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DYNAMIC ARCHITECTURAL SYSTEMS

Parametric Design and Digital Fabrication towards Conversational Customization

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ABSTRACT

The objective of this thesis was to explore possible ways of designing dynamic architectural systems involving both users and their environment in a mutual, continuous, and circular design process. The association of parametric design and digital fabrication is investigated as a design strategy to enable the user to participate in the design process. The ability of parametric models to generate variations and bespoke outcomes, associated with the capability of digital fabrication to render this variety physical, is studied as a design approach that fosters different levels of conversation. The thesis departs from the notion that opening the design parameters to the user, both in the design process and use, is a possible way of including the user in the design process. Architecture is understood as a system that involves people and structures in a dynamic nature, where one determines the other. Therefore, it is argued that the acceptance of the inclusion of the users in a more systemic view of architecture does not only requires changes in the design process and design process research, but it also demands different approaches towards the design of the object itself, rendering it more dynamic and open to uncertainty. This systemic view of architecture expands the notion of design beyond the production of objects towards the creation of systems. The investigation combined design experiments - called research-sketches - developed to trigger preliminary discussions that drove the focus of a literature review concerning dynamic systems in architecture, parametric design, and digital fabrication. The review, in turn, led to a reinterpretation of the sketches and creation of knowledge. This circularity between acting and understanding is structured from a cybernetic perspective, which forms the basis for the general conceptual framework to explore and understand the systemic nature of architecture. The notions of exceedingly complex systems, trivial and non-trivial machines, control systems, feedback, variety, and conversation, form the backbone of both analysis and proposition. The thesis discusses that the development of design system using parametric design interfaces with open parameters may not be sufficient to open the design process to the user if they are not part of a larger system that includes the user. Furthermore, when used as tools, computational design process may end up controlling the designer and, as a consequence, the user. The thesis concludes by discussing an alternative design process called conversational customization. The concept suggests a constraint-oriented design process that interrelates digital design systems with physical design systems. It is argued that those design systems should emerge from inside-out through conversations. Conversational customization is seen as an alternative way to approach the design of architectural systems where the user occupies a central position in the spatial stage.

Keywords: Parametric Design, Digital Fabrication, Second-Order Cybernetics, dynamic architectural systems, Conversational Customization.

RESUMO

O principal objetivo desta tese foi explorar possíveis formas de projetar sistemas arquitetônicos dinâmicos que envolvem usuários e espaço em um processo de design mútuo, contínuo e circular. A associação de design paramétrico e fabricação digital é investigada como uma estratégia de design que permite ao usuário participar do processo de desenho do espaço. A capacidade do design paramétrico para gerar variações e resultados personalizados, associada à capacidade da fabricação digital de materializar essa variedade é investigada como uma abordagem projetual que promove diferentes níveis de conversação. Partiu-se do pressuposto de que abrir os parâmetros de desenho para o usuário, tanto no processo de projeto quanto no uso, permite que o arquiteto inclua o usuário em um processo contínuo de desenho do espaço. A arquitetura é entendida como um sistema que envolve pessoas e estruturas em uma relação dinâmica, de mútua determinação. Argumenta-se que a aceitação da inclusão dos usuários em uma visão mais sistêmica da arquitetura não exige apenas uma mudança no processo e pesquisa de projeto, mas também uma abordagem diferente no desenho do próprio objeto, tornando-o mais dinâmico e aberto à incerteza. Essa visão sistêmica da arquitetura expande a noção de desenho além da criação de objetos para a criação de sistemas. A pesquisa combinou experimentos projetuais - chamados pesquisa-croquis - desenvolvidos para desencadear discussões preliminares que dirigiram o foco de uma revisão de literatura sobre sistemas dinâmicos na arquitetura, desenho paramétrico e fabricação digital. A revisão, por sua vez, levou a uma reinterpretação das pesquisa-croquis e à geração de conhecimento. Essa circularidade entre ação e compreensão é estruturada a partir de uma perspectiva cibernética, que forma a estrutura conceitual para explorar e compreender a natureza sistêmica da arquitetura. As noções de sistemas extremamente complexos, máquinas triviais e não triviais, sistemas de controle, feedback, variedade e conversação, formam a espinha dorsal da análise e proposição. A tese discute que o desenvolvimento de um sistema de projeto que usa interfaces de desenho paramétrico com parâmetros abertos não é suficiente para abrir o processo de projeto ao usuário se estas não fizerem parte de um sistema maior que inclui o usuário. Além disso, quando usado como ferramentas, o processo de desenho computacional pode acabar por controlar o arquiteto e, como consequência, o próprio usuário. A tese conclui com uma orientação geral para o que é chamado de customização conversacional, um processo de desenho orientado por restrições (constraint-oriented design), onde as restrições são estabelecidas a partir do próprio sistema. Este conceito relaciona interfaces de desenho digital e físico que emergem de um processo de conversação envolvendo as diferentes partes interessadas em um sistema de projeto. O conceito é visto como uma abordagem alternativa que convida o usuário a uma posição central no processo de desenho do espaço arquitetônico.

Palavras-chave: Desenho Paramétrico, Fabricação Digital, Cibernética de Segunda Ordem, Sistemas Arquitetônicos Dinâmicos, Customização Conversacional.

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Finally, I would like to dedicate this work to my son Theo, who changed the way I see and understand life.

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1 | INTRODUCTION

In the last decades, a plethora of design processes based on the popularization of digital interfaces for architectural production emerged. Since the first interfaces developed in the sixties, digital processes have become almost ubiquitous in architectural firms today. Computer programming and its promise of machine intelligence in the process of design[1], manufacturing[2] or embedding it in the environment[3] are part of today's design practice. In consequence, architects are now able to deal with a growing amount of information and can work with complex geometries and benefit from new modes of computer-based design and fabrication systems. Despite the technological advances in design and fabrication architecture has been unable to properly address basic problems such as housing shortage, sustainable design, and to generate novelty in a more appropriate and effective way. In most cases, the use of digital design and fabrication in architecture is focused on creating complex shapes that can be intellectually seductive and visually provocative but are still based on formal approaches that do not encompass architecture as a system that involves both users and their environments. Many designers and researchers fail to address this, and as argued by Cabral Filho (2016, p.417):

> "most of the time, the issue of the use of the designed object does not get much attention as if the design role had ended with the creation of the object. Nevertheless, the consideration of the object and its use is not enough: if we understand the systemic nature of design in a radical way, we have to come to terms with the fact that the final product of the design chain is not an object but a system, in which the object is included. Acknowledging this will change, concomitantly, the design process and design process research".

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[1] Among others, the following AI-based techniques are popular: neural networks, genetic algorithms, multi-agent systems, evolutionary architecture (Frazer 1995).

[2] Topology optimization, digital fabrication, and self-assembling are examples of techniques in which computation is applied to the manufacturing process.

[3] In interactive environments and relational architecture, computation is embedded in the environment to enable reactive, interactive and dialogical behavior. See, e.g. the works of Usman Haque, http://www.haque.co.uk, and Ruairy Glynn, http://www.ruairiglynn.co.uk.

In his seminal paper, *The Architectural Relevance of Cybernetics*, Gordon Pask (1969) states that "architects are first and foremost system designers." According to Pask (1969), "a building cannot be viewed simply in isolation. It is only meaningful as a human environment. It perpetually interacts with its inhabitants, on the one hand serving them and on the other hand controlling their behavior." In other words, a system that involves observer and object has a dynamic nature. There is a mutual reciprocity between structure and people (society) where one regulates the other. As Pask (1969) points out, it is clear that the human part of the system is dynamic, but the dynamic nature of the structure is less obvious.

"Dynamic" is a word that may carry different meanings. As a noun it defines a "force that stimulates change or progress within a system or process"[4]. As an adjective it is characterized by "constant change, activity, or progress"[5]. It is therefore not surprising that the idea of dynamic systems in design is seen by many as something connected to technology, and to concepts such as kinetic elements, fluids, robotic environments, and performative structures. Dynamic systems, as interpreted here, are also connected to the notion of change. Nevertheless, the dynamic qualities of the system are not exclusive to its elements (people and objects), but is fruit of their interrelation.

By convention and convenience, people are persuaded to imagine architecture and architectural elements as static. However, although it is seldom perceived, all architectural spaces and elements are in constant motion. Seen from a mechanical level, the integrity of a construction depends on a flux of dynamic internal and external forces (Pask, n.d.). Within a concrete beam, for example, there are compressive and tensile forces that work in consonance to maintain stability. Internally, the movement of the inhabitants changes the loads and creates different vibrations to the structure. Externally, wind makes the structure move and alterations of temperature causes it to contract and expand. Nevertheless, it is not only the mechanical function that gives structures their dynamic qualities, but more importantly, it is the social, perceptual or psychological functions performed by architectural components and elements. (Pask, n.d.)

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[4] 'dynamic' (no date) *Oxforddictionaries*. Available at:https://en.oxforddictionaries.com/definition/dynamic.

[5] Idem

When interacting with space, there is a flow of information going back and forth - feedback loops - through which people perceive, and actively construct, the dynamic character of space. Designers can, within this perspective, design dynamic structures to foster productive and pleasurable dialogue (Pask, 1969). However, when structures incorporate malleable and adaptive properties the dynamic relation between the observer and his surroundings can be enhanced and dialogue refined. Nevertheless, that is not what happens in practice and frequently it is the performative properties of space that gains prominence in the spatial stage. Many dynamic architectural systems that incorporate explicit performative capabilities displace the user to a secondary position in the spatial dance. In some cases, the user is not invited at all.

1.0.1. Cybernetics

The increasing use of digital technologies in design led to a growing interest in cybernetics amongst designers, especially young ones. The development of the different digital processes and techniques was mainly motivated by transformations in praxis led by architects and designers trying to explore the potential of digital technologies in their work. As Neil Leach (2014) points out, much of the research in digital design was done outside the traditional academic environments. Designers had to develop their own software and building process to ensure the feasibility of their designs[6], and many reached out to theories external to design to support their works[7]. But as Rivka Oxman (2006) has noted, the impact of digital design on practices has resulted in a need for a revision of current design theories. Many research groups and designers have looked to cybernetics to create conceptual frameworks to guide research and development.

Digital design research can be seen as a subcategory of design research, but given the impact of computation in designing and in production practices, it is evolving to become a unique field in design (Oxman 2006). In digital design, computation can be integrated in the total process of design, from the initial concept through to materialization,

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[6] See, e.g., the design companies Gehry & Partners and Zaha Hadid Architects.

[7] The special issue of the London journal AD on "Folding in Architecture" (Lynn 1993) has several articles that exemplify how designers reached out to theories external to design to support their works.

production and use. In this “digital continuum,” as it is called by Branko Kolarevic (2003), design is directly connected to materialization, from the initial conceptual stages with rapid prototyping techniques, to the final object with digital fabrication processes and interactive systems. Digital fabrication enables designers to create short feedback cycles of designing, making and reflecting. In that context, practice-based research methods have become more widely used and accepted, as designers are now able to make high-end models and products in a fast and accessible manner through different iterative cycles. Either explicit or not, these feedback cycles are examples of a cybernetic practice. But the relation between cybernetics and design goes far beyond the digital realm. Cybernetics - and specially Second Order Cybernetics - can point towards the creation of an epistemological foundation to digital design, where self-reflexivity, the inclusion of the observer, variety and Conversation Theory are central questions.

