher impacts to be identified rapidly permitting designers the freedom to test iterations for reducing the environmental impact in real time for example by:

- Substituting a material or process
- Changing a manufacturing destination or shipping mode.
- Extending the use phase or changing the desired power source i.e. from a disposable to a rechargeable battery
- Changing the end of life destination for which there are five options: landfill, combustion for energy recovery, recycling, re-engineer, and reuse.

Once all stages are completed the software produces a detailed component level report documenting the embodied energy in MJ and the CO2 footprint in kg. The consideration of the duration of the lifespan of the product also permits this data to be calculated per year of life a useful output in this study.

Second, a qualitative research based on the Circular Product Design: Multiple Loops Life Cycle Design Strategies (Mestre & Cooper, 2017) was conducted to assess the circularity aspects of the products.
Built upon earlier life cycle design principles (e.g. the LiDS wheel, Brezet & Hemel, 1997), this tool approaches design from two levels – 'technical' and 'biological' cycles, based upon the circular economy's technical and biological nutrients, and proposes four complementary strategy groups within these two cycles, addressing the eight stages of a product's life.

Strategies for technical cycles comprise slowing and closing material loops. While both strategies share some aspects fundamental to sustainability (e.g. utilising cleaner materials, reduction in weight and volume, lower energy production), the former concerns slowing material flows in each life cycle phase, and includes material considerations such as 'design for durability', 'product life extension', as well as the user added-value perspective, including 'emotionally durable design'. The latter, conversely seek to ultimately eliminate the flow of waste from the lifecycle – as in nature – by careful consideration of materials (e.g. biodegradable, clean, and reusable) and consideration of post end-of-life (e.g. designing with disassembly and recycling in mind).
Strategies/design for biological cycles, are design solutions that occur in, or are inspired by natural systems of the earth, comprising 'bio-inspired loop strategies' and 'bio-based loop strategies. The first adopts a biomimetic approach, exploring, analysing and replicating the ecologically perfect systems found in nature at the micro (e.g. materials inspired by organic structures) and macro (symbiosis between industries) levels. The second, on the other hand, seeks to directly utilise biological materials as, individually, they are the least impactful to the ecosystem (though landfilling organic materials on an industrial scale remains significantly impactful).

Third, complementary qualitative methods were used to address user considerations, including:

- Semi structured interviews with three key stakeholders: a parent, a childcare worker and a second-hand retailer (typically a charity shop employee) to compare and evaluate both toys in each category. The interviews sought to understand the purchasing decisions, durability perceptions and experiences and the relative value and desire for each toy in the second-hand market.

- An analysis of the economic depreciation of the toy's value, comparing the brand-new recommended retail price (RRP) against second-hand values obtained on online auction sites or valuations from the second-hand retailer employees.

Study Sample / Product Categories

In order to select a sample of toy products, an analysis of the toy market was conducted and the following eight categories were identified to evaluate sixteen toys:

- Construction Toys
- Craft based Toys
- Early Development (Educational) Toys
- Electronic (Educational) Toys
- Playsets
- Outdoor Games and Toys
- Outdoor Ride on Toys
- Soft Toys

These categories were chosen to represent the diversity in the toys market, but are by no means exhaustive. This paper however will only consider 10 toys across the 5 italicised categories above due to the data constraints at the time of writing the paper. Within these categories, key brands and market leaders were considered and two toys were purchased from each category. Where possible for each category, a high value recognisable brand and a lower value non-branded alternative were selected to be analysed by product design students. The toys were purchased second-hand where possible, in recognition of the focus of the study, to reduce the environmental impact. However, this was not possible or appropriate in all cases.

Results

Both qualitative and quantitative research has been conducted to assess the critical aspects of the toys industry in the context of the Circular Economy paradigm, by assessing in detail, a sample of products. The results from the qualitative and quantitative methods were largely complementary. With aspects of the qualitative research highlighting the longer lasting nature of the higher value branded toys, due to more durable construction, higher levels of market recognition and lower cost depreciation, ensuring a longer life, which helped to overcome the initial manufacturing and transportation impacts from the LCA. General findings are presented below with more detailed examples given for three of the toy segments 'Playsets', 'Construction Toys' and 'Craft based' toys highlighting the potential to slowing the loop, closing the loop and adopting bio-based loop approaches respectively.

Quantitative Findings

The LCA's undertaken considered all components in each product and took into account the relative number of items and volume of each toy to ensure a more equitable comparison. For example, the data was weighted to permit both playsets to be compared due to the non-branded set being over twice the weight and size of the branded set, accommodating any disadvantages through the increased product weight. Where possible the country of origin of each toy was thoroughly researched and used to calculate the distance travelled from the manufacturing site to a notional port in Felixstowe by ship, with the reminder of the journey by road to a store in Nottingham UK. For instances where only the country was stated and the exact manufacturing location unknown, assumptions were made choosing the most likely region for example in China, Guangdong is the region that produces the highest number of toys. Where companies listed components being made across several sites such as Lego, a proportion of the components were calculated from each location in accordance with their production levels from each location accordingly. Key details are shown in Table 1.

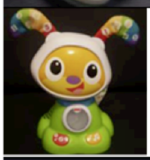
The LCA findings considered data from the stakeholder interview findings, which informed the potential lifespan in years. This considered the age range suitable, the potential for a second life, likelihood of resale and the perceived durability. This was higher for construction toys than for developmental educational toys, as the suggested age range is broader and their value higher. Such factors were used to calculate the relative second and where possible third lives, from the feedback received from the parents, childcare workers and second-hand retailers. Of particular interest to the study was the value placed on the items by a second-hand retailer, if the used value given was particularly high then the product could be deemed to have a potential third life as in the case of the higher value branded

developmental educational toy and construction toys. Where an item was not expected to be durable or have resale value to the second-hand retailer, a value of its suggested longevity was drawn from the age range of the toy and was applied accordingly considering only its initial first life.
The LCA typically showed that some of the high value branded toys had higher initial impacts due to the materials and processes used in construction and or a higher weight affecting the impact of the transportation stage. However, this was outweighed by the potential for a second or third life. The early development toys were a good example of this as the lower value toy was made from PVC and HIP's and weighed only 0.45 kg, whilst the more desirable and durable higher value wooden example made from solid Ash weighed 1.9kg over four times the amount affecting the LCA shipping impact. However, the strong preference for this higher value toy from all stakeholders and high value placed upon the product at the end of life meant that it was more likely to have an extended life meaning that the CO2 (kg/year) equivalent impact, would be lower. This combined with the lower embodied energy in material and processing meant that it had less than half the annual impact when compared to the lower mass and value plastic stacking toy.

Qualitative Findings

The qualitative measures enabled key trade-offs to be estimated with more accuracy for inputting into the LCA. For example, product life was determined from the responses given by the three stakeholders and any relative value of the toy at the end of its first life. This value or lack or value was based on used sold prices on online marketplaces and auctions and the evaluation from the second hand retailers, who for instance noted that some of the cheaper items would not be suitable for re-sale and others such as craft products would be used up and so were limited in this respect.

The qualitative research typically found that the three stakeholders had a greater preference for the higher valued branded products. These were perceived as higher quality and more durable than the lower cost unbranded items. Childcare workers were more likely to purchase the higher cost branded items due to the need for hardwearing toys that endure extensive use.
The second-hand retailers valued the higher value branded goods more highly with higher resale prices expected evidencing a lower depreciation from the RRP than the lower value products. Furthermore, the second hand retailers stated that they would not sell the lower cost unbranded soft toy and early developmental educational toy as they were too cheap and unlikely to be desirable. Contrastingly, the higher quality developmental educational toy was valued at the same price used as the RRP of the item new by the second-hand retailer. Parents interviewed were also more likely to donate or sell the higher initial value toys than the lower value unbranded versions.
Both of the construction toys were universally more acceptable to all three stakeholders, with little difference between the construction sets as expected, because both were higher value branded goods. Both were considered appropriate for resale, having value for a second or even a potential third life, second hand value was also strongly supported with the values of complete or even incomplete mixed sets online. The Playsets also fared well in this respect, however whilst parents felt both the higher value branded and lower value unbranded items could be resold. Parents typically only felt happy selling felt the branded playset stating that they would donate the unbranded playset. Based upon online used sale values the difference in price depreciation was noticeable between the branded playset 8.66% per year over 6 years' vs the unbranded playset 14.3% a year over 4 years despite the unbranded product costing half the branded product new. This could suggest therefore that the willingness to resell toys could be linked to the value and likely return, which in the case of the lower value item would be less appealing and more convenient and time effective to instead gift to charity. However, discussions with the three key stakeholders, in particular the second-hand retailers did highlight aspects were multiple life toys could be improved to prevent for instance loss of parts in the early development stacking toys, that would otherwise affect its potential for resale and a second life.

	Toy	Assumed Life (Years)	Weight packaged Kg	Manufacture location	Equivalent Total Energy for 1st life (MJ)	Equivalent Annual burden (MJ/year)	Equivalent Annual burden CO2 (kg/year)	End of 1st Life potential
	Construction Toy - Lego	5	1.1	Various, mainly China	93.8	18.8	0.742	Resell/ Donate
	Construction Toy - Meccano	3	0.2	France	4.85	1.62	0.108	Resell/ Donate
	Higher Value Craft Toy Play-Doh creations	2	0.81	China	47.2	23.6	1.08	Donate plastic parts, tools etc
	Lower Value Craft Toy Unbranded Squand	0.5	0.75		28.5	28.5	0.614	Landfill
	Higher Value Early Development Toy John Lewis Wooden stacker	1.5	1.9	Tjanjin, China	44.2	21.1	1.05	Resell/ Donate
	Lower Value Early Development Toy Bruin Plastic bear stack	1	0.45	Guangdong, China	47.1	47.1	2.22	Landfill
	Lower Value Electronic Toy - LeapFrog LapPup	2.5	0.29	Indonesia	84.9	34	2.23	Donate
	Higher Value Electronic Toy - Fischer Price BeatBop Wow	2.5	0.42	China	150	60.2	3.76	Donate/ Landfill
	Higher Value Playset PlayMobil Playset	7	0.5	Hamburg, Germany	43.4/86.8*	6.21/12.42*	0.263/0.518*	Resell/ Donate
	Lower Value Playset SuperPlay Playset	5	1.2	Guangdong, China	123/102.5*	24.6/20.5*	1.05/0.875*	Donate

*For Playsets a weighting has been applied as shown in italics for an equivalent weight of 1 kg to account for the difference in size and weight of the two sets.

Table 1. Key considerations and outcomes from the LCA data for five toy typologies.

Life Cycle Design Phase	Slowing the Loop Play Set Toy	Closing the Loop Construction Set Toy	Bio-based Loop Craft Set Toy
Materials extraction - Selection of low impact materials	Preference for recycled high quality durable plastics to enable a long life and ease of cleaning.	Preference for recycled high quality durable plastics to enable a long life and ease of cleaning.	Sole use of bio based materials: Modelling dough made from organic / biological materials Supplied tools and moulds made from a biodegradable plastic PLA
Processing - Reduction of material use	No change to existing	Material is able to be reground and recycled where necessary due to the use of high quality materials initially.	No change to existing
Manufacturing - Optimisation of production techniques	No change to existing	Existing manufacturing to use recycled content from broken or worn parts reground and remoulded into new components	Use of non-toxic additives and natural preservatives where needed. The tools and moulds still use optimized plastic technology.
Transportation - Optimisation of distribution	No change to existing - made in Europe currently	National depots to handle returned and exchange sets in a subscription model.	Biodegradable in the home environment reducing the need for transportation at end of life.
Use - Reduction of impact during use	Alternative to batteries for any functional aspects ● Solar or human power ● Improved second hand viability.	Reusable recycled cardboard packaging supplied to enable sets to be returned for reuse/exchange in a product service system.	Potential to for parents to make replacement dough at home negating transportation impacts.
Product life extension - Optimisation of lifetime	● Long lasting design ● Replacement of components via an online store ● Ease of cleaning advice on cleaning supplied. Information on end of life to encourage reuse ● return to manufacturer's online used store ● donation to a charity/ second hand retailer	● Highly durable product ● Timeless design ● Modular design ● Service based subscription system ● Current high value in the 2nd hand market ● Online platform for instructions and ideas ● Replacement parts for sets easily sourced via website	Not applicable as focussing on bio-based, shorter lifetime is more appropriate.
End-of-life disposal - Optimisation of end-of-life system	● Resale of used sets through a dedicated online store ● Linked to the manufacturer to maintain the value and encourage multiple life's	Take back program with options: ● donate to charity, ● refurbished sets reused in the service system ● recycle raw materials directly in new products.	Instructions on composting at home or through local composting schemes ● Biological materials ● Nutritional value of material ● Educational benefit to children
New concept development	Develop the manufacturer's support role further beyond sale through an enhanced online presence.	New subscription service, manufacturer retains overall control over the product. ● User receives different sets in a mail return system ● Community model to swap sets in local area ● Online algorithm instruction builder - infinite construction from combined sets.	Change of materials and focus to move from an overly long lasting product to product with an optimised bio-based life span.

Table 2. Qualitative Circular Product Design Improvement Suggestions.

Circular Product Design Assessment

The Circular Product Design: Multiple Loops Life Cycle Design Strategies (Mestre and Cooper, 2017) and its defined four loops criteria list was compiled to both assess the circularity aspects of the products, while also generating qualitative guidelines for product improvements in relation to one priority "circularity" loop. From the five toy typologies considered in this paper, three toys (early development toy, playsets, electronic educational toy) utilised strategies for slowing material loops, while one toy (construction toy) utilised the closing the loops and another one (the craft toy) used the bio-based loop strategies with solutions that occur in the biological system of the Earth, such as the use of biodegradable materials and processes. For the purposes of the current paper, three examples are presented in table 2 in order to illustrate the use of the Circular Product Design (CPD) assessment and improvement tool.

The analysis of which shows that the use of these differentiated CPD strategies provides improved solutions with different strengths and trade-offs: Slowing the Loop strategies aim to extend/delay the product end of life (through increased embodied energy/higher material quality), Bio-based Loop strategies aim to maximise biocompatibility (and biodegradability at end of product life), while Closing the Loop strategies provide a more holistic approach, focusing on optimising the material and energy flows throughout the product life cycle.

Conclusions

This paper considers a relatively unexplored area regarding end of life destinations of toys, particularly multiple toys across differing segments. This paper demonstrates the use of a mixed quantitative and qualitative methodological approach to effectively support the improvement of the circularity aspects of products throughout the whole product life cycle.

