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CYBERNETIFICATION I: Cybernetics Feedback Netgraft in Architecture

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During the last decades, architecture has changed its role from fetishizing and fertilizing objectification and objects alike towards glamorising the processing of relations, observations and materialization of the objectile[1]. Steering the design process in contemporary computational architecture through and with a variety of dynamic, interconnecting agents affords re-framing, re-viewing, and re-designing prescribed patterns of creating architecture. It critically encourages to examine the concept of feedback beyond the beloved evolutionary algorithm, which presents a technical rather than architectural cultural calculus. ‚CYBERNETICS FEEDBACK NETGRAFT' proposes cybernetic principles as blueprint or genotype for computational architecture. Such principles allow for a systemic continuation of re-programming the architectural culture currently at stake. The forthcoming observation hovers between theories and meta-models. It argues that the possibilities for design increase through digitization and digitalization[2]. In this respect, the chapter refers to Ross Ashby's *Law of Requisite Variety* (Ashby 1957) on one hand and to emergence through digital self-organization on the other. (DeLanda 2011; Johnson 2001). The text offers a critic of the bio-digital and too fantastic (Werner 2014, pp.229-230). I am starting to suggest an 'architectural laboratorium of and for computational theory' built on a systemic approach to emergence and the unforeseen - nourished by cybernetic principles: a cybernetification that eventually can govern and feed back into practice and the art of architecture.

Keywords: feedback, cybernetification, network, Anthropocene, ecology, architecture

Cybernetification

CYBERNETIFICATION© has been inspired by the 'growth' of *entailment meshes* and the possibility for grafting them as developed by Gordon Pask (Pask 1975; 1976[3]; Werner, forthcoming). The term *cybernetification* appeared first in conjunction with the Cyberneticon, a construct, a virtual cybernetic driver, enabling concepts such as recursive circularity and learning through constant observation and error-control (Werner 2015, pp.38-78). Essentially it is a *Turing Machine* necessary for feedforward through feedback. Cybernetification is enabled through the technical possibilities the Internet with its generous infrastructure offers; leaving aside the critical view towards cyber-hacking, the Internet as money-making-machine or the ecological impact of large data-centers in the desert Nevada and other places. In the abstract I am referring to a CYBERNETIFICATION© that eventually can govern and feed back into practice and the art of architecture. One obstacle for resolving this suggestion, desire, hope or simply process lies in the fact that architecture – design and theory - globally is in a time of crisis. We are not sure how to define architecture, and certainly we are not sure about what the practice of architecture actually does or how to educate our architecture students - contemporary and in future. Alberto Pérez Gómez discusses the 'loss of architecture' by reflecting on the influence of the first industrial revolution on strict architectural and geometrical orders. He brings to life the perturbative aspect of sciences in the evolution of architecture (Pérez-Gómez 1983). In more recent times, Antoine Picon, Professor of the History of Architecture and Technology at Harvard GSD, has been engaging with the feeding back of a digital architectural culture into the architectural culture of material practice through a number of lectures on 'Digital Culture in Architecture' at HGSD, or *'Architecture, Matter and Language in the Digital Age'* at SciArc and his book '*Ornament: The Politics of Architecture and Subjectivity'* (Picon 2013). Alberto Pérez Gómez, Antoine Picon, Mario Carpo and a large number of others offer valuable analyses and advice for us architects to find our way through the forest of code and robotic operations back home or rather towards to an architecture where object-focused geometric notions Vitruvian and Corbusier'an architectural principles can merge with code, new materialism and what I call *Netgraft*[4]. The concept of *netgrafting* describes designing with and through digital conversation, learning algorithms and a trans-cultural approach: in a way assisted or governed self-designing architecture enabled through the Internet, open-source tools and above all a new understanding of ownership,

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that emerged with the emergence of the digital natives, born around the 1990s. The theoretical and academic paradigm through which Pérez Gómez, Picon and Mario Carpo develop their thoughts may be seen critical from the perspective of a practicing architect (which is understandable), it may also be seen as visionary and utopian through the eyes of an architect planning and constructing in less wealthy countries. Thoughts of constructing material ornament through algorithms are distant from the possible urgent necessity to install a sewage system for a school complex in Nepal; however, the facts that our architectural culture is

a) transforming, specifically digitalizing
b) increasingly influenced by direct and indirect digital feedback – in addition to analogue human feedback
c) a product of 'collective' and designed coding, on a communication level, an engineering level and a geometric aesthetic level
d) investigating material intelligence as design driver

indicates that architecture as a discipline is undergoing a process of cybernetification.