The term "cybernetics" is derived from the Greek kybernetes, that means "steersman". When a stearman is trying to maneuver his ship into a port he encounters different forces that may challenge him to attain his goal. The current, the wind, the waves (including those produced by other boats), may deviate him of his course, forcing him to act and adjust the controls. If he steers too hard this might result in another deviation that calls for another reaction. This circular and ongoing dance between the stearman, his boat and the external forces goes on until he reaches his goal. This circularity is the fundamental principle of cybernetics. Cybernetics it is not particular interested in describing the boat, the current or the wind, but is focused in understanding the interaction between them, the dance, that involves a flow of information going back and forth between the parts, (inputs, outputs and feedback cycles), where one system affects the other. In that sense, a cybernetic approach to architecture inevitably demands us to understand architecture beyond its physical nature towards a systemic approach that emphasizes the understanding of the different interactions between spatial agents. The present research departs from this understanding, and investigates possible ways of designing dynamic architectural systems that involve both users and their environments in a mutual, continuous, and circular design process. It acknowledge and embrace the cybernetic nature of design, extending the traditional role of design practice and the way buildings are created.

1.0.2. Background

The research endeavor unfolded from previous academic and professional experiences related to the investigation of more open and conversational design processes. Amongst different experiments, there are three that deserve to be brought to this introduction as they help to contextualize and better frame the research endeavor. Namely, an interactive device developed during my Masters Research (Stralen, 2009), the design of an interactive urban interface called ITUITA (Stralen et al., 2012a) and a teaching experience (van Stralen et al., 2012b).

In the first experiment, the investigation was centered on the incorporation of digital devices into architecture, with a particular focus on experiences that enable or enrich forms of interaction between man and the architectural space. The result was a prototype for an interactive table (figure 1), developed to explore the possibility of using ordinary household objects as tangible interfaces to interact with digital information. The table was built with several magnetic sensors, used to map the position of the magnetic object on its surface. Any magnetic object in contact with the tabletop would serve as input to the system which gave a visual feedback of the position of the object on the table. This information was sent to a microcontroller and a computer programmed to generate different outputs. The object was tested as a control interface for several devices in the lab, such as the room lights and a fan. However, the interesting issue this experiment brought forth was not related to what it did in this test, but to the possibilities the interface opened for different uses. During the development of the table, it was used as a game interface, as a musical instrument, and other unforeseen uses. The experiment revealed two levels of interaction, one with the objects, and a second with the system, by changing how it would operate. This understanding drew attention to the potential of systems that are more engaging and open to the user to generate novelty by enabling and encouraging a modification (design) of the designed object.

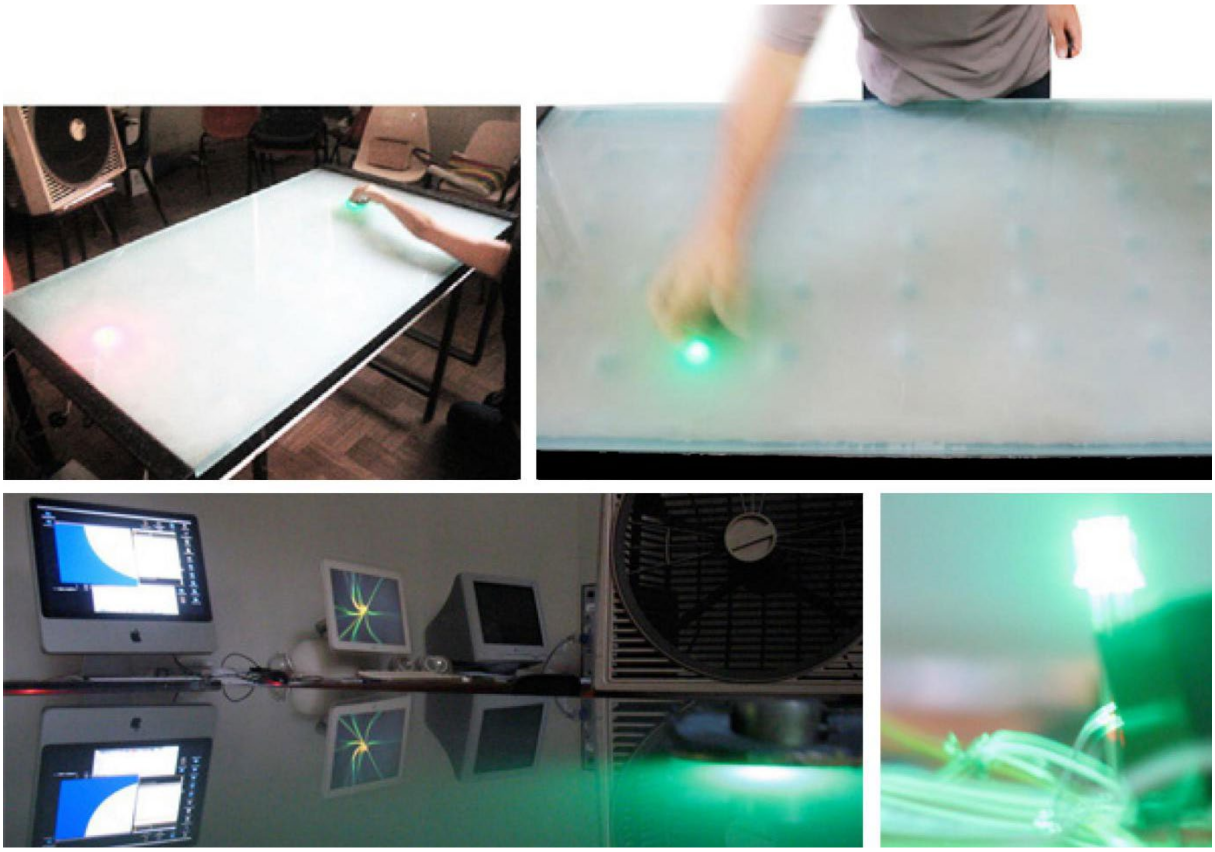

Figure 1 | Photos of the prototype for a physical-digital interface developed during my Masters Research (Stralen, 2009).

The potential of interactivity as a design strategy for more open and user-centered processes was what inspired the second experiment called ITUITA (Stralen et al., 2012a). ITUITA is an interactive Media Cascade located in *Presidente Kubistchek Square*, (Center of the city of Congonhas, Minas Gerais - Brazil). It was part of the project for the revamping of the central area of the city developed by my former company *Opera*. The installation was intended to connect users of an online discussion forum with passersby in the city's main square. This was achieved by using the responses to several online questionnaires to create interactive graphics depicted by the three LED panels of the cascade, forming an interactive display that can be manipulated using two motion sensors (Microsoft Kinect). The interface, created in partnership with LAGEAR[8], was

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[8] LAGEAR is computer lab geared both toward teaching as towards research in architecture and new media. During recent years it has developed a wide variety of works ranging from research on the use of new digital technologies, visual language and interface design. Currently, a major area of research is the implementation of immersive environments of low cost associated with rudimentary systems of 'physical computing'. The laboratory staff consists of specialist teachers (masters and PhDs), architects, researchers, postgraduate and undergraduate students.

an attempt to explore the potential of digital technologies to overcome the functional relationship between people and digital technologies. The system was conceived as a strategy to build social connections and to open space for discussions on the city's problems and possible solutions. Its importance laid mainly in the process of developing open interfaces for dialogue, and less in the final object. In that sense, the constraints that defined the proposed system went beyond the physical object involving the user by providing different levels of interaction: reactive, proactive (Oosterhuis, 2002), and conversational (Dubberly, Haque and Pangaro, 2009). Together with the interactive table, ITUITA highlighted the systemic nature of architecture and the importance of the observers as being part of this system.

The construction of the interactive table and the design of the digital cascade in Congonhas encouraged a deeper investigation of the concept of dynamic systems that are user-centered and allow a continuous transformation of the architectural space. A first hypothesis was that this could be elicited through the use of kinetic elements that can be manipulated and modified to meet different needs. This hypothesis was tested in an experiment developed in a course taught in the School of Architecture at the Federal University of Minas Gerais (UFMG)[9]. The objective of the course was to allow students to investigate the potential of new design processes, parametric modeling and digital manufacturing processes focusing on the use of kinetic components in the architecture. The demand for a product that was not static, finished, but maintained some possibility for change during use was explicit from the start. The discipline resulted in two prototypes of dynamic objects constructed by the students. Those prototypes raised important issues, among which three deserve to be highlighted: (1) the potential of using open parameters (motion) to amplify the ability of a design to respond to different needs; (2) the importance of new methods of physical and digital simulation in the evaluation of the performance of dynamic elements and materials; (3) the problems in separating the behavior between materials and their physical and structural properties, what can possibly lead to excessive mechanization of the system.

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[9] The course was thought by myself with the help of Marcus Vinícius Augustus Fernandes Rocha Bernardo, a master student at the time, and the participation of Professor Ana Paula Baltazar.