With respect to the Circular Product Design assessment and improvement tools, there are implications in materials use and efficiency when considering the expected product life in the design process. This affects the final product characteristic, performance/efficiency, materials consumption and embodied energy. These are critical aspects to consider in Circular Product Design, both on the design, production and end of life phases and no single 'correct' solution exists. The circular economy as a whole possesses scope greater than the design level.

Further work could include the development and testing of methods for increasing the adoption of CPD in the toy industry, policies for the regulation of the toy industry in light of the circular economy, and increasing consumer awareness on, and demand for, circular products, as well as the development of safer and more suitable materials for the toy industry.

This study is exploratory in nature and further work is required in light of the findings and approach taken. This study considered the stakeholder views concerning the longevity and destination of toys but more work is needed to understand the subjective attitudes of consumers particularly regarding their perception of second-hand toys. Positive attitudes towards second-hand toys are crucial for the potential of 2nd and 3rd lifetimes. Are parents or family members less likely to purchase second-hand toys in the early development group for infants? Are some toys more preferable due to the use of materials that ease and permit cleaning? For example, the ability to wash Lego bricks vs say a soft toy, especially one that incorporates electronics. Answers to such questions will need to be addressed in future avenues of research.

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Circular Economy Policy at a Crossroads: Encouraging Durable Products or Enabling Faster Cycling of Short-lived Products?

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Keywords: Circular Economy; Policy; Product-Service System; Non-Ownership; Business Model.

Abstract: Non-ownership models, where firms rather than consumers remain product owners, are advocated as a way for firms to prolong product lifetimes and contribute to a more Circular Economy. However, it has been suggested that such models could actually encourage 'faster cycling', meaning earlier product replacement and shorter product lifetimes. Within recent policy discussions, product durability to prolong product lifetimes has become a key focal point. This paper focuses on how policy can encourage product durability and prolonged life for products distributed through non-ownership models. The paper explores the relationship between policy related to product lifetimes and non-ownership models through a review of existing and proposed policy for two product categories: mobile phones and office furniture. The results suggest there is a gap in policy regarding non-ownership models. While existing policies may address some concerns of faster cycling, additional policy propositions from the European Commission should be considered. In particular, while relevant policies related to either studied product group are identified, the policies with most potential come from outside the existing legislative framework on eco-design and resource efficiency measures. Thus, the findings are not only useful for academics and policymakers in the field of Circular Economy and circular business models, but also to practitioners working in firms where these policy frameworks are relevant.

Introduction

Concerns about the environmental impacts of resource production and consumption have sparked a variety of new policy discussions and legislative proposals within the European Union (Milios, 2018). With the goal of contributing to a more Circular Economy, one focus has been on extending the value of products and resources (European Environment Agency [EEA], 2017). Particular emphasis has been placed on the 'inner loops' of the Circular Economy concept, or how to extend product lifetimes, as keeping existing products in use for longer periods of time can theoretically slow consumption and displace new production (International Resource Panel, 2018).

Within the political discussion, one aspect of achieving extended product lifetimes has focused on designing more durable products. New EU regulations have begun to address durability by providing minimum lifetimes for vacuum cleaners, domestic washing machines, and lighting products (Bundgaard, Mosgaard, & Remmen, 2017). By creating products that are more durable or easily repairable, consumers may be encouraged to use products longer or even buy second-hand instead of new (Bakker, Hollander, Hinte, & Zijlstra, 2014).

At the same time, the idea of Circular Economy has sparked a resurgence of interest in product-service systems (PSS), specifically PSS non-ownership models that provide 'access over ownership' (Bocken, Pauw, Bakker, & Grinte, 2016; Lacy, Keeble, & McNamara, 2014). In fact, moving towards a 'lease society' has been mentioned within the political debate (Merkies, 2012). In non-ownership models, firms, instead of customers, remain product owners over the product's use.

Non-ownership models could help make the business case for firms to undertake product redesign, create more durable products, and contribute to extending product lifetimes (Tukker, 2004). The argumentation is that these models incentivize firms to create more durable products in order to decrease service costs over product lifetimes and reduce the need for new manufacturing (Stahel, 2001). However, these models could also encourage earlier product replacement and shorter product lifetimes by making it easier for customers to switch to the newest and latest product models (Wieser, 2016).

This paper will explore existing and proposed EU policy instruments to better understand how they address product durability and longer lifetimes in the context of non-ownership models. We present a review of EU policies related to two different products as a starting point for our investigation. Policymakers, business developers, and academics may use the findings to help facilitate discussions around non-ownership models and product lifetimes.

Non-ownership models

What happens over a product's lifetime during a non-ownership model is not always transparent or clear. Evidence is scarce that firms design such models with a systems approach in mind (Mont, 2002) and product redesign is not always undertaken (Whalen, 2017). There are also no guarantees that the product is actually redistributed again or used for the entirety of its potential product life, as highlighted by recent media and documentaries (Korus, 2019; Huang, 2018).

Although products within the EU that are not used for the entirety of their possible lifetimes may be directed to other uses and purposes (such as exported to other countries for reuse), the exact fate of these products and their final use or disposal is unknown (EEA, 2012; 2014). Moreover, even if such products were collected for recycling, the system would most likely experience significant efficiency loss due to inefficient recycling technology and limited recovery of materials (Andre, Ljunggren Söderman, & Nordelöf, 2019).

A possible lack of accountability can be discerned in such non-ownership model practices, and it is unclear if existing and proposed policies aimed at encouraging product lifetime extension address these concerns. Although numerous policy instruments are being discussed related to extending product lifetimes (Maitre-Ekern & Dalhammar, 2016) and macro-level policy is seen as a way to encourage circular business practices (Whalen & Whalen, in press), it has yet to be seen how existing and proposed policies encourage product lifetime extension in non-ownership models. In this paper, we aim to develop a better understanding of this by answering the following question: *How do existing and proposed EU policy instruments address durability and longer lifetimes in the context of non-ownership models?*

Cases Studies: Mobile Phones & Office Furniture

As policy measures are often product-focused, we investigate this question by conducting a case study of two specific product categories that have received recent interest from policymakers: mobile phones and office furniture. We first review existing and proposed legislation related to each product category and then reflect on how each would address product life extension (product life extension) in non-ownership models.

Results

Existing regulatory frameworks targeted at product life extension for mobile phones and office furniture are focused on ownership models (see 'Existing policy measures' in Tables 1 and 2). In fact, a variety of frameworks already exist that encourage product life extension on the consumer-side such as minimum guarantees of two years (Svensson et al., 2018) or mandatory availability of supply parts in some countries (EEA, 2016). However, these rules vary from country to country and, even then consumers are often unaware of such measures (European Commission, 2015). Thus, many proposed policy measures aim to increase awareness of consumer rights, such as by labeling (Gåvertsson, Milios, & Dalhammar, 2018).

Other identified *proposed policy measures* can be found under 'General policy recommendations for product life extension' in Tables 1 and 2. These include additional consumer-oriented approaches to protect consumers and encourage product life extension such as guaranteed access to spare parts (Whalen, Milios, & Nussholz et al., 2018; Watson et al., 2017; Sanfelix Forner, Mathieux, & Fulvio, 2014). Green Public Procurement (GPP) is also part of the policy discussion (Öhgren, Milios, Dalhammar & Lindahl, 2019; Forrest, Hilton, Ballinger & Whittaker, 2017). Green Public Procurement (GPP) can be a powerful policy approach as it creates demand for environmentally advantageous options in public purchases, thus creating a pull effect in the market by scaling-up relevant business operations (Renda et al., 2012). The findings are summarized in Tables 1 and 2.

Core aim	Existing policy measures	General policy recommendations for product life extension	Recommendations to address product life extension in non-ownership models
Enable customers to extend product lifetimes by creating awareness of product lifetimes & designing longer lasting phones	• Minimum legal guarantee: EU Consumer Sales Directive: 2 years; Sweden: 3 years; Norway: 5 years; Finland: expected lifetime • France: The Act (Law no. 2014-344) addresses durability and lifespan of consumer goods, including the introduction of extended product guarantees from 6 months to 2 years	• Enforce sellers to inform customers of their rights, labeling of warranty rights, and declaring expected lifespans • Create specific eco-design criteria for mobile phones • Ensure software support through minimum guarantee period	• GPP criteria requiring longer use of products for extended number of years (by product category, e.g. minimum 3 years for mobile phones) • Mandatory priority of software upgrade over hardware upgrade
Enable widespread reuse & increase consumer confidence in second-hand products		• Adopt refurbishment certification standards • Quality labeling for re-used ICT equipment and re-sale opportunities • Non-destructive disassemblability of key components • Adjust WEEE schemes and lower VAT or tax breaks for repair/refurbished electronics	• National re-use targets, to enable a stable market for good quality second-hand products and increase sourcing from 'non-ownership' models • Re-use/recycling certificates – auditing, to ensure responsible treatment and re-use opportunities for EOL products • Data erasure protocols and commonly accepted methodology for protecting the privacy and confidentiality of customer data and enabling re-use of ICT equipment • EPR rules to recognize the need for retrieving functional spare parts from EOL products and redirecting them to repair services and second-hand markets
Increase availability of spare parts	• France: The Act (Law no. 2014-344) - obligation of retailers to inform customers about the time horizon that spare parts will remain available for a product	• Provide access to spare parts for expected lifetime	• EPR rules to recognize the need for retrieving functional spare parts from EOL products and redirecting them to repair services and second-hand markets
Address the variable quality and supply of phones coming back		• Information campaigns on the value of used electronics • Encourage leasing models (starting with public sector)	• Re-use/recycling certificates – auditing. Within this policy approach, there is a possibility for auditing each EOL batch and depending on age and quality it could be either redirected to re-use or recycling • Strategic use of GPP tenders to include more PSS requirements and provisions for extended use-phase of products purchased (with associated repair services)

Table 1. Existing and proposed policy measures related to product lifetimes of mobile phones.

Discussion & Recommendations

In terms of how existing and proposed policy measures address product life extension in the context of non-ownership models, it appears there are limited polices that target life extension when the shift of ownership changes from customer to company. In fact, non-ownership models could perhaps even provide a means for companies to protect themselves from proposed policies. For example, a product producer required to provide guarantees for five years could instead provide the product via a non-ownership model that upgrades the customer to a new product every two years, thus avoiding the minimum legal guarantees. This gap in policy could be addressed by taking a lifecycle perspective for non-ownership models. The authors propose some measures in the final columns of Tables 1 and 2, and conclude this paper by expanding on three proposed recommendations:

Service-Oriented GPP

Currently, GPP criteria mainly focus on the use phase of the product throughout its life within the public organization; elements of resource efficiency in production and disposal after use are not entirely considered (Wasserbaur & Milios, 2019). Additionally, public sector requirements can also be in direct contradiction with product life extension as is now the situation for ICT equipment (e.g. laptops and mobile phones) upgrades in Sweden where replacement happens in regular intervals, irrespective if the product is fully functional or damaged (Crafoord, Dalhammar, & Milios, 2018).

Furthering developing GPP criteria that take the product's entire lifecycle into account could help ensure a selection of non-ownership offerings that contribute to product life extension. New methodologies could be developed to calculate impacts in GPP, by using a mixed method of LCA and LCC and rating systems of IO-MFA (especially on critical raw materials and hazardous substances). Admittedly, this is an enormous task for public authorities to perform individually, so it is essential that a central authority with a strong mandate both from government and industry can liaise with scientific partners to develop such a methodology.

Mandatory national re-use target

Currently, legislation provides only national targets for 'preparation for re-use and/or recycling' without making a distinction between the two operations. In fact, it is most common practice in EU Member States to calculate the target by measuring the amount of waste collected for recycling (not the actual amount being recycled) and excluding any operations related to re-use as these are particularly hard to measure (EEA, 2013).

Core aim	Existing policy measures	General policy recommendations for product life extension	Recommendations to address product life extension in non-ownership models
Enable customers to extend product lifetimes by creating awareness of product lifetimes & designing longer lasting furniture	• Minimum legal guarantee: 2 years for manufacturer or retailer warranty is implied under EU consumer law • Sweden: Eco-labels (i.e. Nordic Swan and Möbelfakta) • Sweden: National guidelines on GPP for furniture, developed by National Agency for Public Procurement (Upphandlingsmyndigheten)	• Longer mandatory warranty (i.e. 5 years) to encourage more durable furniture • EU wide Green Furniture Mark (GFM) and labeling of products based on eco-design requirements, GPP or EU Ecolabel	• Reduce or substitute certain chemical additives (mainly flame retardants). This can extend furniture lifetimes by enabling multiple uses and enhancing indoor environment quality • Re-use/recycling certificates – auditing • National re-use targets
Encourage longer product lifetimes by incentivizing repair and reuse	• Sweden: Tax breaks for repairing household appliances at home, including furniture (the so-called 'rut-avdrag')	• Incentivize product return (i.e. vouchers by firms (e.g. IKEA) encourage customers to return furniture after use) • Utilize modular design principles to enable better repair and component replacement	• Mandatory partnership of OEMs with re-use sector

Table 2. Existing and proposed policy measures related to product lifetimes of office furniture.

Setting a separate and well-defined target for re-use could be considered an institutional reinforcement for re-use in non-ownership models as it does not preclude that product producers would not already re-use their products without the target. Instead, firms operating non-ownership models would find themselves in an advantageous position to redirect their products to re-use, since there would be a guaranteed demand and probably reasonable monetary compensation. Furthermore, a separate target for re-use would send a clear message to the market and related stakeholders that there will be a new stream of resources available that needs to be re-used (which would otherwise end-up in recycling).

Re-use or recycling certificates / auditing

Currently, re-using and/or recycling of products in non-ownership business offerings are not regulated by any means other than internal company policies. Following in the steps of supply-chain auditing and certification schemes, there could be additional controls by independent authorities to prove (and measure) the flows of EOL products. Voluntary certification could be used as a business advantage by firms to engage with customers or even address new GPP criteria as proposed in the previous section.

On the other hand, the authorities could require mandatory certificates for all EOL units. A predetermined list of EOL treatment options and recognized EOL operators could be approved by a specialized public agency (e.g. EPA) and yearly auditing concerning all firms offering non-ownership solutions could be mandated by the agency. Although such a practice might increase the overall administrative costs, it would also enhance the transparency and accountability of EOL products both domestically and abroad. Taking into account that disposal and recycling operations (waste) are more costly and administratively demanding, the re-use option might seem as the preferable option for firms who ultimately look for profit (or at least reduced costs). This could lead to lower costs and increased resource efficiency for product producers and provide a stable stream of good quality second-hand equipment to the re-use market in EU Member States.

