PLATE

Product Lifetimes And The Environment

3rd PLATE Conference
September 18–20, 2019
Berlin, Germany

Nils F. Nissen
Melanie Jaeger-Erben (eds.)

Watkins, Matthew Alan; Mestre, Ana: **A comparative and exploratory study of toy products in the circular economy**. In: Nissen, Nils F.; Jaeger-Erben, Melanie (Eds.): PLATE – Product Lifetimes And The Environment : Proceedings, 3rd PLATE CONFERENCE, BERLIN, GERMANY, 18–20 September 2019. Berlin: Universitätsverlag der TU Berlin, 2021. pp. 835–842. ISBN 978-3-7983-3125-9 (online). https://doi.org/10.14279/depositonce-9253.

Universitätsverlag der TU Berlin

3rd PLATE 2019 Conference
Berlin, Germany, 18-20 September 2019

PLATE
Product Lifetimes And The Environment

A Comparative and Exploratory Study of Toy Products in the Circular Economy

Watkins, M[(a)]; Mestre, A[(a,b)]
a) Nottingham Trent University, Nottingham, UK
b) Loughborough University London, London, UK

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.

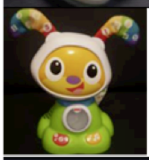
Qualitative Findings

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.

Acknowledgments

This research was undertaken with financial support from the EPSRC funded Centre for Industrial Energy, Materials and Products, grant reference EP/N022645/1. The authors also wish to thank the following students who undertook project work: Archie Davies, Ashley Griffin, Tobias Jarrett, Herbert Kemp, Daniel Kordys, Sean McCarthy, Grigorii Prokhorov, Alex Winter.

References

Ashby, M.F., Miller, A., Rutter, F., Seymour, C. and Wegst, U.G.K., (2012). CES EduPack for Eco Design—A White Paper. In Granta-Teaching Resources (Vol. 5).

Brezet, H., & Hemel, C. V. (1997). Ecodesign: a promising approach to sustainable production and consumption. Paris, France, United Nations Environment Programme, Industry and Environment, Cleaner Production.

McAloone, T.C. and Bey, N., (2009). Environmental improvement through product development: A guide. Danish Environmental Protection Agency.

Mestre, A., & Cooper, T. (2017). Circular Product Design. A Multiple Loops Life Cycle Design Approach for the Circular Economy. The Design Journal. http://doi.org/10.1080/14606925.2017.1352686

Muñoz, I., Gazulla, C., Bala, A., Puig, R., & Fullana, P. (2009). LCA and ecodesign in the toy industry: case study of a teddy bear incorporating electric and electronic components. The International Journal of Life Cycle Assessment, 14(1), 64–72. http://doi.org/10.1007/s11367-008-0044-6

Mustafa, A., Abdollah, M. F. B., Ismail, N., Amiruddin, H. and Umehara, N. (2014) "Materials selection for eco-aware lightweight friction material," Mechanics & Industry. EDP Sciences, 15(4), pp. 279–285. doi: 10.1051/meca/2014039.

NPD Group. (2018). Year to Date, Toy Sales Across Key Global Markets Grew by Almost 2 Percent, Reports NPD. Retrieved 11 January 2019, from https://www.npd.com/wps/portal/npd/us/news/press-releases/2018/year-to-date-toy-sales-across-key-global-markets-grew-by-almost-2-percent-reports-npd/

Toy Industries of Europe. (2017). THE EUROPEAN TOY INDUSTRY FACTS AND FIGURES 2017. Retrieved 11 January 2019, from https://www.toyindustries.eu/wp-content/uploads/2018/01/TIE-EU-Toy-Sector-Facts-and-Figures-FINAL.pdf