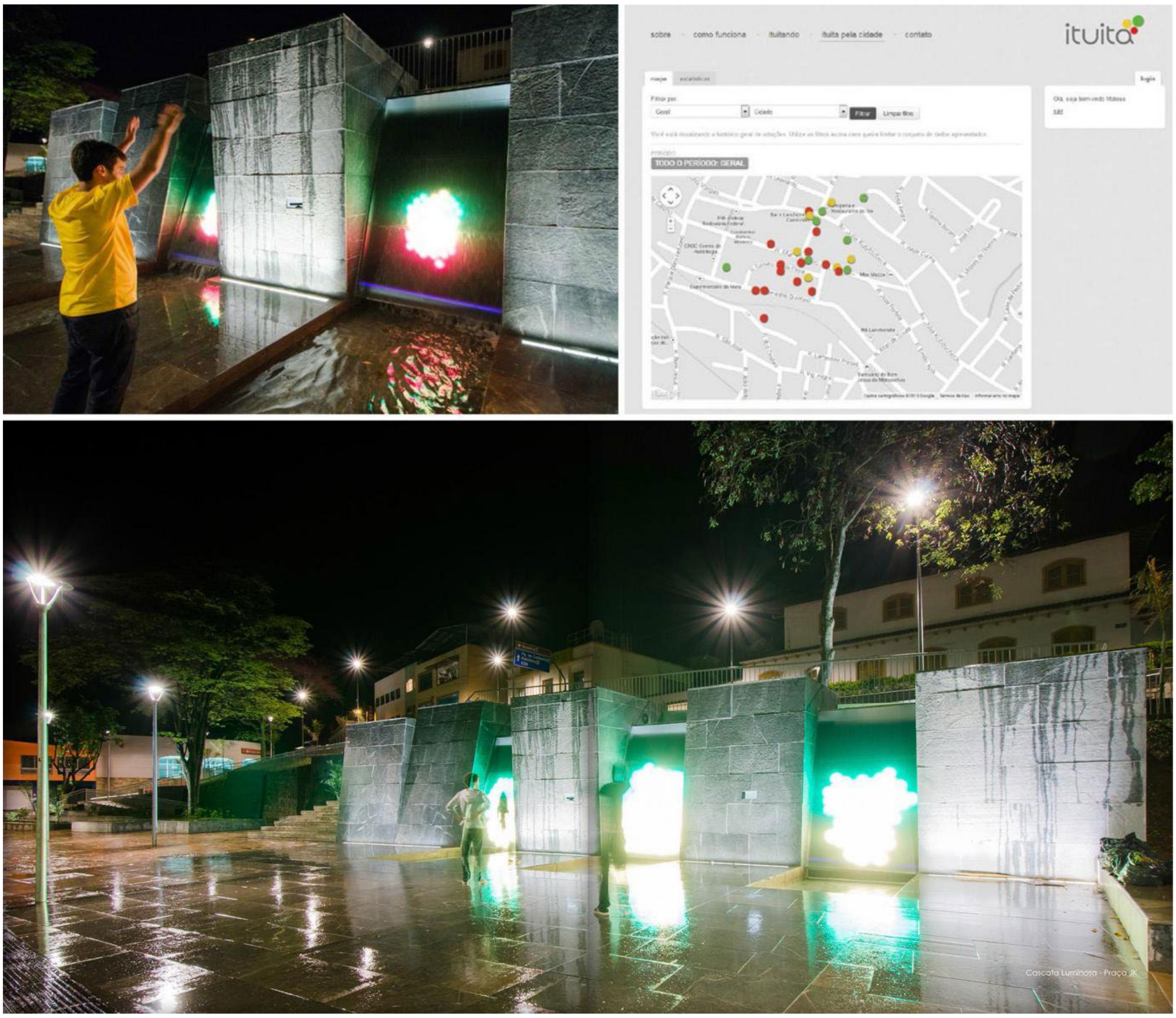

Figure 2 | ITUITA at midnight. Congonhas - Minas Gerais. (Stralen, 2012a).

Figure 3 | Prototypes for kinetic elements. (Stralen et al, 2012b).

Those three experiments converged in the ongoing research that explores parametric design associated with digital fabrication in the creation of dynamic architectural systems. It is an attempt to create a conversational design process based on computational design and fabrication techniques. It seeks to expand the traditional role of design practice and the way buildings and cities are created. In this process, cybernetics offered the necessary toolkit to understand and explore the notions of interactivity, dynamic systems and uncertainty.

1.0.3. Parametric design and digital fabrication - possibilities for conversation.

In what is for some a model situation architects that deals with single clients can understand his tastes, culture, beliefs, and needs. He can make decisions for the client, orientate his thoughts, or give him technical support. Ideally, he can also engage in conversation with his client to generate new thoughts and ideas that will result in a product not foreseen by both. In this case the designed object, when the fruit of meaningful conversations, will be a unique reflection on both architect and client. However, the majority of what is being built today with the participation of the architect is not exposed to the full creative potential of the human environment. High rise buildings with standard apartments and even whole neighborhoods of standard houses are typical in almost every country. Without a specific client the architect designs for a standard user, classifying him according to his social profile. Large-scale solutions are still based on the functionalist paradigm of standardization, where the house is seen as a machine that can be replicated ad infinitum in a production line, built for a standard user with effectively no variety. This system has been broadly criticized in the last decades but is still the primary strategy of production of the architectural space. Nevertheless, the contemporary confluence of parametric design with digital fabrication offers designers new possibilities that enables design conversations to be explored in the context of large-scale architectural solutions.

With the development and diffusion of digital manufacturing processes - mainly in automotive, aerospace and shipbuilding industry - the gap between computer-aided design (CAD) and computer-aided manufacture (CAM) began to close, and a new "digital continuum" between design to construction was established (Kolarevic, 2003). Architecture, seen from the perspective of those working with digital technologies, is returning to the material dimension in a process that converges digital design, materials, structure, form, fabrication, construction, and performance. Parametric design associated with digital fabrication is at the center of this transformation by enabling a new bi-directional flux of information between design, fabrication and use.

In an attempt to create a conceptual framework and theoretical basis for digital design thinking, Rivka Oxman (2006) formulated four paradigmatic classes of digital design: representation, generation, evaluation, and performance. Oxman's systematization was based on four levels of interaction between designer and design medium: (1) interaction with paper-based representation, (2) interaction with digital representation, (3) interaction with digitally generated representation, and (4) interaction with digital environment. Kotnik (2010) builds upon Oxman's taxonomy of digital design methods and proposes a systematization that distinct each class of digital design according to the level of digital computability: the representational, the parametric, and the algorithmic. This thesis is focused on the parametric level of digital computability. Nevertheless, many discussions put forward can be extended to the other levels and are deeply related to the levels of interaction between designer and medium.

Parametric is a general term used in a variety of disciplines and means something that “relates to or is expressed in terms of a parameter or parameters[10].” In design there is no precise definition of the term, and its use often varies according to the context. Several authors claim that all design is parametric (Aish and Woodbury 2005, Hudson, 2010) because all designs use parameters whereas others see it as a style (Schumacher, 2008, 2009, 2016). In general, the term is frequently associated with the generation of complex forms and to the utilization of *parametric models*. In traditional design processes – those that use CAD programs as an extension of the drawing board and explicit modeling techniques – the change of parameters, like the geometry of a room, could only be implemented by suppression and reconstruction. This process is rethought in

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[10] parametric. [Online]. Available at: https://en.oxforddictionaries.com/definition/parametric.

parametric modeling, where the model can be defined as a set of geometric associations that are applied through parametric expressions and constraints. This chain of geometrical relations can be manipulated without losing the consistency of the whole. As an effect, it increases the designer's ability to explore variations and change by diminishing the time spent in reworking the model to generate multiple bespoke outcomes.

If these parameters can be manipulated in a dynamic manner, this opens the possibility to involve the user in the design process. The point of departure for this thesis is the notion that opening the design parameters to the user can significantly increase the number of states of the system, expanding the number of options available and creating the possibility for the development of dynamic architectural systems. The method of producing architecture as well as the work of the architect is substantially modified. However, unfortunately, it does not happen in practice and architects, face an ethical problem by restricting the increase of the number of possibilities to their practice in the office, instead of extending them to the end user (Cabral Filho, 2013). In most cases the parameters are crystallized in final shape, that remains closed and unchanging. This situation is aggravated by the transduction of the coordinates and vectors of a model into a physical matter with the use of digital fabrication processes.

Digital fabrication can be defined as "a way of making that uses digital data to control a fabrication process" (Iwamoto, 2009). The association of CAD and CAM technologies is narrowing the gap between traditional forms of representation and building. It relies on Computer Numerical Control (CNC) tools to build, cut or print parts. Not only it provides a medium for creating different iterative cycles with rapid prototyping techniques, but also enables the creation of innovative working methods, and fabrication processes. Since Leon Battista Alberti, architects have developed a set of highly specialized tools, procedures, and methods to prevent and suppress deviations in design and construction so that the building becomes an identical copy of the author's intentions (Carpo, 2011). However, given the contingent aspect of architecture (Till, 2013) this have been often an unsuccessful effort. Today, with new digital design and fabrication processes, architects are now able to claim full control of the process as the design model can be physically rendered with CNC machines, such as 3d printers, ignoring the contingent aspect of architecture. If in traditional building processes a margin of error was accepted - and sometimes welcome - there is now a claim for zero tolerance in digital processes (Sheil, 2014).

The ability of parametric design to generate variations and bespoke products, associated with the capability of digital fabrication to render this variety physical without compromising the efficiency and economy of production, points to the possibility of creating architectural systems that encourage dialogue between designers and users. The flow of information going back and forth between design and fabrication, and between designer and user, allows a new approach to design that favors cybernetic conversation. This thesis explores this potential and examines the design implications of a *dynamic architectural system* that involves the user in a conversational process of design, fabrication and use.

1.1. METHODOLOGY: DESIGN RESEARCH AND RESEARCH BY DESIGN

> “Cybernetics is the answer, but what was the conversation about?” (Cabral Filho, 2016)

> “No longer can the theorician of architecture remain distinct from the practitioner. Architects and theoricians must (like it or not) act in concert, if mere progress is to engender evolution” (Pask, 1980)

Stafford Beer (1959) makes a distinction between three kinds of systems in the world: (1) "simple," (2) "complex," and (3) "exceedingly complex systems." The first two systems are approachable from methods of modern science because they are, in principle, knowable and predictable. Exceedingly complex systems are systems that change over time, and they are so complex that they cannot be fully grasped through modern scientific methods. For Beer, cybernetics was the science of exceedingly complex systems. (see chapter 5, section 5.1.1.). In this thesis, architecture is understood as an exceedingly complex system that involves material systems, building systems, communication systems and, most importantly, human and social systems. Therefore, the methodology proposed for this research is based on the association of theory and practice in a cybernetic process of investigation. A Cybernetic approach to design research enables a holistic perspective without decomposing the inquired system into simple components.

Studies that deal with the use of new digital tools and technological devices in design represent a challenge because they generally deal with "wicked problems." "Wicked problems" in design is a concept, developed by Horst Rittel together with Melvin Webber, that designates problems that are hard to formulate in advance, where information is confusing, the agents involved have conflicting values, and the ramifications of the system are dubious (Rittel & Webber 1973). Architecture deals with wicked problems because it is contingent, it is constituted by complex and contradictory relationships continually open to uncertainty. As suggested by Jeremy Till (2008) and others, architecture can't be summarized to one idea or concept that can be researched and dissected through linear traditional scientific methods. Buchanan (1992) addresses this notion and points that “(...) the designer must discover or invent a particular subject out of the problems and issues of specific circumstances. This sharply contrasts with the disciplines of science, which are concerned with understanding the principles, laws, rules, or structures that are necessarily embodied in existing subject matters”. It is within the very nature of design to deal with a more holistic and contextualized perspective of the subject. In this thesis we will assume this perspective, acknowledging that design research cannot be based on traditional scientific methods and has to recur to its own epistemological foundations.

The distanciation between scientific methods and design has been primarily discussed and developed since 1980 and represents a shift from the desire to adequate design into a rational scientific foundation. Nigel Cross (2001) identifies two historical moments related to design and science when this desire was most evident. The first, was around 1920 with the Modern Movement, was more focused on scientific design products. This is exemplified by Theo van Doesburg’s (1923, apud Cross 2001) quest for a "method, that is to say, an objective system" to respond to the "new spirit, which already governs almost all modern life", and by the concept of the "machine for living' from Le Corbusier (1923), that suggested that architecture should adopt the industrial process of production by creating standard housing types through mass production. The second moment, more related to the scientific design process, started in the sixties in what came to be known as the "design method movement". The movement was inspired by the scientific and technological optimism that involved novel methods such as computation. Relevant works on design methodologies like *Notes on the Synthesis of Form* from Christopher Alexander (1964) and *Design Methods* by John Christopher Jones (1992) where fruit of that time, which started with the 1962 *Conference on Design Methods* in London (Jones and Thornley, 1963).