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How Can US Law Support Longer Product Lifespans?

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Keywords: Planned Obsolescence; Product Lifespan; Product Regulation; Product Repair, Product Warrantee.

Abstract: This research sought to identify the parts of the legal system in the United States directly influence the lifespans and capacity for repair of manufactured consumer hardgoods. For this, we sorted through the network of statutes and regulations on the federal level and in the fifty states, noting unique characteristics of the US legal system from an international perspective. We also identified the actors that make US statutes and standards. Our secondary research reviewed the statutes, standards and correlated economic and legal literature, and our primary research surveyed lawyers who provide counsel to manufacturers that sell consumer products in the United States. That research revealed the longstanding acceptance of planned obsolescence in mainstream economic theory and a well-established range of product warranties. The work brought into focus the powerful role that product warranties take in US commerce that can be leveraged to support longer product lifespans and greater product repair. In the near-term, consumer-friendly state legislatures are the most probable part of the government that would create new regulations on product lifespans. More proactive antitrust enforcement could also reduce collusion between competing companies to lower product lifespans.

Context

Over a century ago, Henry Ford rolled out the Model-T automobile with the moving assembly line, his highly efficient manufacturing method. Ford Motor Company grew to be the largest and most profitable manufacturing enterprise of its time. Don Norman conveyed an anecdote about Henry Ford. Ford bought broken Ford automobiles to disassemble and sort failing parts from still-functioning parts. His goal was not to redesign the failing parts so that they would last longer. Instead, his goal was to save money by redesigning the functioning parts so that they would fail earlier.

This story tells an unsettling truth about unregulated commercial markets. Because selling products with shorter lifespans is more profitable than selling products with longer lifespans, businesses will find a way to sell products with shorter lifespans. In unregulated markets, manufacturers will carefully design products to malfunction far earlier than is technically required (Slade 2006).

Figure 1. The Model-T Ford automobile: a nascent example of planned obsolescence.

Planned obsolescence increases the economic burden on consumers and puts a growing stress on the Earth's dwindling natural habitats and the tenuous existence of many thousands of living species in those habitats.

Most economists in the US have prioritized increasing per capita consumption of materials and energy. The goal of resource consumption was not to serve basic human needs for food, shelter, education and healthcare, but instead, to fuel the economic engine. Depression-era marketers promoted 'consumer engineering,' where companies use intensive advertising to convince people to buy goods (Shelden & Arens 1932). This program foretold the current ubiquity of television advertising, with the average US viewer watching 45 minutes of commercial ads each day. Over a 75-year lifetime, one could watch TV ads for more than four continuous years (Boradkar 2010).

Figure 2. TV viewers in the US watched an average of 45 minutes of ads each day. © J. Bui.

Mainstream economic theory has not characterized planned obsolescence as a fringe doctrine plagued with ethical conflicts. To the contrary, it is a common practice, so it deserves attention, if not justification. Jeremy Bulow, in *An Economic Theory of Planned Obsolescence* (1986), noted, “A monopolist (a company that dominates a market) desires uneconomically short useful lives for their products. . . An oligopolist (one of many company companies in a market) can generally gain by colluding (with competing companies) to reduce durability.” Most economists embrace planned obsolescence as valid practice from the perspective of the business, but not necessarily from a macro-economic perspective (Fethke & Jagannathan 2002, Orbach 2004). In this business model, a company that manufactures and sells non-perishable goods will secure a degree of higher market demand for its products in the future by:

1) Stimulating sales by adding features and functions, *regardless of whether users need the features and functions* (authors' assertion in italic),
2) Designing the goods to be less durable than is possible, given the market and technological constraints,
3) Convincing customers through a variety of means of the necessity to purchase the new goods, and
4) Selling the goods at high prices compared to competitors.

Many people have disparaged planned obsolescence, the promotion of consumption as a goal, and the subsequent waste of finite natural resources. Victor Papanek projected that the enlightened societies of the future would give: “a greater emphasis on quality, permanence and craftsmanship in designed products” (1971, 1995).

The circular economy is a comprehensive approach that could end planned obsolescence. According to Ken Webster, the circular economy “aims to keep products, components, and materials at their highest utility and value, at all times” (2015). Maximizing product lifespans and enabling product repair are among the core circular economy design strategies (Bakker 2014, White 2017).

Industry governance in the US

Government institutions write most of the policies and regulations in the US. Federal and state governments, known as “hard law,” or legally enforceable statutes and regulations. Trade industries, Non-governmental Organizations (NGOs), and other corporate stakeholders self-regulate by creating “soft law,” that take the form of industry standards and certifications.

A legislative branch (either the U.S. Congress or a state legislature) create both national (federal) statutes and state statutes. Legislatively empowered federal agencies (like the US EPA) promulgate Federal regulations. Likewise, legislatively empowered state agencies (like the California Department of Environmental Quality) make state regulations. The federal judicial branch interprets Federal hard law, while each state's judicial branch interprets that state's hard law.

Any number of non-government groups make soft law. Examples include standards created by independent non-trade organizations (like Underwriter's Laboratory (UL) or Southwest Research Institute (SwRI)) or a professional trade association (like the Institute of Electrical and Electronics Engineers (IEEE)).

National law often sets forth a general outline, and state legislators then create state laws following the framework. For example, § 5 of the Federal Trade Commission (FTC) Act of 1914, the statute that created the FTC, prohibits “unfair or deceptive acts or practices in or affecting commerce.” While this act gave the FTC the authority to enforce actions against companies that engaged in unfair practices against consumers, it provided no relief for harmed consumers. In response, most of the 50 states passed their versions of the act that allow consumer lawsuits to be brought (Nat. Cons. Law Center 2009).

A unique aspect of U.S. industry governance is the class-action lawsuit that allows many people who have been harmed by a well-funded organization to join a 'class' that challenges the harming party in court. For example, the Magnuson-Moss Warranty Act (MMWA) of 1975 is a core statute governing consumer product warrantees. Class actions lawsuits delegate the regulation of consumer product warranties to private citizens, eliminating the need for the complexities of enforcement by hard law (Marcus 2013).

Since the 1950s, US civil courts law have increasingly found any entity that admits to having caused damages to be guilty. The fear of being prosecuted makes companies and individuals avoid speaking publicly about the effects of products because prosecutors can interpret such statements as admitting to guilt.

Commercial guarantee frameworks

After someone purchases a product, she or he may realize that the price paid was much greater than the value that the product provides. Commercial guarantee frameworks, which can be policies or statutes, were designed to remedy such discrepancies.

Modern US commercial transactions use three types of these guarantee frameworks (DiMatteo & Wrbka 2019).

1) Legal guarantees, also known as statutory guarantees,
2) Integral commercial guarantees, also known as warranties, and
3) Paid-for commercial guarantees, also known as extended warranties service contracts (EWSCs).

The MMWA's ban on a warranty that negates a common warranty expectation is an example of a statutory guarantee. The bumper-to-bumper warranty of three years or 36,000 miles on most new cars is an example of an extended service contract, while a seven-year or 100,000-mile warranty on a used vehicle is an example of an extended warranty contract. A fourth legal remedy, an 'Implied Warrantee', can also be applied to any product sold in the US with clear evidence of not delivering basic amenities that are expected by a product of its type.

Survey of legal counsel

We prepared a survey to document current trade practices involving product lifespan and product repairability. We sent the survey with a confidentiality agreement to in-house lawyers in 43 companies that sold durable in many US market sectors, including housewares, home appliances, electronics, sporting/outdoor gear, and toys. Respondents were not paid or compensated for their participation. Twelve completed surveys returned to us, yielding a 28% response rate.

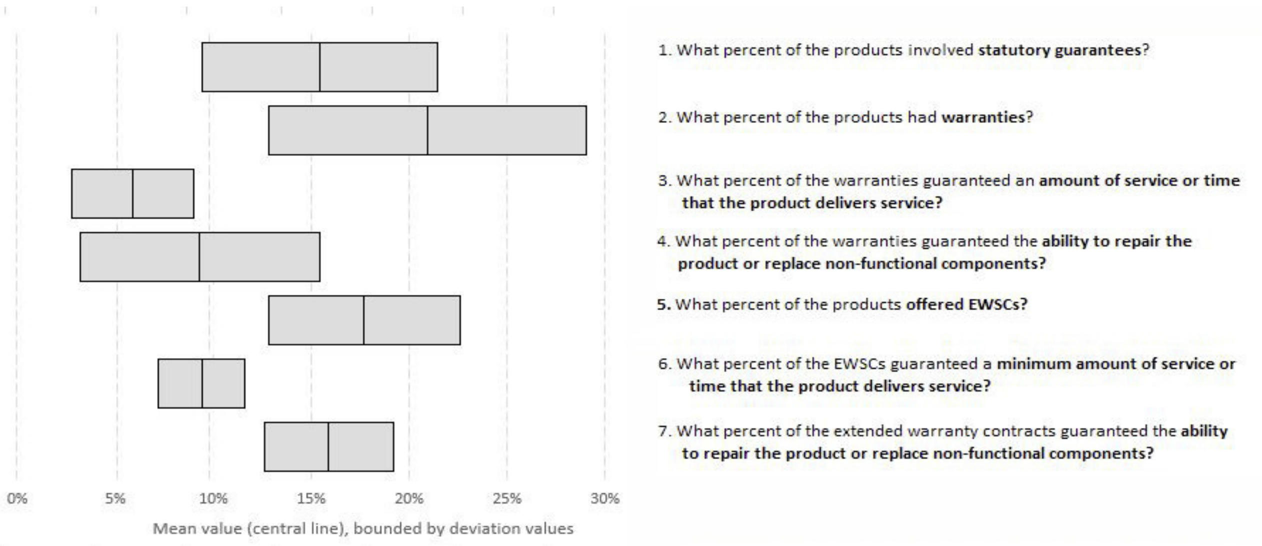

Figure 3. Percentages of products with warranties (central line is the mean value).

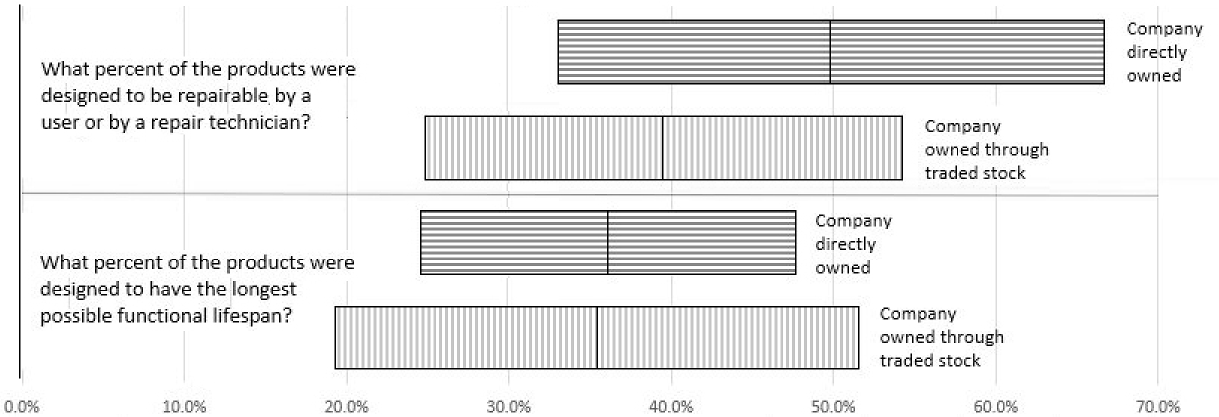

Figure 4. Percentages of products designed for desired characteristics (the central line is the mean value).

Figure 3 shows the next questions about warranties on the right and the answers on the left. For each question, the lawyer estimated the percentage of the total of all the kinds of products sold in the US. Each bar shows the mean value of all responses bounded by the deviation.

On average, 15% of the products had statutory guarantees, while 21% had warranties. Of the products that had warranties, 6% of the warranties guaranteed an amount of service or an amount of time that the product delivers service, while 9% of the warranties guaranteed the ability to repair the product or replace non-functional components. 18% of the products offered extended warranty contracts (EWSCs). Of the products that offered EWSCs, 9% of the contracts guaranteed an amount of service or time that the product provides service. 16% of the contracts guaranteed the ability to repair the product or replace non-functional components.

The data in figure 3 indicated that warranties are more common than extended warranty contracts, which, in turn, are more common than statutory guarantees. The results show that in both warranties and extended warranty contracts, guarantees of ability to the repair or replace worn parts were more prevalent than guarantees of maximized product lifespan.

Respondents next estimated the percentage of the products that the company had designed to have desired characteristics. The questions were, given the available technology and market structure: 1. "*What percentage of the products were designed to be repairable, either by a user or by a repair technician?*", and 2. "*What percentage of the products were designed to have the longest possible functional lifespan?*".

We sorted the responses in figure 4. according to those that are directly owned (3 firms), and those that have publicly traded stocks (9 firms). More of the products were perceived as being designed for repair than were perceived as being designed for the longest lifetime.

We asked the lawyers to indicate how much that kind of logic expressed in the following statement influenced the lifespan of their company's products: "***One microeconomic theory of a durable goods posits that a firm will make non-perishable products to be less durable than they could be, given economic and technological constraints, and sell the products at relatively high prices compared to competitors, to increase some degree of higher market demand for the firm's products in the future"***.

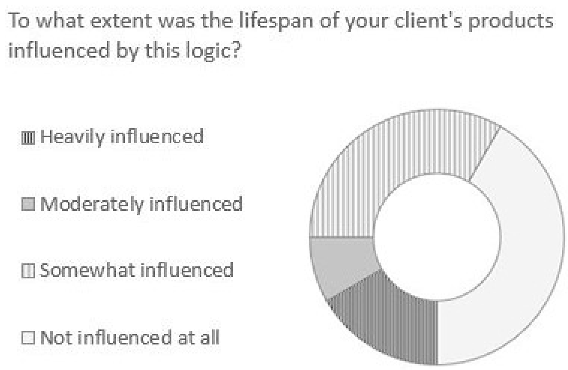

Figure 5. Influence of the theory that shorter product lifespans are more profitable.