Context

CYBERNETICS FEEDBACK NETGRAFT is part of a research focusing on the evolution and development of architectural ecologies in an age of digitization and digitalization, informed by complex political, economic and climatic interdependencies.

CYBERNETICS FEEDBACK NETGRAFT is part of a research focusing on the evolution and development of architectural ecologies in an age of digitization and digitalization, informed by complex political, economic and climatic interdependencies. Research, starting in 2002 with a more intense iteration beginning around 2010, is first of all engaging with cybernetics and architecture as variety system[5]. Work is primarily driven by the research and cybernetic concepts developed by Gordon Pask '*Conversation Theory*' (Pask 1976), Margaret Mead '*Cybernetics of Cybernetics*' (Mead 1968), Heinz von Foerster '*eigen-behavior*' (Heinz von Foerster 1981) and Ranulph Glanville '*Cybernetics and Design*' (Glanville 2009; 2014). It is spinned by an increasing techno-fication and bit-fication of the 'natural' human paired with a humanization of the (mainly digital) technological; all influenced or let's say seasoned by selected perturbing subjects, such as post-ecology, Anthropocene, man-machine co-evolution or what I call involuntary architecture.

It is a process of transformation from a state X to a dynamic state of operation of which it is known that the state is fully based on active and passive feedback, partly governable, partly influencing the system to involuntary operations. This book chapter is the first of a series of the CYBERNETIFICATION© TEXTS[6]. It begins discussing the relationship and influence of cybernetics on humans, machines, our habitual environment and constantly transforming relationship to architecture and the material world. One could locate the writings within the discourse of the socio-technical ecology, written through the lens of digitalization and extend the ecological paradigm of architecture from purely shelter via urban planning to an interconnected organizational design and cultural evolution in a *Technosphere milieu*; an extended ecology where nature and technology seem interchangeable and not differentiable. Gilbert Simondon's description of the 'associated milieu' describes such an "environment, which is at the same time natural and technical […]". In '*The Mode of Existence in Technical Objects*', originally published in 1958[7] (Simondon 1980) p.61. Simondon, ahead of his time, understands 'Technical Objects' as "at the same time natural and technical." It is notable that he prefers and uses specifically the term 'technical' rather than 'artificial'; a term popularized since artificial intelligence has visibly infiltrated human culture. CYBERNETICS FEEDBACK NETGRAFT in architecture was conceived through a series of lectures that focused on digitalization and alien control enabled through the Internet enhancing communication – conversation – between humans (and humans and machines) to generate or optimize form, collectively, touching on conversation between intelligent humanoid or virtual machines, humans and other systems. The latter is a subject perpetuating machinic (Deleuze and Guattari 1987; Werner 2014b) as ecology to be discussed in future CYBERNETIFICATION©TEXT. At this stage, I will discuss CYBERNETICS FEEDBACK NETGRAFT through the lens of a cybernetic architect. The discussion embeds itself within the geological and political context of the Anthropocene and settles on the foundations of Katherine Hayles '*How we became post-human*' (Hayles 1999), Nicholas Negropontes '*Being Digital*' (Negroponte

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1995), Arthur C. Clarke's *'Neuromancer'* (Gibson 1986) paired with a) the contemporary socio-cultural discourse of algorithmically steered self-organization and b) the architectural discourse of the second digital turn[8], even if the chapter does not refer directly to the above mentioned framework. Cybernetics[9] had its high and lows, its heydays and its falls. Throughout the decades of the 20th century it was nourished, treated well and raised from a tool for controlling electric circuits, navigation or warfare to a magic wand for regulating the complex and the unknown[10]. Cybernetics, the study of systems based on circularity, decoding and encoding of information, now, in the beginning of the 21st century "rises from the ashes" (see ch. 01 by Paul Pangaro, 'Cybernetics as Phoenix: Why Ashes, What new Life') as black box encapsulating the DNA of feedback and a foundational tool-kit for mastering the art of the unpredictable. I provide the reader with one definition of what cybernetics can be. However, this is not the one-and-only-text-book definition on which the text builds up upon, instead I integrated an explanation, or rather explanations, in the paragraphs themselves. The cybernetic principle does not allow for ONE definition of cybernetics, since every observer has his or her own reality and epistemological treasure chest of wisdom, which influences the definition. This is one of the magic aspects of cybernetics.