A second conference, the Design Research Society's 1980 conference *Design:Science:Method,* marked a shift in the concerns regarding the relationship between science and design. Some of the most prolific figures of the design methods movement started to question their own work[11]. According to Cross (2001), "the general feeling from that conference was perhaps that it was time to move on from making simplistic comparisons and distinctions between science and design; that perhaps there was not so much for design to learn from science after all, and rather that perhaps science had something to learn from design". The development of an epistemological foundation in design led to the investigation of the design practice itself, what designers do in practice, the "designerly ways of knowing" (Cross, 1982).

This idea of a rupture between design and science is challenged by Ranulph Glanville's (1999) understanding of design, that was seen as a core part of research activity. Glanville (1999) argued that not only science had something to learn from design, but that science should be seen as a form of design activity, reversing the more traditional hierarchy between both. Through his work, Glanville (1999, 2007,2009) has explored the connections between cybernetics and design. He has shown that cybernetics can not only contribute to design, but that design can also inform cybernetics, understanding cybernetics, and design not as separate entities but as a circular interwoven process of acting and reflecting, theory and practice. According to Glanville (1999, p.9) “it is inappropriate to require design to be “scientific”: for scientific research is a subset (a

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[11] Both Christopher Alexander and John Christopher Jones distanciated from the design methods movement. In 1971 Christopher Alexander stated: ‘I’ve disassociated myself from the field... There is so little in what is called “design 2 methods” that has anything useful to say about how to design buildings that I never even read the literature anymore... I would say forget it, forget the whole thing.’ In turn J. Christopher Jones (1977) wrote: "In the 1970s I reacted against design methods. I dislike the machine language, the behaviourism, the continual attempt to fix the whole of life into a logical framework."

restricted form) of design, and we do not generally require the set of a subset to act as the sub-subset to that subset any more than we require [that] the basement of [a] building is its attic”.

Drawing on Glanville's understanding of design research, Ben Sweeting (2016b) discusses how science and design research actually developed in close parallel, focusing primarily on the works of Horst Rittel and Melvin Webber in design (wicked problems) and Paul Feyerabend in science. These parallels are evidence for Glanville’s (2009) characterisation of all research as being a design-like activity. Sweeting (2016b, p.404) explains this further by stating that "as design is the core part of research activity, to research design is to inquire into an aspect of research activity itself." This self-reference reveals the connections to Second Order Cybernetics, commonly characterised as "the cybernetics of cybernetics" (von Foerster, 2003), the application of cybernetics to cybernetics.

According to Sweeting (2016b, p. 405), cybernetics and design "share both ways of working – a conversational forward-looking search and an interactive, non-representational use of modeling – and also core concerns with observer positions and self-reflexivity in the constitution of their research processes." Building on Frayling and others, he draws on Wolfgang Jonas’ examination of categorizations of research about/into, for and through/by design, where he creates the following relations with Glanville´s (1997) descriptions of observers:

- Research through / by design: design as a research process - can be associated with Second-Order Cybernetic observer;
- Research for design: a separate research is applied to design - can be associated with the detached First-Or der Cybernetic observer;
- Research about design: design is the object of research - can be associated with the detached First Order Cybernetic observer;
- Research as design: the Second-Order Cybernetic observer is “inside the inquiring system”

What this systematization show is that in a research by design and research as design endeavor the observer is a part of the inquiring system. This becomes more evident in those practices where computation is inextricably part of the process, such as algorithmic and parametric design, in which the designer designs computational process. In this sense, this thesis reaches out to cybernetics - specially Second-Order Cybernetic - not only to offer new insights but also to fundament its methodological approach. Cybernetics suggests a new way of reflecting about the world by breaking the boundaries between different knowledge fields and disciplines. What is important for cybernetics is not the physical and material properties of a system, but how interaction occurs within the system. It offers a common language for modeling and analyzing those systems, be it biological or artificial.

Because cybernetics is concerned with how something performs prior to its representation, it enables us to think explicitly about our performative being in the world and also the performative relations between things (Pickering, 2011). In this sense, cybernetics anticipates current performative practice of research through/by design. This was the adopted perspective of this research that operated between a performative level and a representational level in a circular way. During the research process, there is a shift of positions between the performative level and the representational level. In this way, it does not establish a fixed epistemological position but navigates between pragmatism, idealism, and empiricism, connecting research for design, research through design and research into design (as suggested by Fischer's (2011) adaptation of the epistemological triangle[12]).

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[12] The epistemological triangle, as described by Umpleby (2007), establishes relations between the world, its description, and the observer with the epistemologie of realism, constructivism, and pragmatism. Umpleby advocates that "viewing the three epistemologies as emphasizing different faces of a triangle clarifies the relationships among the epistemologies and creates an opportunity for unifying them". Fischer (2008) proposes that Frayling's different design models can be mapped in the triangle. The triangle can be used as a map that gives a structured overview over the relations between the different epistemologies and design research models. It establishes a framework that helps to navigate between them and bring them together.

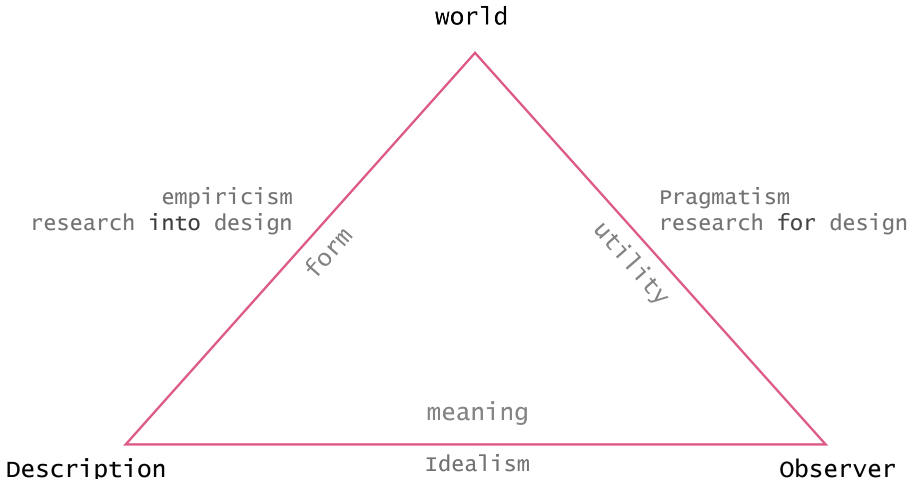

Figure 4 | Epistemological triangle between world, description and observer as describe in Umpleby (2007) associated with Frayling's three kinds of design research as described in Fischer (2011, p.629).

In the research, the performative level is represented by teaching experiences together with design experiments that operate in various dimensions. The experiments were different attempts of designing dynamic architectural systems exploring the connections between digital fabrication and parametric design processes. They cannot be categorized under a precise scientific method and functioned as sketches - conversations with oneself - where it was possible to reflect through action in an effort to investigate the subjects in different contexts. Whereas the goal of some experiments was to inquire determined aspect of the research, others had a more exploratory nature with undetermined goals. In the thesis these *research-sketches* are explored as a performative investigation of the proposed subjects which drive and focus the literature review. The review, in turn, led to a reinterpretation of the *research-sketches* leading to new insights and the creation of knowledge. Accordingly, the methodology proposed in this research cannot be classified under a specific label of design research or research by design process. Rather, it is the combination of different approaches in a circular process of acting and understanding.

1.2. THESIS STRUCTURE

The thesis is divided into seven chapters: the current introduction, one with the description of the design experiments, three background chapters, and two concluding chapters.

The following chapter (chap. 2) describes the *research-sketches* developed in the initial phase of the research process. The process was undertaken in different cycles of acting and reflecting, intertwining theory and practice. The design experiments functioned as "research-sketches" to enable internal and external conversations that guided the overall development of the work. The first experiment was designing a design system for a lamp called MILU (an acronym from the Portuguese "minha luminária" - my lamp), followed by a design workshop. The second, was designing a design system for a house, called WOKA, a name that derives from the wiki (open to) and oca (indigenous house or dwelling). The third experiment - 13MAY - was an educational undertaking that involved students, a makers community and a social group in research about prototyping, parametric design, and fabrication. Each experiment is described and a preliminary discussion is made to raise issues. Those three experiments laid the primary pathway of the research and were developed before theoretical discussions.

In chapter 3 several approaches to the design of dynamic architectural systems are described and discussed. The objective is to situate the research in relation to a broader perspective on the notion of dynamic systems with a focus to the role of the user in each system.

Chapter 4 discusses the association of parametric design and digital fabrication as a strategy to involve the user in the design process. Various definitions of parametric modelling are examined together with a discussion on digital fabrication. The association between the two concepts is explored by examining the possibilities they open for mass customization, personalization and design democratization.

Chapter 5 presents the reader with some fundamental concepts of cybernetics with a special emphasis on the notion of systems, control, variety, and conversation. It puts forward the understanding of architecture as an exceedingly complex system and introduces the reader to conceptual tools that are useful for designers to come to terms with this complexity.

Chapters 6 and 7 conclude the work by reconciling issues brought forth by the design experiments (research-sketches) described in chapter 2 and the literature review and theoretical discussions of chapters 3, 4, and 5. The point of departure is the notion that, in face of the exceedingly complexity of architectural systems, it is no longer possible for designers to rely on their capacity to solve problems. It explores the idea that the tools used by designers to amplify their capacity (variety) to deal with the complexity of architectural systems have become self-referential systems that amplify themselves. The notion of *conversational customization* is discussed to offer a conceptual base to for architects to explore conversation in a design approach where people are involved in the design of their own space through conversational interaction between several agents, man, and machine alike. The concept is explored as a form of critique to contemporary discourse of computational design practices that is self-referential and detached to its social context.

2 | RESEARCH SKETCHES

This chapter presents the main research-sketches developed during the initial phase of the research. They are part of a larger body of design experiments put forward to explore the creation of dynamic architectural systems. Those ranged from experimenting with shape-memory alloys (nitinol), exploring different wood joints, designing robotic buildings (within an architectural competition), and working with parametric design on professional assignments (refer to Attachment I). Although those experiments were important to understand the different possibilities of dynamic systems, the focus of the research was directed towards the ones directly related to the association of parametric design and digital fabrication in the creation of design interfaces. Therefore, three research-sketches were framed together to unveil related issues and orientate further discussions. The first two embody different design scales - the object and the body. The third was an educational undertaking that involved students, a makers community, and a social group called '13 de maio' (13 of may). Those three experiments laid the primary pathway of the research and were developed prior to more profound theoretical discussions.

It is important to notice that the research-sketches presented in this chapter do not represent a definitive work developed to test predetermined hypotheses. Therefore none of the research-sketches should be understood for their formal properties or procedural effectiveness. They were developed to trigger preliminary discussions to be further elaborated in the following chapters.