Figure 5 shows that five respondents indicated that the firm was "not influenced at all," four thought that the company was "somewhat influenced," one thought that the firm was "moderately influenced" and two thought that the firm was "heavily influenced" by the logic of planned obsolescence.

Next, we asked: *"What' would motivate the company to maximize or significantly increase the lifespan of its products*?" and *"What would motivate the company to maximize or significantly increase product repairability and the replaceability of product components*" All respondents (12, 12) marked "New statutory regulations on product lifespan - repairability." Some (5, 6) marked "Industry standards such as the FTC Green Guides with new product lifespan - repairability requirements." A handful (1, 2) marked "Voluntary Ecolabels with product repairability requirements such as the EPEAT electronics ecolabel."

Lastly, we asked, "*If the United States was to begin regulating planned obsolescence of durable goods, which branch of government do you expect would first make such regulations?*" Potential answers included:

- The US Congress, via omnibus legislation
- Federal agencies via command-and-control regulation
- Consumer-friendly state legislatures, such as Connecticut, Hawaii, Illinois, or Vermont
- Consumer-friendly state courts, such as Florida, California, St. Louis, Philadelphia, New Jersey, or Illinois

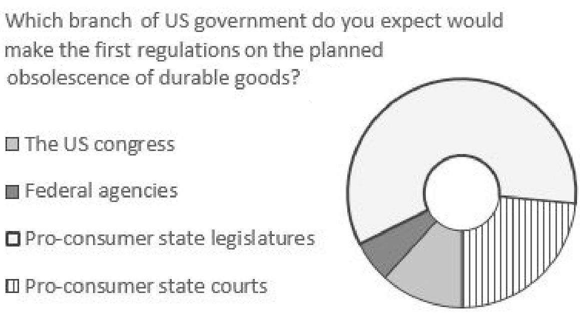

Figure 6. Branches of the US government that can regulate planned obsolescence.

Figure 6 shows that most respondents (11) thought that Pro-consumer state legislatures have the greatest probability of making the regulations, with some (5) indicating that pro-consumer state courts would make them. Two thought that the US Congress and one thought that Federal agencies would make the regulations.

Observations

- The long history of mass-manufactured products in the US parallels the long history of planned obsolescence in mass-manufactured products.
- Most economists accept planned obsolescence and the substantive environmental damage that it causes as a common and micro-economically beneficial business practice. We were surprised by how uniformly mainstream economic theories support planned obsolescence.
- Commercially established guarantee frameworks in the US offer a foundation for extending product lifespans and for increasing the capacity for product repair.
- A 28% response rate is strong for a survey sent via email to unfamiliar recipients, but a larger pool of responses would boost the statistical significance. Because our sample size was too small to be statistically significant, we interpret the data qualitatively.
- A substantial segment of products in the US market, 15-30% (figure 3) have some form of warranty.
- The complex questions in the figures 4., 5., and 6. required specialized knowledge and elicited more subjective answers. Ideally, we should evaluate these questions using more objective methods.
- Respondents indicated that approximately 46% of their products were designed to be repairable, and approximately 36% were designed to have the longest possible lifespan (figure 4.). Fear of negative repercussions from employers could explain the potentially exaggerated responses about current product lifespans (figure 4). Most respondents indicated that their products' lifespans were "not influenced at all" or "somewhat influenced" by the theory planned obsolescence (figure 5.). A research method that would deliver more objective results, like that of Catherine Rose (2000), would independently determine product lifespans through physical tests.
- All respondents thought that mandatory measures (laws) would most motivate their firms to increase product lifespans. The firms were less motivated by industry standards, and even less by ecolabels. Most respondents also thought that state legislatures currently have the greatest

probability of regulating the lifespans of products. Confirming our assumptions, these replies reflect the current anti-regulatory stance of much of the US federal government.

Conclusions

We identified and thoroughly endorse several actions with strong potential to support longer product lifespans. These actions overlap those recommended by DiMatteo and Wrbka 538–43:

- The FTC could require manufacturers to label products with expected lifespans.
- Congress could add to the MMWA with a tripartite framework, *a la* The Netherlands and Finland, that classify products into expected minimum periods of usability.
- The FTC and the DoJ could increase enforcement of antitrust law and consumer protection raised by the more egregious examples of planned obsolescence, such as competitor collusion to reduce product lifespans.

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Electronic Textiles and Product Lifetimes: Teardowns

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Keywords: Electronic-textiles; E-textiles; Product Longevity; Eco-design.

Abstract: Electronic textiles (E-textiles), the combination of electronics with textiles, pose significant challenges for the extension of product lifetimes, reuse, recycling and end-of-life disposal. E-textiles products can be divided into two categories: the first is the 'vision' of ubiquitous computing, achieved using computation seamlessly integrated into garments, home furnishings and other textiles; the second is the often-overlooked commercial reality of E-textiles that covers a variety of hybrid electronic-textile products such as electric blankets and novelty items such as light-up musical Christmas jumpers. The products in both categories contain a combination of hazardous and valuable substances dispersed throughout low value, difficult to recycle, heterogeneous material. The market for E-textiles is predicted to expand rapidly, but little has been done to ensure environmental factors are considered during product design and development. This paper reports on a series of E-textile product teardowns conducted to identify the strengths and weakness of commercially available E-textile products, using eco-design and clothing longevity guidelines (Cooper et al., 2016; Köhler, 2013b) as a framework for analysis.

Context

The electronic or E-textiles market is predicted to see considerable commercial growth (Hughes-Riley, Dias, & Cork, 2018). The inclusion of information and communication technology (ICT) in new product categories, such as textiles, could accelerate the rate at which these products are replaced. In the UK a jacket is expected on average to be actively used for over 5 years (Langley, Durkacz, & Tanase, 2013) whereas the lifecycle of a smartphone is usually less than 2 years (Baldé et al., 2017, p. 21). E-textiles need to be designed to avoid lowering the lifespan of otherwise longer lasting products, or strategies that reduce the impact of shorter lifespans should be adopted. This is especially important in the case of E-textile products, due to the difficulty in separating mixed textile-electronic materials for recycling (Köhler, Hilty, & Bakker, 2011). With current infrastructure, E-textile products are incompatible for processing either as textiles or electronics and are likely be sorted out by recyclers for disposal in landfill or through incineration, increasing the importance of longevity as a sustainability strategy.

Longevity as a sustainability strategy for E-textiles

The lifespan of both consumer electronics and clothing can be notoriously short. It is estimated that increasing the active lifetime of 50% of UK clothing by extending the period of active use by 9 months would reduce total carbon, water and waste footprint of UK clothing by around 4-10% (WRAP, 2017b, p. 2). Extending product lifetimes has also been identified as crucial to reducing the burden of Electrical and Electronic Equipment (EEE) on the environment (WRAP, 2017a), making it a fundamental strategy for more sustainable E-textiles.

Designers and brands can positively influence product lifetime by considering the physical durability of the materials used or the reparability of the products (Cooper et al., 2014). For garment design, reparability might mean providing a spare button or darning thread to fix a hole. For an electronic device, including an E-textile, it could mean using a standard battery type and making the battery easy to locate and replace (Köhler, 2013b).

A product's active life is also determined by emotional and experiential connection between person and object (Chapman, 2009; Fletcher, 2012), a concept known as emotional durability.

Product failure is frequently not the reason that clothing and textiles are discarded. More often it is due to being considered poorly fitting, out of fashion or looking worn (Langley et al., 2013, p. 9). Similarly, an exploratory study found that only 31% of smartphones were replaced because they were considered to be broken (Martinho, Magalhães, & Pires, 2017). Electronics, like textiles, are likely to be discarded for reasons other than physical product failure.

The Clothing Durability Dozen (Cooper et al., 2016) offers a range of strategies to increase clothing longevity, including physical and emotional durability, but also alternative business models, methods of communication and promotion, product labelling and longer life guarantees. These strategies can be equally useful when considering the longevity of E-textile products.

E-textile product teardowns

A teardown is a workshop in which items are deconstructed and analysed. Greenpeace uses repairability scores generated by carrying out teardowns as part of their 'Guide to Greener Electronics' (Cook & Jardim, 2017) and the RSA (Royal Society for the encouragement of Arts, Manufactures and Commerce) Great Recovery project (2015) used them to examine waste and circular economy design opportunities. Teardowns carried out for the project described in this paper were conducted by an interdisciplinary team as an opportunity to discuss the knowledge required to minimise the potential impact of E-textile production in a rapidly growing global industry. The findings from the teardowns were evaluated against eco design and longevity guidelines (Cooper et al., 2016; ECMA, 2010; Köhler, 2013) and are discussed in the latter section of this paper.

Three commercially available E-textile products from different market segments were selected for analysis: the Levi's® Commuter™ Trucker jacket with Jacquard™ by Google, a premium fashion product and the first commercially available outcome of the Google Jacquard™ project; a heart rate (HR) monitoring sports bra, an example of a functional E-textile; and a light-up musical Christmas jumper, representing the novelty end of the E-textile market. In tearing-down the products they were unavoidably destroyed, except for the Levi's® jacket which was required for future research.

The Premium

A Levi's® Commuter™ Trucker jacket with Jacquard™ by Google, launched in 2017, was purchased for this project in August 2018 for $350 US.

Figure 1. Levi's® Commuter™ Trucker jacket.

The jacket (Figure 1) came in a cardboard box containing the garment, the electronic tag required for the jacket to function and an information leaflet. The jacket was labelled with a standard garment label stating country of manufacture (China), composition (outer 100% cotton, lining 86% polyester and 14% elastane, trim 93% polyamide and 7% elastane) and laundry care instructions (Figure 2). No reference was made to the metal and plastic of the Jacquard™ threads or connector in the left sleeve, but details of their composition have been published by the research team that developed the technology (Poupyrev et al., 2016).

The laundry care instructions on the jacket's label indicated that it should be washed at 30°C. It cannot be dry cleaned and the left cuff of the jacket containing the Jacquard™ threads, seen magnified in Figure 3, cannot be ironed. The electronic snap tag (Figure 4) must be removed before washing. Information stating that the jacket has been tested by the developers to last 'at least 10 washes' was in the pamphlet that accompanied the jacket and on the product website (Google, 2019), not on the laundry care label.

Figure 2. Jacket label.

Unlike traditional textile products, the Levi's® jacket was labelled with the Waste Electrical and Electronic Equipment (WEEE) symbol (see Figure 2) that indicated the product was considered to be EEE and should not be disposed of in household waste. Products are classed as EEE when their primary function is considered to be electrical or electronic, so not all E-textiles fall under this classification. The CE mark has also been used, indicating that the product conforms to the health, safety and environmental protection standards of the European Economic Area (EEA).

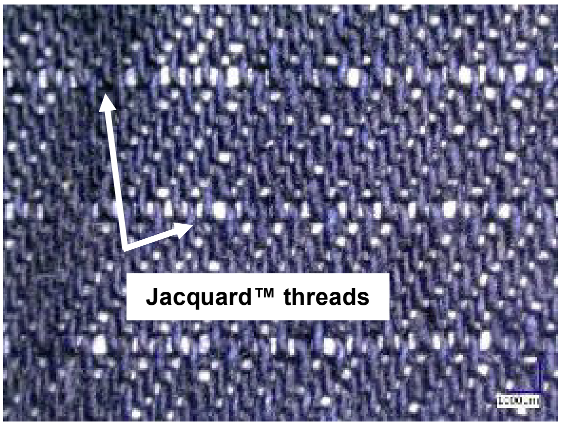

Figure 3. Jacquard™ cuff close-up.

Some of the jacket's electronic components are integrated into the textile, whereas other components are removable. The Jacquard™ threads that make up the sensor are woven into the fabric of the cuff and as such are completely inseparable from the other textile fibres. However, the electronic tag can be removed and must be for washing. The tag has a USB rechargeable battery, but should it fail it cannot be replaced.

Google offers a support service for battery issues, though it is unclear if this applies after the one-year warranty expires. This information could be found in the pamphlet that accompanied the jacket and on the product's website, but not on the product label. A quark code label on the inside of the jacket also led to the online information.

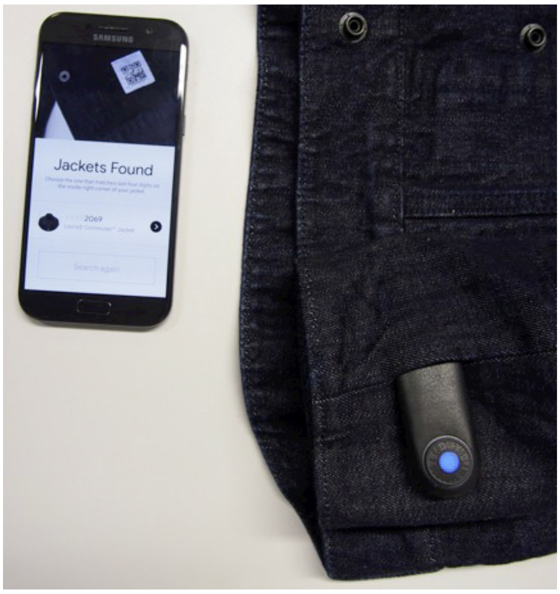

Figure 4. Jacket tag and app.

The jacket was tested with the app that controls the use of the jacket's electronics. Limited testing found installation and use of the Jacquard™ cuff, which recognises four user gestures (up-swipe, down-swipe, double tap and hold), to be relatively simple.

The Functional

A Heart Rate (HR) monitoring sports bra branded 'Berlei' was purchased in August 2017 from Amazon for £23.14. An electronic module to pick up the readings from the sensor, and a sports watch to display the readings, were not included, so functionality of the garment could not be tested. The modules and watches are made by a number of brands, including Garmin and Géonaute.

The garment came in a clear plastic bag with no information indicating the compatibility of the product with different modules or display devices. The bra had two metal snap fasteners at the front to attach the electronic module (Figure 5). The product was labelled as 'Made in China' and consisted of 47% polyamide, 37% polyester and 16% elastane (exclusive of trims). The garment was hand wash only and could not be ironed or tumble dried. The WEEE symbol was not present and the garment did not have a warranty.

Figure 5. Front HR monitoring sports bra.

An electrode was on the inside of the bra to pick up HR signals (Figure 6). The conductivity of the electrode was tested, but without the electronic module it was unclear if the electrode was sufficiently conductive to produce a reliable HR signal. To understand the composition of the electrode, a small section was heated so the polymer layers could be separated. The electrode was made up of several layers of polymer-based film adhered to the fabric. Some of the film contained carbon particles and was conductive, with other non-conductive film areas acting as an insulator (Figure 7).