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> *"CYBERNETICS is a young discipline which, like applied mathematics, cuts across the entrenched departments of natural science; the sky, the earth, the animals and the plants. Its interdisciplinary character emerges when it considers economy not as an economist, biology not as a biologist, engines not as an engineer. In each case its theme remains the same, namely, how systems regulate themselves, reproduce themselves, evolve and learn. Its high spot is the question of how they organize themselves."*
>
> Pask, 1961

Feedback

Feedback according to the cybernetician and radical constructivist Ernst von Glasersfeld is "something that is produced by a machine or organism is led back to modify the process of production."

(Glasersfeld 2002). Feedback (negative feedback and positive feedback / feed forward) as a concept can be defined as the process of routing back an output as input to the same processing / producing 'machine'. The process of feedback is a tool for regulating a system in order for it to traverse towards its goal or 'advising' a system to adjust, change or even replace its goal. It allows for communication between a sensor and a regulator, which is the one that instructs a system to 'react'. It has been defined slightly differently over the decades and in accordance to the definition source. I think we can say that overall is an indicator of cause-and-effect relationships, which may be assessed differently in controlled environments than in uncontrolled environments; despite that the underlying behavioral rules may be the same. The difference is that an uncontrolled environment can evolve and mutate according to the individual agent's or actor's possibilities and a controlled environment can only act according to a controlling 'force' or limiting circumstance. Systems in uncontrolled environments may also be more resilient than systems in other environments. A controlled environment could be a classroom, a family, a political system or a biological milieu where a certain species of bacteria resides, live and evolve. An uncontrolled environment is the Internet. Now, almost 30 years after its conception, known societal instruments, such as respect, laws, codes of communication conduct or legal regulation, steering functioning social systems (a people, a village, a family or simply a small group of friends) are disappearing. The uncontrolled Internet, including the milieu of the Darknet, has grown a scale of complexity based on feedback loops, nourished by societal change and learning algorithms that is simply unsteerable and to interwoven to comprehend. The once controlled Apranet (Advanced Research Project Agency Network) which was conceived and brought online as the first switching network in 1969 applied TPCs (Transmission Control Protocols) and IPs (Internet Protocols), the foundations of our Internet, opened to the world in 1991. Feedback as motor for digital growth and tool for qualitative optimization is a relatively new understanding. In the 1940s and decades after, Norbert Wiener in *'The Human use of Human Beings: Cybernetics and Society'*, first

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published in 1950, considers the quantitative application of feedback, as used in machine performance. He states

> *"This control of a machine on the basis of its actual performance rather than its expected performance is known as feedback, and involves sensory members which are actuated by motor members and perform the function of tell-tales or monitors – that is, of elements which indicate a performance."*
>
> Wiener, 1989 p.25

explaining feedback functions of an elevator or a gun and regards those as 'feedback' and 'reflex' before considering – and this is the core of his book- feedback as an operation for human and societal evolution and optimization.

Wiener continues explaining feedback functions of an elevator or a gun and regards those as 'feedback' and 'reflex' before considering – and this is the core of his book- feedback as an operation for human and societal evolution and optimization. At this stage, he redefines an at that time already obsolete understanding of feedback. In light of the differentiation between first (information transport and observer exclusion) and second-order cybernetics (feedback, learning and observer integration) I would like to quote one of the relevant sections of the chapter 'Progress and Entropy' (Wiener, 1989 pp.28-47):

> *"Feedback may be as simple as that of the common reflex, or it may be a higher order feedback, in which past experience is used not only to regulate specific movements, but also whole policies of behaviour. Such a policy-feedback may, and often does, appear to be what we know under one aspect as a conditioned reflex, and under another as learning."*
>
> Wiener, 1989 p.33

The notion, concept, process or tool that we call feedback entered a new territory through Norbert Wiener on one hand, but also through the Macy Conferences, held between 1946 and 1953, funded by the Josiah Macy Foundation. Cybernetics was a young field, not yet established in any way beyond the hard sciences, navigation, mechanization, thermodynamics (physics), hence conference titles changed throughout the years. The sixth Macy Conference, held 24th and 25th March 1949 in New York, received the title 'Cybernetics