2.1. MILU

MILU, a Portuguese acronym for "my lamp" (minha luminária), is a design experiment elaborated to investigate the potentials and limitations of opening the design parameters to the user by associating parametric design and digital fabrication. It is a computational design process created to enable the user to design and fabricate a lamp, by changing design parameters of a parametric model. The variables that can be modified by the user within the model are called *open design parameters* or *dynamic parameters*. Both concepts are adopted with the same meaning and will be used interchangeably. The purpose of this experiment was to understand the implications of the use of dynamic parameters in a design process, both for designer and user. From the start there was the intention to enable the fabrication of a one to one scale prototype of the object, therefore, the focus was placed on the development of a computational design process for a small lamp. That allowed the use of the CNC Laser cutter available in the laboratory LAGEAR and guaranteed the feasibility of the prototypes. The objective was to develop a process where the user could easily customize and fabricate the design in a short time span. It is worth pointing out that the goal of this research sketch was not to create a finished product or process, an effort that would demand various iterative cycles and rigorous usability tests, but to create an understanding about issues that can only be unveiled through empirical experience and observation.

2.1.1. Overview

MILU is a prototype for a design process that associates a parametric model built in Grasshopper 3D[13], and a digital fabrication technique, to enable the user to design, fabricate and assemble a lamp. Grasshopper uses a node based interface for algorithm design, where components are dragged into a canvas, and are interconnected to perform a certain function. Each component has input and output pins that can be interconnected to create a flow of data between different components, generating what is called a

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[13] Grasshopper is a graphical algorithm editor integrated with Rhino 3D modeling system. Grasshopper [online], n.d. URL http://www.grasshopper3d.com/ (accessed 7.12.17).

definition. Any parameter change in the chain of components of the definition can affect the whole model. The parameter input can be of a specific invariable number, or can be described as variables, where the maximum and minimum values are stated. Those values can be changed with number-sliders that operate between the defined numerical constraints. In the MILU definition, different sliders were used to enable the user to modify the design parameters. Every change of parameters in the model is displayed in real time through the Rhino 3D[14] viewport. When all parameters are set, the cut files can be automatically generated, and send to the CNC laser cutter that produces the pieces to be manually assembled.

2.1.1.1. Parametric Model

The design strategy (or generative strategy) adopted to generate the geometry was to revolve a spline (parametric curve) around a central axis, and decompose the resulted shape in parallel horizontal sections and radially distributed vertical sections. This simple design principle is largely adopted in industry, and in itself does not represent a novel design solution. This design principle was chosen because it is a straightforward process for generating 3d objects with 2d planes, well suited for the proposed 2d fabrication process. The dynamic parameters (table 1) were divided in three main groups: (1) general parameters with the total height and orientation of the lamp (hanging or table), and the position and type of light bulb; (2) formal parameters that change the control points of the spline that regulates the final shape; (3) fabrication parameters that determine how to decompose the created geometry in sections. Each of those listed parameters could be changed within the designed constraints, which were chosen according to the perceived procedural restraints. The more explicit limitations were the size of the cutting bed of the CNC laser cutter[15] (120cm x 90xm), maximum and minimum material thickness (varies

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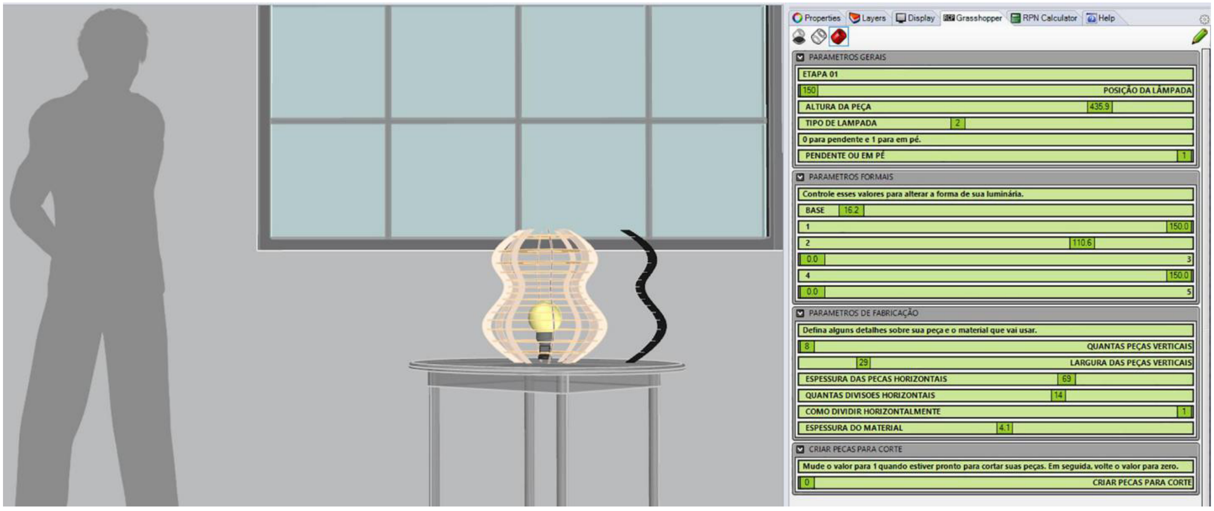
[14] Rhinoceros, or Rhino 3D, is a 3D modeling system from Robert McNeel & Associates that became very popular with architecture students after the development of Grasshopper. Rhinoceros [online], n.d. URL https://www.rhino3d.com/ (accessed 7.24.17).

[15] Larger and thicker sections are possible to be fabricated by decomposing each piece into smaller ones and gluing them together. However, that would lead to additional steps in the assembling process and create unnecessary difficulties for the workshop.

according to the material), and placement of the central axis to hold the light bulb socket in place (fitting for the socket and space for the light bulb).



PARAMETROS GERAIS
ETAPA 01
150 POSIÇÃO DA LÂMPADA
ALTURA DA PEÇA 435.9
TIPO DE LAMPADA 2
0 para pendente e 1 para em pé.
PENDENTE OU EM PÉ 1

PARAMETROS FORMAIS
Controle esses valores para alterar a forma de sua luminária.
BASE 16.2
1 150.0
2 110.6
0.0 3
4 150.0
0.0 5

PARAMETROS DE FABRICAÇÃO
Defina alguns detalhes sobre sua peça e o material que vai usar.
8 QUANTAS PEÇAS VERTICAIS
29 LARGURA DAS PEÇAS VERTICAIS
ESPESSURA DAS PECAS HORIZONTAIS 69
QUANTAS DIVISOES HORIZONTAIS 14
COMO DIVIDIR HORIZONTALMENTE 1
ESPESSURA DO MATERIAL 4.1

CRIAR PECAS PARA CORTE
Mude o valor para 1 quando estiver pronto para cortar suas peças. Em seguida, volte o valor para zero.
0 CRIAR PECAS PARA CORTE

Figure 5 | MILU interface with the Rhino viewport that depicts a human scale model and a table to facilitate the user to understand the scale of the lamp. In the right corner the RCP shows all parameters that can be changed in the model. (author, 2014)

The user interface (UI) was created with the Remote Control Panel (RCP) that connects Rhino3D and Grasshopper. It enables the user to control the design parameters within the Rhino interface. The different control sliders were displayed in the RCP (figure 5) to enable the users to change the dynamic parameters of the model. Changing the values of the elements in the RCP, updates the value in the graph, and modifies the geometry in the Rhino 3D viewport. The interface incorporated the three parameters groups with a command to generate the cut file. The file is automatically generated and can be loaded into the CNC laser cutter. In the cut file, vertical and horizontal sections received cutouts to fit each other properly.

Designing the design interface was challenging and took more time than foreseen at the beginning of the initiative. The process initiated with the design and evaluation of the overall workflow, involving the creation of a parametric model, generation of the cut drawings, fabrication of the sections, and assembling of a prototype. The initial model did not incorporate many dynamic parameters, and the geometry was primarily generated using a series of extrusions and boolean operations. This strategy created some problems further on in the process, as each applied change on the model required the computer to process different operations, significantly slowing the display of the varying parameters. To overcome this difficulty, the model had to be rebuild from scratch using a more elegant geometrical solution that would not demand high processing power. Along the process, seven models were build before reaching a satisfactory solution.

MILU design parameters		
I General Parameters		
1	Position of the light bulb	Controls the height of the light bulb in the central axis
2	Height of the lamp	Configures the total height of the lamp
3	Type of light bulb (1,2,3 and 4)	The user chooses the type of light bulb so that it can fit into the final object
4	Orientation: table or hanging	The user choosesbetween table lamp or hanging lamp.
II Formal Parameters		
1	Base width	Defines the width of the base of the lamp
2	Control point 1	Defines the x and y position of control point 1
3	Control point 2	Defines the x and y position of control point 2
4	Control point 3	Defines the x and y position of control point 3
5	Control point 4	Defines the x and y position of control point 4
6	Control point 5	Defines the x and y position of control point 5
7	Control point 6	Defines the x and y position of control point 6
III Fabrication Parameters		
1	Number of vertical planes	Sets the number or vertical slices
2	Width of vertical plane	Sets the width of the profile of the vertical slices
3	Number of horizontal planes	Sets the number of horizontal planes
4	Depth of horizontal plane	Sets the depth of the profile of the horizontal planes
5	Mode of division of horizontal planes	Sets the mode of division to determine the spacing of horizontal planes. Mode 0 is along the height of the lamb and mode 1 is along the spline.
6	Material thickness (mm)	Sets the material thickness

Table 01 | Overview of the MILU design parameters. (author, 2014)

The first experience with the design workflow was important to fine-tune the fabrication parameters in relation to the CNC laser cutter in use. The fittings had to be adjusted according to the chosen material. Using 4mm thick plywood is, for example, different from using 4mm gray cardboard paper, as the laser beam interacts differently with each material. In that sense, if a 4mm fitting is desired to be cut in plywood, the cut drawing should be smaller to take the material loss into account. This value differs according to the choice of material, machine, and machine setup.

After the first test, the work was presented and discussed with a senior researcher from LAGEAR - Ana Paula Baltazar. She pointed out that, even though the proposed system created the possibility for the user to adjust the open design parameters, this possibility ceased when the design was finished, as the parameters did not remain variable after the fabrication and assembly process. This discussion, about open parameters from design through use, was already present in a previous teaching experiment that motivated the research (see in the introduction). However, in this research sketch, the initial objective was to explore the open parameters in the design process, and not in the final object. Notwithstanding, the development and first test of the interface showed that the proposed process with dynamic parameters did not seem to provide meaningful gaps to enable the users to give deliberate creative inputs. Such inputs would be important to allow the users to make nonprogrammed adjustments to the object. In an attempt to respond to this issue without restarting the process, the fittings from the horizontal sections were removed so that the vertical sections could be distributed in different ways along the circular horizontal section. That would leave the possibility for the user to change the design after fabrication. A wedge could be used to fixate the sections in place in a chosen section.

In the preparation for the workshop, other adjustments were made to the definition. The first was to create the option for the user to choose between 5 different light bulbs. The inclusion of the light bulbs changed the adjustments of various parameters as enough space was needed to place them inside the lamp. Furthermore, a warning was issued to the user if there was insufficient space to install a given lightbulb. The fitting for the light bulb socket was placed on the closest horizontal section, and as a consequence its position depended on the number of horizontal sections. During the process, the possibility to include the choice for removing the light bulb in was discussed. The idea was intended to open the possibility for the user to create other objects. However, this option was not incorporated in the interface build for the workshop.