Figure 6. Inside HR monitoring sports bra.

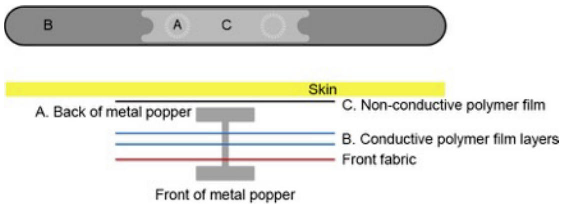

Figure 7. Electrode construction.

The Novelty

A Next women's Christmas jumper was purchased from Ebay second-hand for £6.00 in July 2018 (Figure 8). The date or price of its first purchase are unknown but prices for this type of product in December 2018 were around £30. Prior to the teardown the electronics in the jumper were still functional. The reindeer's nose would light up and play a Christmas jingle when pressed.

Figure 8. Christmas jumper.

The label indicated that the jumper was 100% acrylic and washable but made no reference to the electronic pod held in a textile pocket on the back of the jumper (Figure 9), either in terms of materials or any instruction indicating whether the pod should be removed for washing. Unsurprisingly for a relatively low-cost novelty item, the jumper did not come with a warranty.

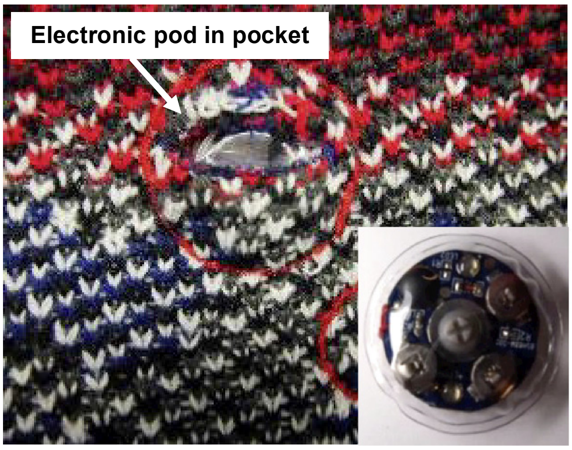

Figure 9. Electronic pod.

The electronics were encapsulated in a sealed plastic capsule 4cm in diameter and held tightly inside the pocket on the reverse of the garment. The label did not carry the WEEE symbol despite the Bliss Electronic (2019) pod containing many electronic components, as shown in Figure 10. To access the components the pod had to be cut open.

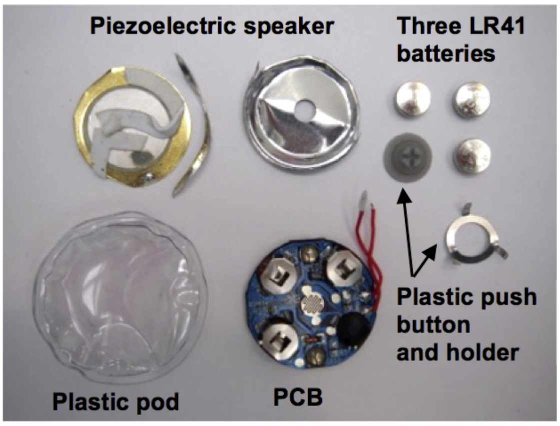

Figure 10. Pod components.

Discussion

All three E-textile products were labelled with standard textile product labels informing consumers of where they were manufactured, their textile composition and laundry care requirements. Only the Levi's® jacket, representing the premium end of the market, made any reference to the electronic components on the label in the laundry care instructions. Textile manufacturers are not required to include the material composition of trimmings and non-textile parts on their labels and hence the electronics can be excluded (BIS, 2016). The Levi's® jacket was also the only product that gave disposal instructions through the use of the WEEE symbol and a product warranty.

The Levi's® jacket and HR monitoring sports bra both required separate electronic modules and display devices, but they also both had electrical components that were inseparable from the fabric. This heterogeneous material is nearly impossible to repair, recycle or separate and reuse (Köhler, 2013a). The Christmas jumper has the advantage that the electronics were contained in a removeable pod which allows the electronics and textile to be separated and processed through their designated waste streams. However, for this to happen the WEEE symbol and ideally a written explanation would be needed to inform the consumer.

When electronic modules are not attached to the jacket or bra there is a visible missing piece. Despite them still functioning as garments, users may not want to wear these items should the electronics fail or become obsolete, due to them appearing incomplete or unattractive. A standard denim jacket can be considered a design classic and remain in active use for decades, a lifespan few electronic products can claim. The electronics can be removed from the Christmas jumper without anything perceivably missing, in contrast to the other products reviewed, perhaps making the garment more likely to be used after the electronic components have failed.

Making E-textiles washable is a considerable technical challenge. The Levi's® jacket is engineered to last only 10 washes, which is a problem as the jacket was designed with commuters in mind. A cycling jacket could easily need frequent washing to remain in acceptable condition for its user. The bra was not tested to see whether washing affected the performance of the electrode, but it is a garment that would be likely to require washing each time it was used. The information regarding the limited number of washes the Levi's® jacket was engineered to withstand was not found on the jacket label alongside other laundry care information, but in the pamphlet that accompanied the jacket and on the website (Google, 2019), placing the onus on the consumer to find the necessary information.
Research has shown that care labels are rarely followed after the first wash and often poorly understood, ignored or removed (Mclaren, Goworek, Cooper, Oxborrow, & Hill,

2016). Not following care instructions can reduce product longevity and, in the case of E-textiles, may irreversibly damage the electronic components and invalidate the warranty. The jacket's care instructions highlight the greater demands placed on consumers to correctly care for E-textile products. The premium nature of this product may mean owners are more likely to take necessary caution, but may not be with cheaper products, which are more likely to be viewed as disposable.

Compatibility achieved through the standardisation of components is a recommended eco-design principal to ward against obsolescence (Köhler, 2013b). The Levi's® jacket uses a standard USB connection to recharge the tag making it widely compatible. The bra is compatible with a range of electronic modules which can be seen as positive, but the fact the manufacturer takes no responsibility for product compatibility creates a risk that the product will not function. Any lack or loss of functionality could lead to the product being quickly discarded as it has a relatively low price and no warranty.

Traceable supply chains are a longevity strategy that involves better connection between consumers, brands and manufacturers (Cooper et al., 2016). The bra was purchased through Amazon, not directly from Berlei. Contact with the Berlei customer service team confirmed that the product was genuine but discontinued several years ago. As the bra was bought through a third party, the consumer potentially has no support in the case of product failure. In contrast, the consumer of the Levi's® jacket is provided with a point of contact to resolve any problems.

Conclusion

Only the premium product analysed during this project was labelled with the WEEE symbol. While its use is a small improvement, it is made somewhat redundant when the electronics cannot be separated from the textile. Integration is seen as key to the development of E-textiles (Cherenack & Van Pieterson, 2012) but limits opportunities for repair, re-use or recycling, and likely reduces the longevity of products and components. All the products analysed potentially have a shorter lifespan than a classic textile equivalent due to the possible failure of the electronics.

In the case of novel smart materials such as E-textiles, it can appear that any transformation that uses their functional capability can be seen as a success independent of whether it creates value to society (Karana, Barati, Rognoli, & Van Der Laan, 2015). However, arguably the utility of E-textile products should be assessed in the context of their environmental impact, and the societal need for E-textile products is an issue deserving of further research (Berglin, 2008, p. 98).

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PLATE
Product Lifetimes And The Environment

Challenges in Obsolescence Management and System Engineering Using the Example of the German Supplier Industry

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Keywords: Obsolescence; Product Lifetime; Electronic Components; Components Obsolescence Group; EcoReliability; EcoDesign.

Abstract: Obsolescence, in the sense of short lifetime of predominantly electronic products, is increasingly becoming a problem for industrial processes and ultimately for the community. The number of cases in which professional customers want to buy products, which are no longer available for purchase is steadily increasing. In the industrial setting this situation leads to strategies, which are necessary but actually undesired, in order to be able to maintain the business activities. Basically, more money and time has to be spent on countering obsolescence. In order to better meet these challenges, enabling people to exchange ideas with like-minded colleagues, who are in the same situation, and to jointly develop strategies for solution processes, an interest group driven primarily by the electronics industry has been founded under the name *Component Obsolescence Group Germany* (COG-D). The purpose of this paper is to describe the current state of affairs regarding Obsolescence Management (hereinafter referred as OM). OM in the sense of dealing with obsolete or discontinued components is not completely new, but the problem has increased significantly in recent years, which makes it interesting to take a closer look at the reasons in order to derive solutions. The findings are based on a survey taken among the members of the COG-D.

Purpose

The aim of the paper and its underlying survey was to find out about the challenges the German industry are confronted with regarding the discontinuation of especially electronic components and ensuring maintenance and repair.
These issues on a national market can be seen as a representative of the international industry.

Survey Design and Approach

The surveyed group consisted of members of the COG-D. An online questionnaire was sent to the members of the industry group, which was prepared by the BMBF Young Researcher Group "OHA" (Obsoleszenz als Herausforderung für Nachhaltigkeit = obsolescence as a challenge for sustainability) and partners, in which they were able to provide detailed information on the current situation, with regard to the discontinuation of components.
Additionally, they were able to describe their experiences from the past, outlining their method of resolution and providing outlooks and trends regarding the discontinuation of components. 63 people anonymously took part in the member survey, which was conducted between 27th of September 2018 and 30th of October 2018 and was exclusively addressed to the members of the COG-D. The participants took part as representatives of companies that are members of the COG.
The sectors represented in the survey group of the COG are shown in the following graph, with multiple responses being possible since many member companies operate across several industries.

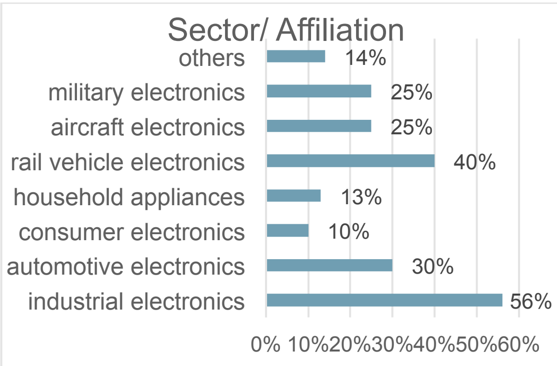

Figure 1. Industry sector affiliations of the COG.

Challenges of obsolescence management in companies

84% of the respondents stated that they were actively managing obsolescence in their company. Those 84% of respondents were asked a number of questions about OM that they were free to answer.

The first question dealt with how OM is practiced in the different companies. The three most frequent answers were that they carry out OM reactively (20), proactively (18) or strategically (11).

Proactive means, to be active in OM with foresight and planning in mind, as opposed to reactive, which is more tangible and follow-up. Reactive in this context means, that if e.g. a discontinuation occurs, the final covering of the discontinued components will be bought up as last-time-buy (LTB) and then usually stashed in long-term storage. Proactive OM is primarily concerned with the early detection of delivery bottlenecks and non-availabilities. That way, the assurance of ongoing production as well as service and maintenance can be guaranteed more safely to ultimately minimize or at least improve reactive measures.

To the question which problems in OM were encountered practically the answers varied strongly, although lack of understanding OM in the company (14) was the most common one. Lack of understanding OM means, for example, the meaningfulness and importance of the task field. In the context of business processes, OM is rather seen as a necessity, dealing mostly with solving problems. This inevitably means that the employees of OM constantly have to inform management about new issues which increases their risk of being perceived negatively.

The second most frequently cited aspect was the lack of communication or short-term communication of discontinuations (13) which also vary strongly with each company and are therefore very individual.

In addition, the problem of shortage of know-how or lack of successor series creates complications in the practice of OM, according to the respondents.

The third and last question on the topic of OM in companies was on the changing perception of obsolescence in the past 10 years.

On the one hand, it was often answered that the obsolescence of products has increased whereas at the same time long-term availability of components has decreased. On the other hand, there has been a rise in attention to the topic of obsolescence linked with a more professional approach. Some respondents describe they only established the topic of OM in their companies in recent years.

However, this also reflects the fact that some sectors were affected earlier and more severely by obsolescence and they therefore had to act earlier, while other sectors have only had to deal with the problem more intensively in recent years.

Of the 63 respondents, 58 said they were affected by component discontinuation (Figure 2).

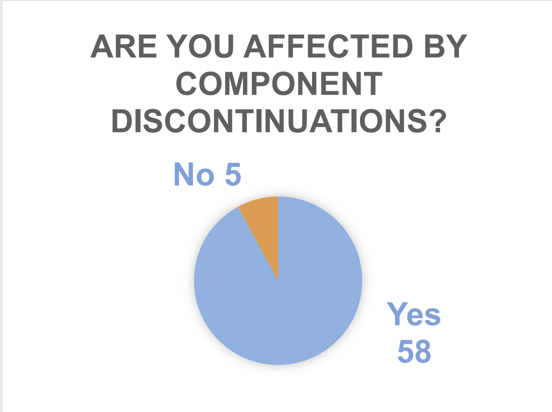

Figure 2. Affected by component discontinuations.

In the further course of the survey, these 58 respondents were asked in which areas they thought there would be an increase in discontinuations. Since it was possible to respond freely here, the spectrum of the respective answers is broad. They range from the smallest electronic components to mechanical items, plastics, adhesives and silicones. It should be emphasised that according to the answers of the respondents that semiconductor components (e.g. memories) and passive components (capacitors in particular), are affected more often. In this context, however, it was also described that many discontinuations occurred as a result of fusions or merger of suppliers. When asked what consequences this has for the company, it was often mentioned that one is forced to look for alternative components, which very often have to be re-qualified. The process of re-qualification is seen as negative, because it is associated with additional time and costs. If no result can be achieved in the process of component substitution, the assembly must be redesigned. In the answers, it was repeatedly expressed that re-designs are avoided as much as possible because they involve large capacities of personnel and are time- and cost-intensive. A second possible solution is seen in the LTB and the subsequent long-term storage. LTB means that if a supplier no longer wants to produce a product, he gives his customers a Product Change Notification (PCN), which states until when the product will still be produced. A LTB is therefore the last possibility for a company to get newly produced components. Different answers were given regarding the measures taken to prevent discontinuations, which strongly depend on the affected components or assemblies. Often partnerships and so-called "Second Sources" are seen as a preventive measure to secure the component supply on a long-term basis. Partnerships in this context are agreements with suppliers, their involvement in product development, as well as their contractual commitment to supply over several years. Others try to work preventively with component databases, market observation, a sustainable component selection or professional OM.