– Circular Causal, and Feedback Mechanisms in Biological and Social Systems', initiated by Heinz von Foerster, to exactly discuss this subject between different disciplines ranging from computer sciences to anthropology and philosophy. The group of scientists included Claude E. Shannon, Norbert Wiener, Gregory Bateson, Margaret Mead, Warren McCullough and others. At that stage Wiener, according to his first book 'Cybernetics: Communication and Control in the Animal and the Machine', suggested that "today [in 1949] "Cybernetics" has ultimately come to stand for the science of regulation in the most general sense." (Foerster 2003 p.192). In the 21st century, the Anthropocene, the time where most humans - and an increasing number of 'intelligent', 'smart' machines - are connected and 'controlled' by digital 'artificial' algorithms more than our human instincts (technically also based on algorithms), the process of feedback is common practice. Digital feedback, often invisible, has undergone a naturalization process, similar to the existence of technologies such as running water, the telephone or a pencil – the generation of the digital natives is the first truly embodying cyberspace. Increasing and complex interconnectedness feature trans-communicational tools, uncountable coding languages and multi-parametric design requirements and nourishes some designers desire, urgent necessity and quest for suitable design strategies and design models.

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Netgraft

In my lectures and writings I emphasize that "The architect is no longer a designer of discrete objects, matter and space, but a designer of systems with complex components and multi-layered relationships." (Werner 2014; 2014a). At this moment in time I would like expand the statement and suggest that the architect, in fact, all designers are designers of relationship. Depending on how a relationship is designed the system will test and establish systemic operational and behavioural rules, including rules for feedback; which essentially is the systematic behind 'negrafting', hence cybernetification. The term 'netgrafting' stands for a networked ‚graftsmanship'. It is a hybrid between the 'net' and 'graft'. The 'net' can be any net, from very small closed systems, such as a pencil and a designer, to very large complex such as the Internet. In light of the current debate on digitalization of the architectural culture and the rise of novel design strategies embracing emergence, 'net' refers to the latter. The term 'graft' or 'grafting' means to "insert a shoot from one tree into another" and relates to regulated forming of plants, etymologically 'graft' stems from the Latin graphium meaning 'stylus' and the Greek equivalent grapheion meaning 'to write'. Thus 'netgrafting' is the action of directed collective design, the 'styling', the development of stabile or permanent or temporary conversational systems. Architects and designers of all disciplines – including creatives in astrophysics, quantum mechanics, economy, computer sciences, anthropology, material sciences or digital humanities, biology – are facing a similar challenge in the sea of information overload. Namely to find a tool and a tool-maker for creating a filtering device that would regard or (temporarily) leave behind unnecessary, obsolete bits and bytes in a design process of any kind. In contrast to the linear suitable in and for a straight and predictable environment we are now longing for tools that can craft and graft dynamic self-organizing systems for meta-environments, able to adjust their goals and subsequently behavior in response to perturbations[11]. One way of designing or generating those tools is to work collectively rather than individual and exclusive. Knowledge-sharing and collective problem solving has experienced a full start over the last decade. We, Internet users, have been building a strong network in and through cyberspace; a large metasystem, an expanding field with smaller netgrafted sub-regions[12]. Open source platforms describe such sub-regions, which can change in shape and size where parts / variables interconnect, create relationships. The application of collective intelligence to solve technical design problems takes place in such systems, which we may recognize as open systems. Open systems can be accessed from the outside, agents or parts located inside the system can also access the outside, hence they are different to closed systems since they. Information-flow and conversation between inside and outside is enabled. The open system can underlie principles of 'dynamic equilibrium', however this is not a requirement. In contrast to processes carried out in closed

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systems, processes in open systems are irreversible and cannot be undone (Bertalanffy 1968 pp.30-52)[13]. Once the system is made of a group of parts, it underlies basic principles of complex systems, with interconnected parts (agents or actors). Communication about a given problem is possible through the infrastructure of the Internet. Feedback is essential for the complex open system to 'work', to be viable and resistant.

Thoughts on Foundations of Netgrafting Form

To understand the logic of how an architectural form (a form-giving algorithm or a script to operate a robot arm) is grafted by 'graftsmen' around the globe we need to analyze the complexity system as a whole and the 'make-up' of its parts in order. According to Ashby, this becomes difficult in system with high complexity: "when there are only two parts joined so that each affects the other, the properties of the feedback give important and useful information about the properties of the whole. But when the parts rise to even as few as four, if everyone affects the other three, then twenty circuits can be traced through them; and knowing the properties of all the twenty circuits does not give complete information about the system. Such complex systems cannot be treated as an interlaced set of more or less independent feedback circuits, but only as a whole." (Ashby, 1957 p.54).