2.1.1.2. Workshop

The design workshop was organized to understand three main points: how people would interact with the system, the variety and quality of the outcomes, and if the participants would feel co-authors of the resulted objects. An open invitation was sent to students, colleagues and friends. The cost for participating in the workshop of thirty reais (R$30,00) was calculated to cover the manufacturing and material expenses. Several sheets of plywood and gray cardboard paper were made available for the users to choose from, together with the five types of light bulbs. The electrical circuit was also assembled in advance to facilitate the process. A kit of electronic tools was ready for use if a participant would desire to make changes in that circuit.

The workshop team was composed of two students: Pedro Henrique Figueiredo Magalhães and Ricardo Hanyu. The first was involved in the process from the beginning and helped to program the parametric model. During the workshop he helped to answer questions and aided the participants with the design interface. The second was present to guide the participants through the fabrication steps and operate the CNC laser cutter.

Figure 6 | Pictures of the workshop that took place at LAGEAR in 2014. (author, 2014).

The workshop was held at LAGEAR in November 2014 and involved seven participants. The group was composed of users with the same level of education, same income range and common interest regarding the object of the research. Because there were only five computers with the design interface two pairs were formed. In a short presentation, the participants were introduced to the interface and the fabrication and assembly procedures.

In sequence, each participant received a task list with given assignments. The task list suggested the following steps:

1 - Play freely with the interface to understand how it operates

2 - Change the parameters of the design

3 - Generate drawings for the CNC laser cutter and export the cut files.

4 - Fabrication. Upload the cut files to the CNC laser cutter.

5 - Assembly and adaptation.

6 - Answer the questionnaire.

During the initial phase of the workshop, each participant worked on their own design and most of them did not show any difficulties in using the parameters interface (RCP). At the beginning they explored how each parameter affected the whole by setting each slider in the RCP to its limit. At first, the participants changed the sliders expecting a linear effect on the model. However, because some parameters are interrelated, different combinations of parameter values create different outcomes. In other words, the value chosen for one slider affects the geometrical results of other parameter sliders. In that sense, pushing each slider to the limit does not reveal all possible states of the system. That became evident for most participants when they started to fine-tune their designs.

Throughout the first design phase no meaningful interchanges between participants were noticed (except from those working together). Each worked on his own design, and showed little interest in what others were doing. However, when the assembling phase started they all cooperated to build the prototypes. What could have stimulated this cooperation was probably the time it took to cut the sections in the laser cutter. Each participant had to wait until the sections of their lamps were fabricated, and used this time to help others that already had their sections cut. Unfortunately, the time scheduled (three hours) for the workshop was miscalculated, and was not sufficient for the fabrication and assembling of all lamps. The fabrication time was not taken into account as a design constraint, and participants that used many sections on their design did not have enough time to fabricate their objects. Only three were able to build the one to one scale prototype of the lamp using plywood.

When observing the assembling of the prototypes a problem became evident with the fittings. The difficulty in holding the structure of the lamp together without the fittings in the horizontal sections made the participants struggled to position each segment in an exact distance between each other, and align the section oriented to the center. It was noticed that, during the workshop, none of the them took advantage of the possibility to change the position, or orientation, of the vertical sections.

At the end, all participants answered the questionnaire, including those that did not finish their lamp. In their responses they all indicated that they would consider to participate again in such workshops, and found the experience very pleasurable. They were unanimous to express that they consider themselves designers of their objects, and because of that, see it as less disposable. Two years after the workshop the participants that managed to fabricate the lamps were asked if they were still using the lamp, and two of the three responses were affirmative.

2.1.1.3. Designing Variability

The ability to easily generate variations is praised by many as one of the key distinctions of parametric models. To understand how this operates in MILU an investigation of the multiplicity of outcomes offered by the system was put forward. In MILU, the changes of parameters occur in finite steps (absolute numbers), where each step generates a new object. That is to say that the system enables 1.458×10^{15} combinations[16] when external noise is not considered in the equation. In that sense, if the system is observed not by what it is, but by what it produces, it could be said that it generates 1.458×10^{15} different lamps. Nonetheless, this mathematical interpretation does not say much about the system, because many of those variations would not be perceived by the users. Small modifications in the parameters can generate numerical differences, but will not originate

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[16] This number was obtained by multiplication of the maximum value of each open design parameter.

recognizable changes in the objects. However, by placing the focus on the different perceptible sets MILU can produce, instead of looking at all the individual productions, new insights may emerge. Following this reasoning, it is necessary to understand which differences in the parameters would make a difference in the perception of the object.

To start this investigation, a sample of 234 different designs were generated using the interface (figure 07). At each step, a combination of parameters was changed to create different outputs. Those outputs were compared to understand the combination of parameters that seemed more relevant at each step. Subjective visual criteria were used to produce enough samples to demonstrate the system's capability to generate objects with distinguishable differences. In order to better visualize the relationship between the qualitative observation of the objects, and the quantitative input value of the parameters, a graph (figure 08) was created in Gephi[17].

The qualitative analysis of the different designs show that the parameters that generated the most prominent features of the objects were: (a) the overall height, (b) the number of vertical and horizontal sections, and (c) the width of the vertical and horizontal sections. Those parameters were used as input to build the graph that depicts how each parameter is interconnected. The graph maps the weight of each parameter in the final form. To examine the effectiveness of the graph, the designs that represent the main features of each set of possibilities were chosen between the 234 designs, and their position was documented in the graph. It was verified that most lamps that were chosen occupied a position at the borders of the graph. Both analyses confirmed that the lamps with the most prominent features are those where the parameter values are close to the extremes - either to the minimum or maximum values. In this process, it was interesting to notice that the variation of parameters that control the spline of the basic geometry occupied a secondary position in terms of the generation of different sets.

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[17] Gephi - The Open Graph Viz Platform [WWW Document], n.d. URL https://gephi.org/ (accessed 8.2.17

Figure 07 | 234 different outputs from the parametric model (author, 2016).

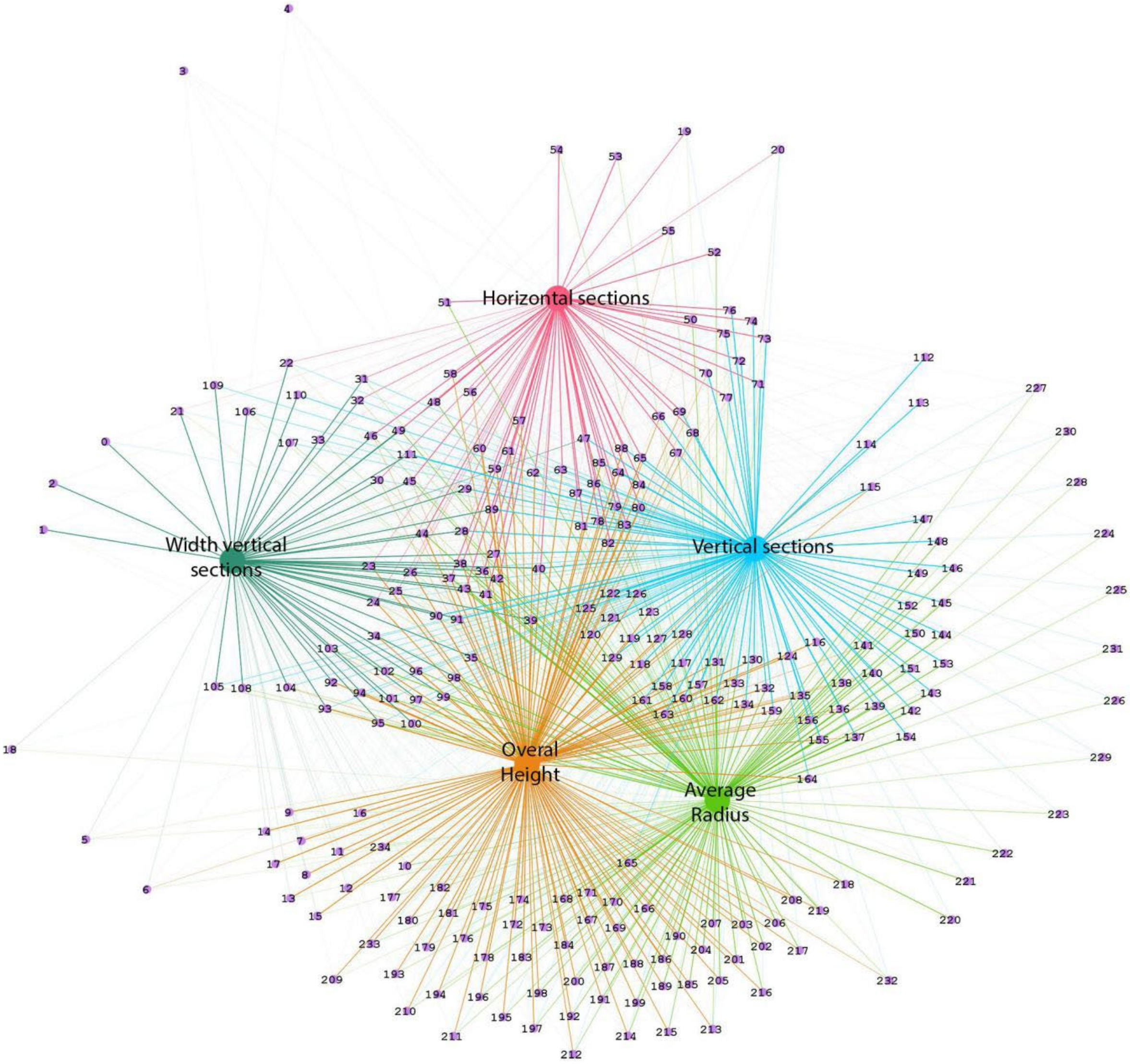

Figure 08 | Graph developed in Gephi with the relation between different parameters. (author, 2016).

This analysis showed that the number of possible sets, or families, that can be produced are connected to the number of parameters that define the main formal features of the parametric model. This conclusion does not lead to new insights, but reinforces that the multiplicity of forms is closely related to the design principles, and may be not as vast as a mathematical description would suggest. Following this reasoning, the choice of the design principles for generating the different sets of possibilities is of paramount importance for the development of meaningful variations.

In a second iteration, different design proposals were made to explore the formal potential of the interface (figure 09). Various materials, colours, and textures were explored to observe if other external inputs would produce novel sets of lamps. The combination of materials created interesting results that demonstrated the viability of expanding the number of possible sets by opening the system to different external inputs. In a third iteration this potential was further explored by using ready made objects as inputs to the system. Because the system can be used to make objects with dimensional precision, it enables the user to create hybrids by combining the digital fabricated sections with other ready-made objects with a perfect fit. Furthermore, the combination of a series of objects can generate compositions of large scale objects. In this third iteration those possibilities were explored in the creation of a new set of designs. Figure 10 shows a number of compositions that explore the MILU interface. Two young designers (Paulo Fontes and Marcelo Azarias) were invited to play with the interface beyond its original purpose. The product of their playful explorations point out that if external inputs are incorporated to the system the number of possible sets is expanded and becomes indeterminable. This points out that there is a large field to be explored when the user’s creative potential is acknowledged in the process.