In the survey, the participants also stated that they were seriously interested in the long-term storage of electronic components or assemblies. In the strategic mix of possibilities, many see long-term storage at least as a temporary solution, well knowing that the number of parts ultimately required can never be predicted exactly. Either the quantity stored is too large or too small. Additionally the high costs are a negative aspect according to the interviewees.

Furthermore, long-term storage is feared to cause damage which would make processing at the desired time in the future impossible. Mentioned here in particular were soldering problems caused by poor absorption of solder at the contact pins.

In addition to long-term storage and purchasing from distributors, brokers also play a major role. The difference between brokers and component distributors will be briefly explained in the following.

While independent distributors and brokers both pursue the same goal (or have the same essential function) - namely to support buyers and sellers in their search - the similarities end there.

The value a broker offers is to procure electronic parts on demand. However, they tend to lack other services such as a comprehensive quality review process, discrepancy checks and visibility of existing market conditions. However, the range of services offered by an independent distributor of electronic components goes far beyond a mere goods transaction.

When asked where they purchase components after discontinuation from, only twelve of the participants answered that they buy components from brokers while at the same time it is often emphasized that they mainly access brokers known in the COG. The dependence on urgency was also mentioned repeatedly as an important factor.

It is striking to note that there was no clear answer to the question which obsolete components were bought. Half would purchase everything that is available rather than paying attention to the urgency. The remaining answers cover active and passive components, as well as semiconductors and many more.

The advantages of buying obsolete components from brokers are rather described as a necessity. Answers often stating that availability could be guaranteed or that there would be no downtime in production. The topic of avoiding re-designs was stated as an upside, although one of the recipients replied that this problem is only being postponed, not solved completely.

Disadvantages arising from buying from brokers, etc., are mainly costs, e.g. in the form of purchase or paying for storage, as well as the commitment of time that comes with the examination of the construction units. A non-transparent supply chain was criticized and two of the participants noted that the consumption of the obsolete products by clients was uncertain. Plagiarism was mentioned repeatedly as an issue, next to the reliability and guarantee of the purchased components.

Levels of Obsolescence Management (OM)

In addition to the specific questions which problems of OM currently exist at the market, the participants were also asked what constitutes a good OM at all. The strategic approach can be roughly divided into reactive, proactive and strategic obsolescence management.

Reactive obsolescence management

The reactive OM is characterised by the fact that an action is executed after an End-of-Life (EoL) message has been received (Bartels et al. 2012: 157 ff.). The following process could also be described as "troubleshooting", in which an attempt is made to salvage everything that can be saved, which makes that type of management very high risk. The reactive OM uses fewer measures as proactive OM. In the best case scenario this can include: Last time buy, long-term storage of components and assemblies, after-market supply and redesign of entire products or at least assemblies.

Proactive obsolescence management
The proactive OM is characterised by the fact that action is being taken before an EoL message arrives. The staff is thus warned early on and can adjust to unavailability. The proactive OM uses the following measures: People responsible for the OM have been appointed and are given time for the task, active risk assessment of the components, lifecycle analyses of item lists already in the development phase, positive partnership and contract design with suppliers, automatic/electronic monitoring of key components and regular coordination with customers. In addition, the measures from the reactive OM mentioned above are included.

Strategic obsolescence management
The strategic OM is characterised by the fact that all actions take place at an early stage. This means that regular forecast and cost analyses are made over the entire product life cycle, already starting in the development phase. Along with the methods from the reactive and proactive OM, strategic OM uses the following measures. A second or third source strategy, active inventory management (at least of the company's own inventories, or better yet of the suppliers' inventories), development of a sustainable and modular design and early development of an alternative design.

Conclusions
The results of the COG-D survey show very clearly that there is a steady increase in obsolescence in the form of discontinuation of components. The electronics industry is strongly affected across many sectors. Unavailability of components or subsystems impacts even ongoing production, but more severely the maintenance, repair and overhaul operations. The area of mechanical parts is of less concern but follows similar patterns.
In the area of electronic components, active components are particularly affected. However, the survey also shows that passive components such as ceramic multi-layer capacitors can also become obsolete. The example of ceramic multilayer capacitors shows, among other things, that company acquisitions and the streamlining of the product range quickly lead to bottlenecks in availability that can last for many months (Winzer 2017: 9).
In the case of active components in particular, it is evident that the market is increasingly dominated by a few large producers.
The concentration has to do with the fact that the investments for new generations of high-performance semiconductors are becoming ever larger and only big corporations can raise the immense financial resources. As a result, smaller manufacturers, which fabricate niche products, are disappearing from the market.
There will be no simple solution to the problems of obsolescence management.
In order to prepare oneself as well as possible, a strategy with several options is needed. It is crucial for companies to move from reactive obsolescence management to strategic obsolescence management. The experience of companies that have taken this path shows that production is more predictable, redesigns are fewer and the supply of spare parts can be guaranteed without interruption.

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Laptop Use Patterns Research on Product Lifetime and Obsolescence Aspects

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Keywords: Laptop Obsolescence; Use Pattern; Survey; Students.

Abstract: The aim of this study is to acquire information on the user behavior of laptop (including notebooks, laptops, subnotebooks, netbooks, or ultrabooks) users. A questionnaire-based survey was carried out at a University in Southwestern Germany in 2015, and duplicated in 2018. Results show amongst others that on average no defect occurs immediately after the manufacturers' warranty period. About 80% of all devices worked flawlessly throughout their use phase. Life time expectation for the devices clearly exceeded 5 years, but the actual use phase duration was found to be only about 80% of this time span. Almost 2/3 of all predecessor notebooks were stored after the end of their useful life, and only 11% disposed of.

Introduction and Study Goal

Planned obsolescence is an effect often discussed but not proven in empirical research. Portable computers according to literature typically show use phase lengths between 3 and 6 years (Hennies & Stamminger, 2016). Research shows that the duration of the first usage period of electrical products such as notebooks, TV sets or other household appliances was observed to become lower in recent years (Prakash et al., 2016).

The aim of this study is to present the current state of discussion on the obsolescence of electrical and electronic devices and to acquire information on the user behavior of laptop users by evaluating empirical data, which can be associated with obsolescence observations.

Research was carried out not only to define the exact use phase length of portable computers, but also to identify the user's expectations and attitudes towards use patterns, use phase length expectations, and tentative planned obsolescence experiences. The hypothesis to be researched was that laptop users may claim to have become victims of planned obsolescence if their devices fail to meet their use phase length expectations, regardless of the actual technical performance of the devices.

Definitions

In this study, all portable computers such as notebooks, laptops, subnotebooks, netbooks, or ultrabooks are counted under the term "laptop".

The useful life is defined as the period between the first and last use of a product. It may also denote the period of time between the first and last use of a product by the same person, family or organization. In this case, it is referred to as the first/second/… usage period.

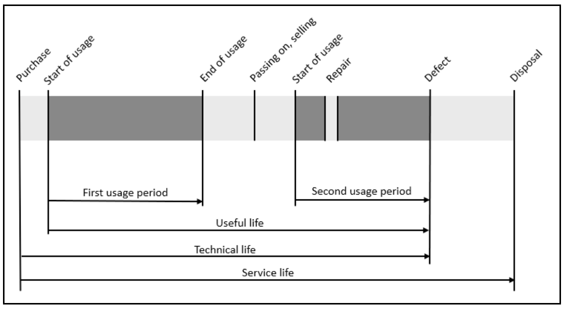

Figure 1. Use phase and life time of products (based on Tröger et al., 2017)

The service life is defined as the period between the purchase or acquisition of the product and its disposal. The technical life, on the other hand, indicates the time between the purchase and the defect of the device. Technical life and service life may not be necessarily identical (Figure 1) (Tröger et al., 2017).

The term "obsolescence" includes all processes that lead to the wear and tear, ageing or loss of value of a product, regardless

of whether these occur naturally or artificially (Reuß, 2015; Prakash et al., 2016).
Natural obsolescence expresses ageing due to normal wear and tear, whereas artificial obsolescence can be caused either by the users' misconduct or intentionally by the manufacturer or the retailer. The latter is referred to as "planned obsolescence". (Hübner, 2013)

State of Technology

In 2018 alone, approximately 164.1 million notebook devices were sold worldwide (IDC, 2019). Table 1 shows the manufacturers' market shares of notebook sales worldwide. The three most successful manufacturers in recent years have been HP, Lenovo and Dell. Since 2015, these three manufacturers together have covered more than half of the market, and in 2018, their projected market share was at 60.8%.
Literature research shows a wide range of the average useful and service life (Table 2) for laptop computers, in the case of useful life span ranging from 4 to 6 years, with service life ranging from 4.1 to 5.6 years.

	2013	2014	2015	2016	2017	2018**
HP	17.5 %	20.1 %	20.5 %	22.4 %	24.3 %	24.4 %
Lenovo	15.9 %	17.5 %	19.9 %	21.7 %	20.2 %	20.8 %
Dell	11.3 %	12.3 %	13.7 %	15.4 %	15.2 %	15.6 %
Asus	9.7 %	11.0 %	10.3 %	10.3 %	9.5 %	9.8 %
Apple	6.6 %	9.3 %	10.3 %	8.3 %	9.6 %	10.4 %
Acer	10.4 %	10.0 %	8.9 %	8.1 %	8.0 %	8.2 %
Samsung*	7.7 %	2.7 %	1.7 %	-	-	-
Toshiba*	7.5 %	6.6 %	4.2 %	-	-	-
Sony*	3.7 %	0.6 %	-	-	-	-
Other	9.8 %	9.9 %	10.3 %	13.8 %	13.0 %	11.0 %
* The source does not provide information on sales in all quarters. ** Forecast						

Table 1. Manufacturers' market shares of notebook sales worldwide (Trendforce, 2017).

Type of data collection	Useful life in years	Service life in years	Reference [* data reference year]
German household survey (2004-2007)	5.4 – 6 (2004-2007*)		(Prakash et al., 2016)
German household survey (2010-2012)	5.1 (2012*)		(Prakash et al., 2016)
Consumer survey in the Netherlands verified by data from recycling facilities		4.1 (2000*)	(Bakker et al., 2014)
Consumer survey in the Netherlands verified by data from recycling facilities		4.3 (2005*)	(Bakker et al., 2014)
Student survey (2015)	4		(Adrion, 2015)
Online survey in Austria	4.1		(Wieser & Tröger, 2015)
Online survey in Germany (2013/2014)		5	(Hennies & Stamminger, 2016)
Student survey (2018)	4.7		(Müller et al., 2018)
Life-cycle assessment study		5.6	(IVF, 2007)
Life-cycle assessment study		4	(O'Connell & Stutz, 2010)
Life-cycle assessment study		5	(Prakash et al., 2012)

Table 2. Useful life and service life of laptops in literature.

Survey Methods

Adrion (Adrion, 2015) carried out a questionnaire-based survey in a student environment in Southwestern Germany with several hundred students. A pre-tested questionnaire comprising in total 29 questions on the previously used and on the actual laptop was used. Details on the interviewees' attitudes, laptop use phase lengths and use pattern, repairs, and also sociological milieus were collected.
Based on multi-stage cluster sampling, randomly selected groups (courses) of bachelor students (8 out of 21 bachelor study programs) and master students (6 out of 12) of

the schools of Engineering and Business/Law were selected as interviewees. After coding of the answers, SPSS was used for answer processing and analysis. This panel study was carried out in May 2015 by Adrion (Adrion, 2015), and duplicated after small modifications in June 2018 by Müller et al. (Müller et al., 2018).

With SPSS, the data were analyzed both statistically and graphically. For the evaluation of special cases, minimum scopes, such as at least 10 valid answers, were defined. In a final step, all data sets of the 2015 and 2018 works were checked for consistency.

As recommended by Akremi et al. (2011), the data window is first viewed, to notice any unusualness. In the next step, the data values are compared with the values in the code plan. Subsequently, questions that are related to each other are considered. First, all questions about the current notebook were displayed and then all questions about the previous notebook. This is intended to eliminate or adapt inconclusive answers. The inconsistencies determined with the help of Excel are changed and improved in the data set before the actual evaluation of the data takes place. The data is then analyzed and evaluated regarding the user behavior of the respondents.

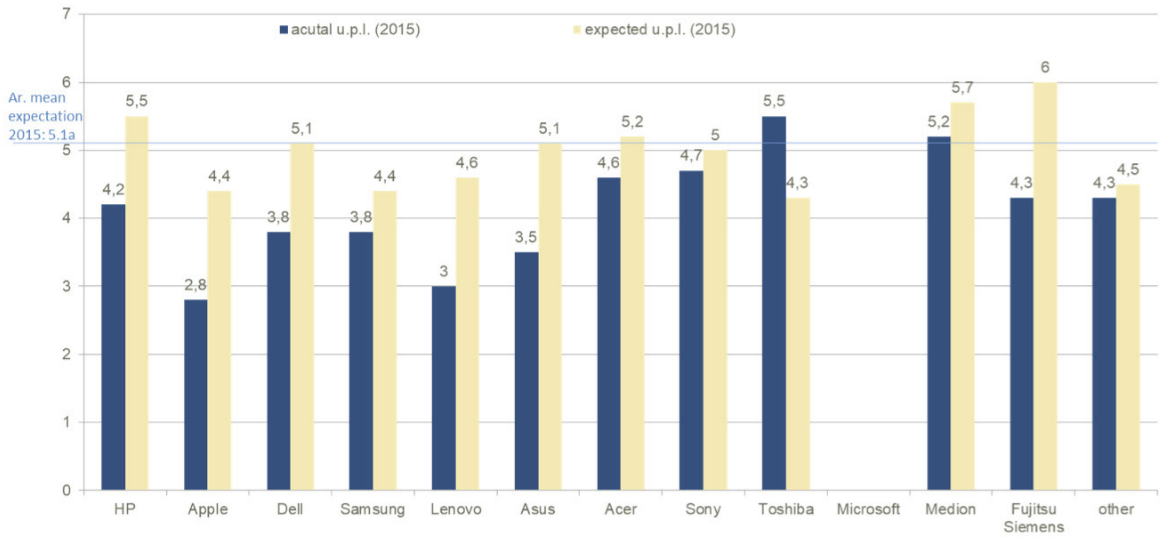

Figure 1. Expected and actual use phase lengths of laptops (2015 survey results).