Ashby's understanding of the complex system as a whole is visible in crowd-behavior of any kind where, let's say, parts in a colony communicate with each other, including schools of fish, swarms of birds, connected IoT-devices, algorithms, bots, ants and also humans. In intelligent brain-like network structure allows the parts to regulate the whole's survival strategy. The mentioned examples are all resilient living systems – some of them biological and organic, some not. Resilient systems found in nature, biology and physics have developed techniques (scripts) that behold a large number of possibilities of reaction in case of danger. A strategy based on knowledge (information embedded in the systems and in the parts) guarantees development and evolution through error control. Error control implies that the effectors of a certain error are known to the

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system, that the system has sufficient information in order to 'sense' an error. In cybernetics terms, such systems or organizations are equipped with requisite variety. The Law of Requisite Variety, known as the first law of cybernetics, was developed by Ross Ashby and first published in '*An Introduction to Cybernetics'* in 1957. The law states that the number of actions available to control a system must be equal or larger than the variety of perturbations (Ashby 1957). Thus the number of elements and its material behavior determines the degree of complexity of the system, while the relationship between degree of complexity and resilience – or comprehension of information - is isomorph.

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We could argue that only if the designer of a system understands each element he or she can steer/graft the design process of the system. Since it is impossible to fully understand each part in a complex system, an abstraction of the part's attributes is applied. This manifests in the temporary coupling with a small number of parts in the system. In our case of computational architecture, the knowledge (information embedded in the systems and in the parts) mentioned above does not imply or even guarantee a clear vision of the formal outcome, but an idea of behavioral patterns and possible consequences of relationships between the elements. According to Ashby a set of distinguishable elements in a system enabling a distinguishable number of actions gives the system its number of variety and its number of behavioral patterns – internal and external. Architecturally speaking, each behavioral pattern has the potential to give birth to one or more typologies of form - more or less complex[14]. Both terms, 'form' and 'pattern', are long established in architecture. Wentworth D'Arcy Thompson (Thompson 1961)[15], Christopher Alexander (Alexander 1971), Nicholas Negroponte (Negroponte 1975) have primed several generations of architects. John Frazer's *'Evolutionary Architecture'* (Frazer 1995), and Greg Lynn's *'Animate Form'* (Lynn 1999) gave way to exploring the feedback, the novel tools and the digital offered. "In addition to the aesthetic and material consequences of computer-generated forms, computer software […] offers capabilities as a conceptual and organizational tool." (Lynn 1999).

Ranulph Glanville gave ground to a cybernetics and design and reflecting disciplines (Glanville 2009). In architecture, especially since the first digital turn in the 1990s, computer software has offered formal variety and organizational 'skills'. In the 2010s reaching an overwhelming level of complexity between hardware and software, designer and computational design-strategy (multi-agent systems, flocking, DLA, genetics, subdivision, structural optimization), aesthetics and engineering, politics, tectonics and environmental context. The science of complexity has grown into a major field of research in itself in order to shed light on the interwoven processes of the natural and ubiquitous digital world. Continuously improved code, regulates symbiotic relationships between industrial robots and natural spiders, digitized tectonics and augmented reality – and receives feedback. Interacting living processes between seemingly unrelated domains are digitally linked. A life form of organization is driving the second generation of *cybernetics and architecture*. The characteristic of life "[…] does not lie in a distinctiveness of single life processes (Lebensvorgänge), but rather in a certain order among all the processes" (Bertalanffy 1934). Platforms or virtual codelabs such as OpenProcessing and GitHub are nodal points for an order of living organization that has grown to a common good over the last years. They have contributed to the shifting notion – and by now illusion - of singular authorship. Instead a netgrafted systemic design approach is present and applicable to at least some parts or even all parts of a project. Architecture emerges into what we could call a multi-parametric net-verse. A dynamic space inhabited by a growing number of users and designers found in almost all disciplines, formally alien to each other.