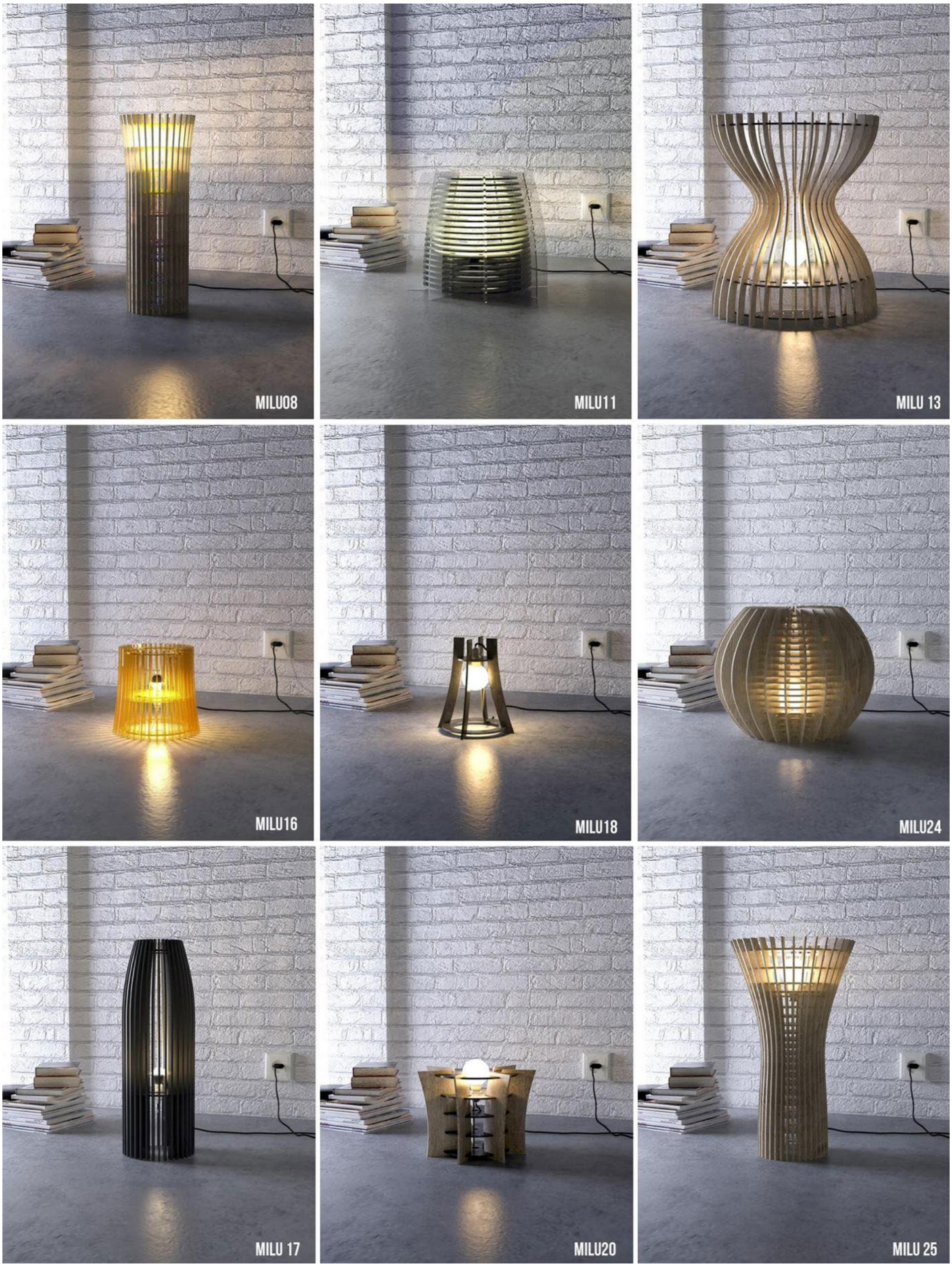

Figure 9 | Lamps rendered with different materials, such as acrylic, plywood and iron to create novel sets of possible results. (author, 2016).

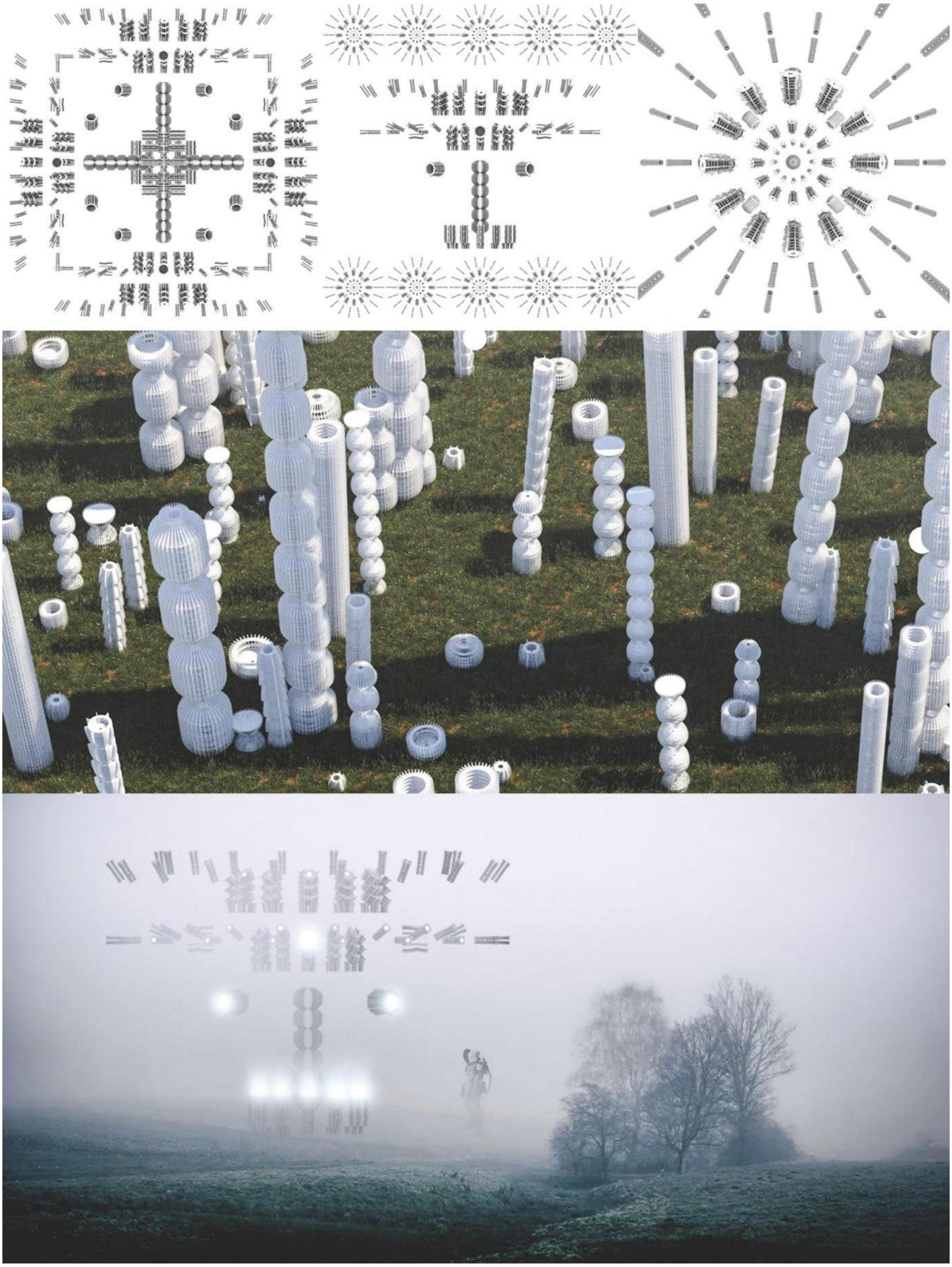

Figure 10 | Different explorations with the MILU interface beyond its original scope (Grasshopper, Rhino, 3D Max and Adobe Photoshop). (author, 2017).

2.1.2. Preliminary discussion

MILU raised interesting issues related to the design of a design process such as the development of interfaces, authorship, and different levels of conversations in design. Because it was an exercise - a research-sketch - many of these issues were not thoroughly discussed during the process. They serve, however, as starting points for further discussions and were important to raise different issues that indicate that a unique framework is required for the design of a user centered design process. The first issue is related to the implications - for designers and users - of the use of dynamic parameters in the design process. MILU has shown that for designers the design of user centered design processes with dynamic parameters represents a challenge. During the research-sketch it became clear that new strategies are needed to enable the user to give creative inputs to personalize his design. Those are related to the creation of dynamic parametric models and the improvement of the design process.

In conventional digital design processes that adopt parametric models, the model can be created in many ways using various techniques. In open parametric models, accurate modeling strategies are needed to make the model dynamic, enabling it to respond to parameters changes in real time. In that process, modifications in the design intent frequently require the model to be rebuild. To hinder unnecessary work, designing the constraints and geometrical relations before starting the model may be helpful to diminish the need to adjust the model definition. However, because making and remaking the definition is part of the creative endeavor, an effort to simply jump this step may impoverish the process. The creative process involved in the design of the definition has a conversational nature that is somehow similar to other creative processes, such as writing a text and making a sketch. To take this conversational nature of designing parametric models into account, and improve the design process, a new design framework is needed.

With regard to the improvement of the design process, a first point to be made is related to the users interactions with the parametric model. Although many dynamic parameters were conceived in the definition, they apparently did not invite the users to engage in more profound creative interactions with the system. In the workshop, as would be expected, none of the participants took the initiative to venture outside the possibilities already programmed in the interface. What might have contributed to this is the use of parameters sliders that, with its determined limits, can give the impression that it is only possible to interact with the designed model within the given constraints. A possible alternative to counter this restriction of the interface is to loosen the constraints to give the user more control, and create feedback channels to give warnings if a defined limit is exceeded. Those channels can also be used to improve the interaction with the system by giving the user more general information, such as the time and cost needed to fabricate a given design. A second alternative is to invite the user to look beyond the interface, and directly access the algorithms of the parametric model to understand the interrelation between each parameter and make the desired changes. Both alternatives are related to the levels of interaction enabled by the designed system, and demand a broader investigation on the degree of openness that would be desirable to generate better outcomes in terms of process and product.

The second point concerns the opening of design parameters in the object. That is to say, the design of dynamic properties in the object that enable the user to continue the design process after fabrication and assembly. In this first experiment the removal of the fitting in the horizontal sections was not effective in expanding the variety of outcomes, and even became an obstacle in the assembling phase. This problem, however, cannot be credited to the initiative to open design parameters in the object. The generative strategy used, where the vertical sections are organized concentrically, limits the array of solutions because it indicates a fixed organization. In that sense, the choice for a design principle that suggests a closed geometrical organization did not stimulate the observers to explore new possibilities and arrangements.

Although the first points are focused on design issues - design principle, design interface and dynamic model - a broader look on the process including how the workshop was developed can be revealing. Intentionally, there were no prior conversations about design and creativity during the workshop, and external inputs (materials and conversations between users and users and designer) were not stimulated. This may have contributed to the notion of a closed process, where the participants had to follow predefined steps.