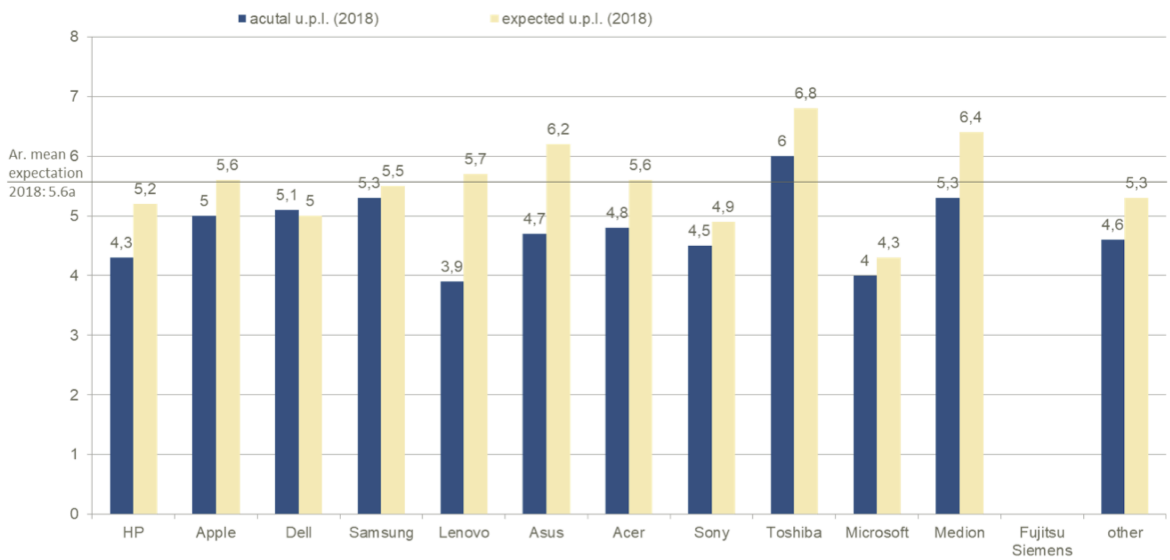

Figure 2. Expected and actual use phase lengths of laptops (2018 survey results).

Results and Discussion

The number of interviewees in 2015 was 215 students, and 336 in 2018. In total, 212 evaluable questionnaires (99%) in 2015 were obtained, and 332 questionnaires in 2018 with a share of 98.8% evaluable results. The share of female interviewees in 2015 was 51% and 44.6% in 2018, respectively.

Laptop Useful Life Length

The main result obtained from the surveys was the mean actual life length of the previous laptop, i. e. information on the users' laptop which is not in use any more: This laptops useful life has ended and thus it is clearly defined. The mean actual useful life of these devices in 2015 was 4.0 years (ranging from 2.8 years of Apple devices to 5.5 years of Toshiba devices), and 4.7 years in 2018 (from 3.9 years of Lenovo devices to 6.0 years of Toshiba laptops). Comprehensive brand specific results are shown in Figure 1 for 2015 and in Figure 2 for 2018, both for actual and expected useful life length.

The mean expected useful life duration in 2015 was 5.1 years. This expectation was only met by Toshiba devices (5.5 years actual use phase length), and Medion devices (5.2 years). The expected useful life in 2018 was 5.6 years, which was only exceeded by the actual mean useful life duration of Toshiba devices with 6.0 years.

Brands and Brand Loyalty

In both 2015 and 2018 surveys, Apple (2015: 20.9 %; 2018: 23.8 %) and Lenovo (2015: 20.4 %; 2018: 19.6 %) were the most frequently named brands among current devices. They were able to significantly increase the current number compared to the previous one. ACER and Asus also lead in both years for the predecessor models. In the year 2018, the number of current HP devices (2015: 9.2 %; 2018: 15.6 %) has increased remarkably. Compared to the global notebook market, differences can be identified. Worldwide, HP has the largest market share in all years, while Apple had a market share of 10.3% in 2015, a market share of 10.4% was forecasted for 2018. Another difference includes Dell's shares. In the surveys (2015: 6.3%, 2018: 1.6%), Dell's share in the sample is considerably lower than its global market share (2015: 13.7%, 2018: 15.6%). The differences could originate from the fact that data originate from a specific regional market: Students have different demands and requirements, and they only cover a narrow range of age.

Looking at the users' brand changing behavior from previous and actual devices, brand loyalty was quantified. The results show that users are predominantly switching between the brands. It is noticeable that Apple is the only manufacturer showing relatively low churn rates in both surveys (2015: 14.29 %; 2018: 33.33 %). In order to further question the facts, the importance of the brand prestige was analyzed. More than 50% of Apple users rate brand prestige as "important" or "very important" in both surveys, again distinguishing it strongly from other users. Consequently, it can be said that notebook users tend to have a low level of brand loyalty, except for Apple users. They seem to value Apple's brand prestige, which is reflected in low churn rates from the brand. Moreover, Apples products form a closed system, which obstructs brand switching ("lock-in effect").

Repairs and Warranty Period

In 2015, more than one fifth of the devices in use were repaired at least once. In the case of the predecessor models, the value was approximately one third. If all repairs are taken together, half of the repairs were carried out within 2 years. 22% of all repairs took place at the devices age between two and three years. (Adrion, 2015)

In 2018, 17.8% of current notebooks and just over a third of old devices are repaired at least once. Most repairs are carried out after one to two years on both the current and the previous notebook. (Müller et al., 2018)

The respondents were also asked about the manufacturers' warranty. Comparison of the average manufacturers' warranty duration with the average useful life shows that on average no defect occurs immediately after the manufacturers' warranty period has ended. (Adrion, 2015; Müller et al., 2018)

Expected Useful Life vs Actual Useful Life

Asking for expectations about how many years of use a notebook should provide, average values of 5.3 years in 2015 and 5.6 years in 2018 were obtained. The average actual useful life of predecessor devices was 4 years (2015), or 4.7 years respectively (2018). Thus, the expected useful life in both cases is significantly higher than the actual useful life of the predecessor devices. (Adrion, 2015; Müller et al., 2018)

Müller et al. note that in 2015 the average actual useful life (4.0 years) corresponded to 75 % of the average expected useful life (5.3 years), while in 2018 the average actual useful life (4.7 years) corresponded to 84 % of average expected useful life (5.6 years).
For the 2015 study a rank correlation according to Spearman was performed. It determined a correlation coefficient of 0.332, which indicates a low positive correlation, meaning that predominantly above-average or below-average x- (actual useful life) and y-values (expected useful life) fall together. Thus, the actual useful life of the predecessor model has a positive influence on the expected useful life. On the one hand, Adrion assumes that the long expected useful life may mean that consumers will not adjust their expectations despite the shorter useful lives of the predecessor. On the other hand, the constant innovations and short time intervals and the high-quality standards of the users could trigger higher expectations. The result of Müller et al. is to be interpreted in a similar way, since they determined a correlation coefficient of 0.324 for 2018.
Moreover, 2015 results showed that devices of those respondents who had read the instructions for use and who thought they were using the device in accordance with the specifications had the highest average useful life of 4.6 years. The lowest useful life was found with the combination "instruction manual not read" and "specifications not known" with 3.3 years. The 2018 survey confirmed the highest average service life for persons who have read the instructions for use and are of the opinion to use the device in accordance with the specifications.

Replacement and Disposal

The survey results indicate that in 2018 a defect is responsible for almost 40% of the disposals of previous notebooks (2015: ca. 50%). 49% (2018) of the respondents identify the item “no longer up-to-date” as a reason (2015: 40%). “Lack of compatibility” does not play a major role with 5% (2018) as a reason for disposal (2015: 6%), and the remaining percentages are covering other reasons. (Adrion, 2015; Müller et al., 2018)
In 2015, the average useful life of defective notebooks is 4.2 years, as well as that of notebooks that have been replaced because they are no longer up to date. In 2018, the useful life of notebooks with the replacement reason "no longer up to date" (5.1 years) exceeds the useful life of the defects (4.5 years). The answer category "Lack of compatibility" is not considered because the number of valid answers (2015: n=8; 2018: n=11) is low.
In 2018, 62% of all predecessor notebooks were stored after the end of their useful life, 17% were given away, 11% disposed of and 7% sold (others: 3%).
It has to be pointed out that, on the one hand, the surveys only measure the useful life (or only one usage period) and, on the other hand, a defect device cannot be regarded as evidence of planned obsolescence. Even under this assumption, in 2018 no shorter useful life (with reason of disposal: defect) than 2015 is determined.

Conclusions

The 2015 and 2018 surveys show that in the students’ environment surveyed both the useful life expectations (2015: 5.3 years; 2018: 5.6 years) and the actual useful life length of laptops increased from 2015 (4 years) to 2018 (4.7 years), but with a higher increase of the actual useful life.
It can be seen, that the user behavior (e.g. expressed in reading the instruction manual) and their socioeconomic background (e.g. expressed by self-assignment to a specific milieu) can also have an influence on the useful, technical or service life of a notebook.
Even in the case of a defect, some notebooks are given away instead of being disposed of, resulting in a tentative “second life” after having been repaired by the next owners.
A defect immediately after the end of manufacturer’s warranty could not be observed. All in all, proof of planned obsolescence was not obtained in this study.

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Consumer’s Perceptions toward Longer Product Use and Their Influence on Product Lifespan

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Keywords: Product Lifespan; Consumer Behavior; Survival Time Analysis; Attitude; Expected Lifespan.

Abstract: Product lifespan extension is effective for reducing material throughput and thus turning our resource use to a more sustainable style. It is crucial not only to design a more durable product but to encourage consumers to actually use their products longer. Therefore, the understanding of the influences of consumer's psychological attributes upon product lifespan is required. This paper attempted to quantitatively assess the influences of consumer's perceptions toward longer product use to the actual and expected lifespan through a questionnaire survey. It was shown that intention and attitude toward longer product use both had significant influences of extending both the actual and intended lifespan. However, the intended lifespan was influenced also by several other perceptions, while the actual lifespan was influenced by none of the others. In addition, consumers who had a stronger intention or attitude were more likely to experience a larger gap between the intended and actual lifespan. The paper concludes with an implication to researchers and policymakers that work on product lifespan.

Introduction

The realization of more sustainable resource use, especially the reduction of natural resource consumption, is urgent in order to sustain the global economy and environment (UN Environment, 2011). Material circulation approaches such as reusing and recycling are indispensable to reduce input of natural resources (European Commission, 2015), while our resource throughput must be reduced, too. Extending product lifespan has vast potential to reduce both input and throughput (Dominish et al., 2018). (Hereinafter, “product lifespan” is just referred to as “lifespan.”) (Note that, in this research, the term “lifespan” only signifies the period during which only a single consumer uses a specific product, which is referred to as “duration in use” in Murakami et al. (2010)).

To design a highly durable product, if consumers accept and use that product, seems one possibility (Wilhelm, 2012). However, many researches have shown that a large extent of End-of-Life products could still be used (Wieser and Tröger, 2018; Echegaray, 2016). It is, therefore, not sufficient to simply extend the physical/mechanical life of products. There is a need to encourage consumers to actually use products longer so as to extend their actual lifespan. Therefore, the understanding of the influences of consumer characteristics on lifespan seems essential. In particular, in social psychology and behavioral science research, psychological attributes such as attitude and awareness of consequences of a specific behavior are regarded as predictors of the behavior itself (Ajzen, 1991; Schwartz, 1977). These relationships have been verified for various behaviors concerning sustainable resource use, such as recycling (Chan and Bishop, 2013), reusing (Barr, 2007), and remanufacturing (Wang et al., 2018). Similarly, with regard to lifespan, relationships with psychological attributes such as attitudes and expectations, as well as socio-demographic variables, have been pointed out (Evans and Cooper, 2010; Cox et al., 2013). However, these are only indicated by qualitative analysis, and few studies have performed quantitative analysis. Fernandez (2001) and Gutiérrez et al. (2011) analyzed the influences of socio-demographic variables using survival time analysis, but consumer's psychological attributes were not taken into consideration. Grewal et al. (2004) analyzed the influences of attitudes toward products themselves but did not analyze those of attitudes toward longer product use.

Another key subject regarding lifespan is the expected lifespan, which represents a period during which consumers expect to use or want to use the product (Oguchi et al., 2016). This is because the gap between the expected lifespan and the actual lifespan is considered to show the potential for extending the actual lifespan (Gnanapragasam et al., 2017). In addition, we can assume that the expected lifespan, which represents the lifespan based on the consumer's expectation or intention to use a product, is more directly influenced by consumer's psychological attributes compared to the actual lifespan which is more strongly affected also by external factors. Therefore, it is expected that the comparison between the influences of consumer's psychological attributes on the actual lifespan and those on the expected lifespan may deepen our understanding of the actual lifespan.
Based on the aforementioned background, in this research, the influences of the consumer's perceptions toward longer product use on the actual lifespan as well as the expected lifespan are analyzed quantitatively. By comparing these results, implications for encouraging longer product use are discussed.

Method

Survey design

An online questionnaire survey was conducted in March 2018 in Japan, with a total sample size of 2310. The population balance of gender, age and area followed the national census. PC was selected as the product subject since it is one of the widespread electronic devices around the world and has a considerable environmental impact during its lifecycle (Ahwulia and Nema, 2007). In addition to demographic variables (see Appendix 1), the following data were obtained through the questionnaire.

1. Lifespan of PCs

Respondents were asked to answer the lifespan of the PC which they acquired most recently and were using (hereafter referred to as "In-use PCs"), and that of the PC which they most recently disposed of ("End-of-Life PCs") as well. The actual lifespan and the intended lifespan (how long respondents intend or intended to use their PC (Oguchi et al, 2016)) were asked for each item in a year unit.

2. Perceptions toward longer use of PCs

10 items of statements concerning longer use of PCs shown in Table 1 were prepared. The statements were constructed based on existing studies of lifespan (Cooper, 2004; Evans and Cooper, 2010) as well as of social psychology (Ajzen, 1991; Schwartz, 1977). Respondents were asked to choose whether they agreed or disagreed with the statements in 5-point Likert scale.