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Conclusion

Leaving aside the techniques in form of multitudes of virtualization and digital design and manufacturing methods makes room for understanding architecture form, beauty, aesthetics, tactility based on feedback. Prerequisite for this argument is that architecture has cognitive, hence biological, capabilities. Past and contemporary excursions lead us into the world of the bio-digital and genetic architecture. We the 'creators' of architecture interacting with the mechanics of biological principles such as growth, aggregation or subdivision. Intriguing results lured us into a world of form-fantasm. Still, "we are […] happy to 'borrow', but the advent of the genetic algorithm in architecture, and still limited interdisciplinary exchange bears the risk for bio-digital and genetic architecture to remain as representative, formalist stylistic betrayal; rather than comprehending, and adopting concepts of behavior, information, feedback and biological-cognition as the design-processes leading to form." (Werner 2014). Cybernetics as metasystem offers tools that can create interpolants between the various design-requirements, data sets, parameters, processes, operations and approaches mentioned above. The act and knowledge of defining the projects we work on and with through architectural AND cybernetic terms may assist in distinguishing trails and error from governing design. If we start understanding architecture not as architects, but as cyberneticians we may learn about it as organization, closed or open system, autopoietic ecology, evolutionary or coupling (Varela 1974). Understanding the architecture we create as learning network, as phenomenon constructed out of difference (Bateson 1999, 1971)[16] and distinction (Brown 1972), treating the actors (the scripting architects) and the agents they code as carriers of information for conversation (Pask 1976) may lead us towards a clarification of the new architectural craft we are trying to master. Cybernetics, once understood as *Control and Communication in the Animal and the Machine* (Wiener 1948) is starting to take an effect on design disciplines, as processor as interface as protocol.

If we start understanding architecture not as architects, but as cyberneticians we may learn about it as organization, closed or open system, autopoietic ecology, evolutionary or coupling (Varela 1974).

The questions still to be answered or to be discussed include

a) how can we refer back to our architectural heritage, or should we accept current developments as a stage change, a step in the evolution of architecture, and

b) will the new typologies that are emerging and merging through netgrafting and design processes between humans and machines create new architectural spatial and material values?

Whatever the answer is, there are exciting times to come for architecture and cybernetics.

Endnotes

1 The term ‘objectile’ stems from Deleuze, The Fold p.20: “[…] the object assumes a place in a continuum by variation; where industrial automation or serial machineries replace stamped forms. The new status of the object no longer refers its condition to a spatial mold – in other words, to a relation of form-matter – but to a temporal modulation that implies as much the beginnings of a continuous variation of matter as a continuous development of form.” (G. Deleuze, 2006). In the present ‘objectile’ refers to the iterative design process enabled through programs designed for designing and testing variations according to adjustment of parameters, hence a technological evolution from mechanical industrial automation to digitally ‘generated’ and operated industrial automation of morphology of form.

2 ‘digitization’ refers to the process of transforming / converting information into a digital form, ‘digitalization’ refers to the process of a cultural, hence political, sociological and possibly teleological transformation caused and fed by digitization. The digitization of architectural construction process influences the culture of building inherently. The digitization of generating form (through algorithms in form of code) transforms the culture of form-finding.

3 Gordon Pask used the term pruning, referring to the process of regulating the shape of plants during their future growth process

4 Netgraft is a networked ‚graftsmanship’ related to a ‚neurotecture’, developed as a term and action in ‚Codes in the Clouds: Observing new Design Strategies’, (Werner, 2011)

5 See Ross Ashby’s ‚Laws of Requisite Variety’, introduced in ‘An Introduction to Cybernetics’, 1957. (Ashby, 1957)

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7 Erich Hörl embeds this theory of Gilbert Simondon in his introduction to ‘General Ecology’, (Hörl, 2017) p.11,

8 see Carpo, 2017. (Carpa, 2017)

9 The Greek term ‘cybernetics’ was first used by Plato in the ‘Politea’. It means steersman, ‘cyber’ means steering or governing. Since the 1950s Cybernetics has reached its third iteration, ‘the cybernetics of cybernetics of cybernetics’.

10 The reader may refer to the introduction as well as chapters 01 and 02 of this book

11 See Paul Pangaro and Hugh Dubberly

12 see similarity to Christopher Alexander, chapter ‘The Source of good Fit’. Alexander graphically describes a system of interconnected, interlaced points (variables). In the next diagram, he circumferences two parts of the network with one circle each, showing that “[…] since not all the variables are equally strongly connected (in other words there are not only dependences among the variables, but also independences), there will always be subsystems like those circled below, which in principle, operate fairly independently.” (C. e. a. Alexander, 1977) p.43. Alexander at this point refers to Ashby “For the accumulation of adaptations to be possible, the system must not be fully joined” (Ashby, 1954) p. 155.

13 I recommend a study of ch. 1-2 of ‘The General Systems Theory’, by Ludwig v. Bertalanffy. In the 1st ed., he shows the differences between Ashby’s understanding of (open) systems and his theory of systems. (Bertalanffy, 1968)

14 See ‘On Growth and Form’, D’Arcy Wentworth Thompson, 1917

15 originally published in 1917

16 “Information is a difference that makes a difference.”, Gregory Bateson, (Bateson 1999, 1971) p.459

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