Statements	Abbre viation
I actually intend to use my PC longer.	INT
I want to use my PC longer.	ATT
I think using a PC longer is a good thing.	EVL
I think using a PC longer is economical.	ECO
I think using a PC longer is good for the environment.	ENV
I think using a PC longer can save energy consumption.	ENE
I think using a PC longer can save material consumption (metals, plastics).	MAT
Actually using a PC longer is difficult.	DIF
I think using a PC longer takes a lot of trouble.	TRO
I am negative about using my PC longer because its functions become obsolete.	OBS

Table 1. Statements of consumer's perceptions toward longer use of PC.

Statistical analysis

Cox proportional hazard model was utilized to assess the influences of variables on lifespan. In the model, the hazard function is defined by the following equation

$$h(t,x) = h_0(t)\exp(\boldsymbol{\beta x})$$

where $h_0(t)$ denotes the non-parametric baseline hazard function, $\boldsymbol{x}$ the explanatory variables vector, and $\boldsymbol{\beta}$ the regression coefficients vector. Positive coefficients indicate the corresponding explanatory variables have influences of shortening the lifespan, whereas negative coefficients indicate the influences of extending the lifespan.
In this research, explanatory variables include psychological variables concerning consumer's perceptions toward longer use of PCs, and demographic variables as control variables. Since there existed missing values in household income and personal income, multiple imputation by chained equation was conducted 50 times each using the other demographic variables. Generalized VIF was used to check the multicollinearity.

Proportional hazard assumption of each explanatory variable was verified by the log-log plot of lifespan and cumulative hazard function, and by scaled Schoenfeld residuals. As for variables that didn't satisfy the assumption, interaction terms of the variables with the natural logarithm of survival time were added as time-dependent variables if they were psychological variables, or if they were demographic variables they were utilized as stratification variables. The overall fit of the model was evaluated using deviance residuals and the following fit index proposed by Royston (2006) which is similar to R^2 of linear regression.

$$R_{p,v}^2 = \frac{R_{p,e}^2}{R_{p,e}^2 + \frac{\pi^2}{6}\left(1 - R_{p,e}^2\right)}$$

where

$$R_{p,e}^2 = 1 - \left\{exp\left[\frac{2}{m}\left(L_0 - L_p\right)\right]\right\}$$

(L_0 denotes the log-likelihood of the null model, L_p the log-likelihood of the estimated model, and m the number of events).

Result

Descriptive statistics

- **Actual and expected lifespan**

The number of collected data was 2,177 for In-use PC and 1,572 for End-of-Life PC. Kaplan-Meier method was utilized to estimate the median lifespan of both the actual and intended lifespan. The median actual lifespan was estimated to be 7.5 years whereas the median intended lifespan to be 6.5 years. This result that the actual lifespan was longer than the intended lifespan occurred due to a large number of censored data, i.e. data of In-use PCs, for actual lifespan, while for intended lifespan data are not censored. When we look at the gap between the intended lifespan and the actual lifespan (Figure 1), there are more End-of-Life PCs that have a positive gap, indicating that people tend to use their PCs shorter than they have intended. This is also supported by the fact that, when we only use data of End-of-Life PCs, the median actual lifespan decreased to 5.5 years. Most of the PCs had the lifespan of shorter than 10 years for both actual and intended lifespan, while some had extreme values, especially for the intended lifespan. The median lifespan values of this study are similar to surveys in other countries (Wieser and Tröger, 2015; Echegaray, 2016; Hennies and Stamminger, 2016).

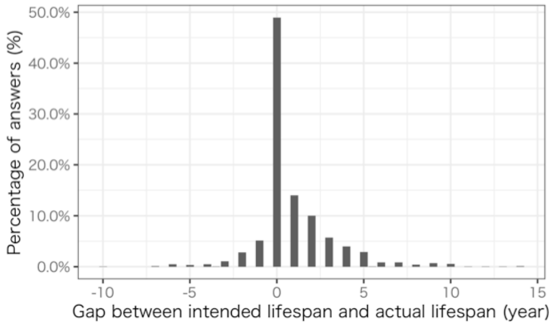

Figure 1. Gap between the intended lifespan and the actual lifespan of End-of-Life PCs (positive gap indicates the intended lifespan is longer than the actual lifespan).

- **Perceptions toward longer product use**

The proportions of answers to the items of consumer's perceptions toward longer use of PCs are shown in Figure 2. All items show a similar trend, that is, a large proportion of respondents agreed with or were neutral to the statements, while very few disagreed, not only for positive perceptions but negative ones (DIF, TRB, and OBS). Therefore, people mostly have positive perceptions toward longer use of PCs, while at the same time they also have negative perceptions, indicating their ambivalent perceptions toward longer product use.
Correlations between the items were mostly moderately strong among positive perceptions (0.4-0.75) as well as among negative ones (0.35-0.45), whereas correlations between positive perceptions and negative perceptions were weak (0.05-0.3).

Influence of consumer's perceptions on lifespan

According to the preliminary analysis, three outlier data points (data of which the intended lifespan was longer than 30 years) were excluded. Age and TRB didn't satisfy the proportional hazard assumption, and thus age was utilized for stratification and a time-dependent term of TRB was added. Result from the main analysis are shown in Table 2 (The result including demographic variables are shown in Appendix 2). For both the actual lifespan and the intended lifespan, INT and ATT

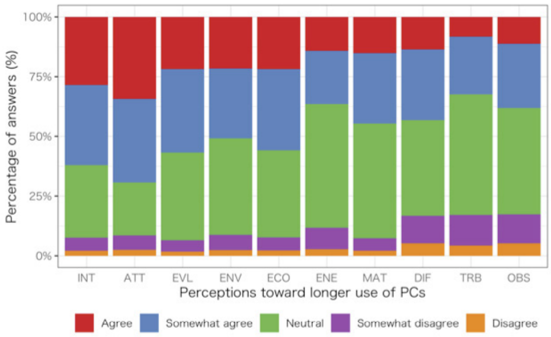

Figure 2. Proportion of answers to statements of consumer's perception toward longer use of PC.

Variables	Actual	Intended
INT	-0.131**	-0.128**
ATT	-0.120**	-0.151**
EVL	-0.020	-0.043
ECO	0.080	0.054
ENV	0.010	-0.063*
ENE	-0.051	0.065*
MAT	0.040	0.020
DIF	0.047	0.043*
TRB	0.048	0.107*
OBS	0.014	0.098**
t(TRB)	-0.043	-0.076**

** p<0.01; * p<0.05

Table 2. Influence of consumer's perceptions on lifespan. (t() denotes the time-dependent term).

had significant negative coefficients, indicating their influences of extending lifespans. However, although several other variables showed significant influences on the intended lifespan, which ENV and t(TRB) had influences of extending the intended lifespan and ENE, DIF, TRB, and OBS had influences of shortening, no other psychological variables had a significant influence on the actual lifespan. The fit index value was 0.034 for the actual lifespan and was 0.055 for intended lifespan, that is, the investigated variables had slightly stronger explanatory power for the intended lifespan than for the actual lifespan.

To further investigate the differences between the influences of consumer's perceptions on the actual lifespan and those on the intended lifespan, respondents were classified into three groups based on their strength of each item of

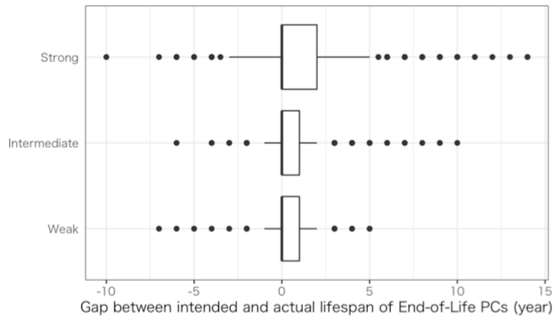

Figure 3. Difference in the gap between intended and actual lifespan among groups classified based on ATT.

perceptions respectively (those who chose "agree" or "somewhat agree" as "Strong", "neutral" as "Intermediate", and "somewhat disagree" or "disagree" as "Weak",) and the distributions of the gap between the intended lifespan and the actual lifespan were compared among groups with one-way ANOVA.
It was shown that there existed significant differences in the gap among groups when we classified based on INT, ATT, EVL, ECO, ENV, and OBS. Particularly, respondents with strong INT or ATT were more likely to experience a positive gap between the intended lifespan and the actual lifespan (Figure 3).

Discussion

The influences of consumer's perceptions toward longer product use on the actual and intended lifespan were sought in this study. The result from the Cox proportional hazard model showed that, similar to the other behaviors concerning material circulation (Chan and Bishop, 2013), intention and attitude toward longer product use had significant influences for extending the actual lifespan, which supported the findings from existing studies of lifespan in a quantitative method (Evans and Cooper, 2010). We can, therefore, state that it is indeed effective to promote longer product use by improving consumer's intention and attitude toward it, for example by providing knowledge about the benefits (Barr, 2007).
On the contrary, those who had a stronger intention or attitude to use their product longer were more likely to experience a short actual lifespan compared with their intended lifespan. That is, despite the aforementioned fact that strong intention or attitude can extend the actual lifespan, they did not affect the actual lifespan as much as they affected the intended lifespan. This can be interpreted as one form of

the intention-behavior gap that their influences of extending the actual lifespan are restricted, possibly due to external factors.
This argument is supported by another finding that the other psychological variables had no significant influence on the actual lifespan whereas many of them had significant influences on the intended lifespan. And accordingly, the fit of the model was lower for the actual lifespan than for intended lifespan. This means that, unlike the intended lifespan which represents the consumer's willingness to use their products, the actual lifespan is largely influenced by factors other than psychological attributes.
Above all, although there exist significant influences of consumer's intention and attitude toward longer product use on the actual lifespan, it has a lot to do with other external factors.

Limitations of this study and suggestions for future works

Despite the important findings, there are several limitations to this study. The main limitation is, as is already mentioned, the insufficiency of factors in consideration. Although the main focus of this research was on the influences of consumer's psychological attributes upon lifespan, the overall explanatory power of the model was quite low, indicating that necessary factors were not included in the model. The lack of those influential factors may also pose questions to the reliability of our findings, that obtained data were not adequately controlled.
Another issue is the relationships between the psychological variables. Even though we know that intention and attitude have influences for extending lifespan, it is not yet well known how to improve them. Causal relationships among psychological attributes have been analyzed using structural equation modeling in numbers of studies for other behaviors (Wan et al., 2017), which were not conducted in this study.
While there are other limitations (the definition of the expected lifespan, different product subjects, etc.), future studies should primarily focus on including factors other than consumer's psychological attributes and investigating their influences as well as the interactions between themselves.

Conclusion

Product lifespan extension is a powerful approach to reduce resource throughput and accordingly natural resource consumption. This study investigated the influences of consumer's perceptions toward longer product use on product lifespan in order to identify ways to encourage consumers to actually use their products longer. One important finding is that improving consumer's intention and attitude to use their products longer can indeed lead to longer actual lifespan. Therefore, policymakers or product designers aiming to realize longer product lifespan should set approaches that can improve consumer's intention and attitude. While at the same time their influences are limited, and factors other than consumer's psychological attributes have much influence on the actual lifespan. There is a strong need for further studies to analyze the influences of other factors, not only on the lifespan itself but among factors, specifically influences on intention and attitude, so that more detailed, effective approaches can be determined.

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Appendix 1: Sample design

Category	N (%)
Gender	
Male	1116 (48.3%)
Female	1194 (51.7%)
Age	
20-29	289 (12.5%)
30-39	344 (14.9%)
40-49	425 (18.4%)
50-59	340 (14.7%)
60-	912 (39.5%)
Area	
Hokkaido	104 (4.5%)
Tohoku	167 (7.2%)
Kanto	775 (33.5%)
Chubu	416 (18.0%)
Kinki	370 (16.0%)
Chubu	139 (6.0%)
Shikoku	79 (3.4%)
Kyushu	260 (11.3%)
Marriage	
Married	1525 (66.0%)
Not married	785 (34.0%)
Child	
Have children	1455 (63.0%)
No child	855 (37.0%)
Household income	
Low income	721 (31.2%)
High income	1123 (48.6%)
DK / NA	466 (20.2%)
Personal income	
Low income	1433 (62.0%)
High income	482 (20.9%)
DK / NA	395 (17.1%)
Occupation	
Unemployed	979 (42.4%)
Part-time worker	304 (13.2%)
Full-time worker	1027 (44.5%)

Appendix 2: Results of Cox proportional hazard model analysis including demographic variables

Variables	Actual	Intended
INT	-0.131**	-0.128**
ATT	-0.120**	-0.151**
EVL	-0.020	-0.043
ECO	0.080	0.054
ENV	0.010	-0.063*
ENE	-0.051	0.065*
MAT	0.040	0.020
DIF	0.047	0.043*
TRB	0.048	0.107*
OBS	0.014	0.098**
t(TRB)	-0.043	-0.076**
Gender		
Female	-0.073	-0.024
Area		
Tohoku	0.01	0.024
Kanto	0.035	0.023
Chubu	-0.088	-0.073
Kinki	0.044	0.037
Chugoku	-0.073	-0.05
Shikoku	-0.217	-0.074
Kyushu	-0.04	-0.007
Marriage		
Married	0.013	-0.1*
Child		
Have children	0.088	0.093*
Household income		
High income	0.101	0.119*
Personal income		
High income	0.085	0.157**
Occupation		
Part-time worker	0.031	0.127*
Full-time worker	0.033	0.066

** p<0.01; * p<0.05
Age was incorporated in as a stratification variable

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PLATE – Product Lifetimes And The Environment
Proceedings of the 3rd PLATE Conference

The current systems of consumption and production cause long-lasting social-ecological damage and a fundamental change seems inevitable, if livelihoods of present and future generations are to be preserved. The lifetimes of products and their performance concerning reliability, functionality, re-usability and recyclability are core issues in the transformation from a linear to a more sustainable circular economy. While discussions on product lifetimes have been going on for a number of years, the topic has come to the forefront of current (political, scientific & societal) debates due to its interconnectedness with a number of recent prominent movements, such as the circular economy, ecodesign and collaborative consumption. The 3rd international PLATE conference (Product Lifetimes And The Environment), held from 18-20 June 2019 in Berlin, Germany, addressed product lifetimes in the context of sustainability. The proceedings of this conference present a great variety of significant research on how to enable more sustainable practices of designing, producing, using, re-pur-posing and recycling products and on how to assess the sustainability of these endeavours. The authors work in inter- and transdisciplinary teams that operate at the crossroads of engineering, design, social sciences and environmental sciences.

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