Further experimentations with the interface showed that external inputs can generate new design possibilities. That was the case when using materials beyond those available at the workshop and by combining digital fabricated with ready-mades. This expansion of possibilities may point out that the initial difficulty in creating a larger variety was probably not only related to the number of dynamic parameters, but to the excessive focus on the digital process as the main interface for interactions and for generating differentiations. Despite the fact that the digital interface uses dynamic parameters it cannot be called a dynamic system, because it does not adapt to the users needs. It only offers more choices for the user, which is not a problem in itself, but cannot be said to be a system that enables personalization - *the process of making something suitable for the needs of a particular person*[18]. A broader understanding of the system, including the possibilities of using a larger array of materials and objects, with an emphasis on the different levels of interactions between the different observers, may lead to a promising path towards a more creative endeavor.

The attempt to explore a different form of user centered design practice can be associated with the concept of open design that is defined by Paul Atkinson (2011) as “the collaborative creation of artifacts by a dispersed group of otherwise unrelated individuals and of individualized production.” This concept is related to a movement where individuals collaborate to the creation of knowledge, objects, cultural production, services, etc., that has been given a high impulse since the popularization of the internet. Atkinson (2011) notes two aspects that should be considered to make the open design technologies more acceptable to a wider public: the development of more user-friendly interfaces with a more intuitive system for the creation of tridimensional models; and the distribution of more appropriated materials for the use in digital fabrication machines. The role of the designer goes from the design of closed objects into the design of interfaces, or processes, to provide the user with support to create their own design. Jos de Mul (2011) calls this new process database design, where the designer does not design objects but creates a drawing space where inexperienced users can access user-friendly interfaces wherein they can draw their own objects. In this sense, the designer

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[18] personalization Meaning in the Cambridge English Dictionary [WWW Document], n.d. URL http://dictionary.cambridge.org/dictionary/english/personalization (accessed 9.7.17).

creates a design of the design - a metadesign - that only materializes as a product through the interaction with the user. Jones (1991) advocates this shift of focus from product to process since the goal of the design should not be the finished product with a particular function, but the very continuity of the design process. In this sense, the focus on the process allows the user to be transformed into co-author of the design of the architectural space, increasing their active role.

Those issues and considerations point out that the development of dynamic systems requires the designer to rethink the whole process, going beyond the design of interfaces to explore the different interactions between user and process, user and object, user and designer, and among users. This conclusion reinforces the need for a design framework to structure those different forms of conversation and improve both the design process, and outcome.

2.1.3. Findings

This first research-sketch showed that the association of parametric modeling and digital fabrication can lead to the creation of a design process that is more inclusive and acknowledges the user in the process. However, further investigation is needed for the development of a system that enables more profound interchanges between the different stakeholders and invites creative inputs. The parametric interface is an open system, but this feature does not guarantee openness in the design process. It is the adopted procedure, which favors conversations between the different stakeholders, which allows the platform to be used as a facilitator in the creative process.

The quality of the works designed and built in a short time span has effectively shown that the association of parametric design and digital fabrication is a promising method of designing design processes that involve the user. However, to expand the design possibilities and generate novelty for both user and designer, a different approach is needed. The choice of which parameters should be open, and which should remain closed, together with the degree of openness is not a trivial one and demands a qualitative analysis on the set of possibilities created by each parameter. Furthermore, the parametric model alone may not be sufficient for an optimal result, and a broader understanding of the system is needed to invite relevant external inputs.

Designing with open parameters represents a challenge, and requires a framework that is different from a conventional design process. Some issues raised during the process that can point towards the creation of this framework are:

- The creation of dynamic parametric models requires a specific framework to enable real time changes in the model;
- Dynamic parametric models should incorporate feedback channels to inform the user and alert him about the consequence of transgressing predetermined limits instead of restricting his actions;
- Skilled users should have the possibility to directly access the algorithms to make desirable changes in the definition;
- The choice of the design principles is of paramount importance to generate differentiations and a strong formal structure will be less inviting for people to propose changes in the object;
- The design system is not restricted to the design interface and should be open to external inputs; and
- The use of dynamic parameters and user centered design interfaces are not enough to create dynamic design systems that enables the user to create objects adapted to their needs.

2.2. WOKA

The name WOKA derives from the wiki (open to) and oca (indigenous house or dwelling). It is a proposal for an open construction system that updates the building tradition of indigenous people, in which residents design and build their own homes. Based on a DIY (Do it Yourself) principle, it is a process developed to allow anyone to design, download, print, build, and complete their house or components. WOKA explores the integration between Wikihouse[19], SketchUp[20], and a plug-in called Bimbon[21] as an interface that mediates the design and building process of a house. It is an investigation on the potential of parametric design and digital fabrication to involve the user in the design process at an architectural scale.

The WOKA research-sketch was developed in LAGEAR with the participation of Cristiano Cezarino, teacher and colleague from EA UFMG, Marcus Vinicius Augustus Fernandes Rocha Bernardo, at the time a master student, and two undergraduate students, Pedro Henrique Figueiredo Magalhães and Ricardo Hanyu. The design exercise was triggered by a call for a design competition in 2014 that demanded a proposal for a small house using industrialized materials to be built within a 10m x 10m plot. The project should address constructive efficiency, fast assembly, spatial quality and innovative solutions[22]. Today, most design strategies related to the use of industrialized materials and processes in architecture are still primarily based on standardization, mass production, and prefabrication methods, which some have referred to as "modern architecture's oldest new idea" (Stevens, 2008).

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[19] WikiHouse is an open source project aimed at reinventing the way homes are made. The project is developed by an online community of architects, designers, engineers, inventors, manufacturers and builders, collaborating to develop high-performance building technologies, which anyone can use and improve.The aim is for these technologies to become new industry standards. WikiHouse [WWW Document], n.d. . WikiHouse. URL https://wikihouse.cc/ (accessed 7.26.17).

[20] SketchUp is a 3d modeling software developed by Trimble. 3D modeling for everyone | SketchUp [WWW Document], n.d. URL http://www.sketchup.com/pt-BR?field_region_tid=186 (accessed 7.28.17).

[21] Bim.bon is a plug-in that connects SketchUp 3D with a online database of materials, labor and household objects with up-to-date 3D models and prices. It helps to calculate the cost of the project. (Plug-in bim.bon para SketchUp. [WWW Document], n.d. URL https://www.hometeka.com.br/plugin-bim-bon-para-sketchup/ (accessed 7.26.17).

[22] prêmio 2014 | bim.bon [WWW Document], n.d. URL http://portfolio.bimbon.com.br/premio2014 (accessed 7.26.17).

The proposal developed by the team sought to advance this discussion by designing a house that could be constructed with the use of digital fabrication processes, which enables new modes of production. Because the design endeavor took longer than expected, the proposal was not finished in time to take part in the competition. However, from the beginning, the participation in the competition was not the main goal, but was seen as strategy to trigger a research process related to this thesis.

2.2.1. Overview

The design process started with a brainstorm session to problematize the competition briefing and determine the primary design strategies. According to the briefing, the main points demanded by the jury were: (1) spatial quality and innovative solutions; (2) easy and quick assembly; (3) insertion in consolidate urban areas in set of houses or village; (4) flexibility of the proposed space to adapt to different audiences and needs (families, couples, shared housing, home-office, etc.); and (5) optimization of natural ventilation and lighting. Following a traditional brainstorm method, many ideas were put forward and at the end a list of topics was created to summarize the discussion and orientate the investigation of related works. This process led to the following conclusions about what the design proposal should address:

- Create a process and not a finished product;
- Be fast and easy to assemble (and disassemble) observing that not everything has to be dismountable and flexible;
- Make innovative use of SketchUp;
- Create a continuous process that use SketchUp and Bimbon to study modifications and expansions of space;
- Enable the use of new design and fabrication techniques;
- Incorporate time as a design parameter; and
- Take into account the fine line that separates a system that is enabling and other that obstructs the involvement of the user in the design process.

During the brainstorm session, the Wikihouse concept was brought forward as a possible point of departure, which addresses the main concerns raised. However, before opting for the system, a broader investigation of related works was undertaken. Other design systems were investigated, such as Hermit Houses and Click-Raft[23]. Hermit Houses is a system based on an online interface that enables the user to change the geometry of a shed by modifying predefined parameters while maintaining the same structural logic. The interface is simple and fast, however because of its formal constraints the variety of possible outcomes is limited. Click-Raft, on the other hand, offers many possible configurations. It is a construction system based on digital fabrication to generate beams and planes to form structure, walls, floors and roofs that can be snapped (clicked) together to conform a space. However, the system would demand the user to make a project (or hire an architect) to define the plans. Essentially, the design process would not be very different from designing with conventional modular structures such as light steel frame. In that sense, neither Hermit Houses and Click-Raft offer the level of user-participation as proposed in Wikihouse.

The Wikihouse process, as proposed by the English architects Alastair Parvin and Nick Ierodiaconou, is characterized by the creation of design principles, the use of the SketchUp software, and the creation of a shared database (Parvin, 2013). The first design principles define which type of wood is to be used, how to think about the fitting of different elements, and its resistance. These principles also cover how one should draw the elements in SketchUp. Parvin and Lerodiaconou developed a plug-in specially designed for SketchUp. This plug-in is presented as one of the great advances of the system, as well as one of its advantages. In this manner, Wikihouse is not specifically a house, but an integrated set of processes that enables people to produce an architectural artifact.

The plug-in developed for Wikihouse generates the cutting diagrams, that is, it transforms the 3D model into a file with bidimensional drawings of the pieces that can be read by a CNC cutting machine. This operation represents the automation of a relatively complex task that is executed with one command in the software. Because this is an

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[23] CLICK-RAFT [WWW Document], n.d. URL http://click-raft.blogspot.com.br/ (accessed 9.27.17).

application designed under the Creative Commons license, the Wikihouse encourages sharing of the designs produced by the same logic with other users through the online database. The database is constantly updated and enables an exchange of experiences between different users in several parts of the world such as New Zealand, Brazil, and Holland, among other countries. Each of these centers has developed an autonomous and different approach to Wikihouse in their specific contexts, which has resulted in very different experiences. Today the shared database and the network of users has migrated to Slack[24], a more general communication and team management interface. The codes and library are also available at github. In that sense, the choice for Wikihouse was interesting not only due to a specific design principle, but more importantly, because of the community that is part of the system.

Although the Wikihouse system had great potential, the first design tests with the process revealed some problems in operating the SketchUp plug-in and in handling the Wren[25] structure. The Wikihouse SketchUp plug-in often failed to create the right joints, and several adjustments were needed to correct or improve the structural system. The initial interactions with the system also showed that some technical expertise is needed to design a proper structure, what can be troublesome for non-expert users. WOKA sought to resolve those issues by creating a simple and straightforward design process that enables non-experts to use the Wikihouse system without technical difficulties.

2.2.1.1. WOKA system

Following the Wikihouse design principle, WOKA is not a finished house, but an open construction system, based on dynamic parameters and digital fabrication, intended to trigger the design and building process. The idea is based on the Wikihouse Wren concept to generate an inner shell that is immediately deployable combined with a more durable outer layer that can be added later with conventional building systems available at the site. This enables people to create an initial proposal to respond to their

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[24] Where work happens | Slack [WWW Document], n.d. URL https://slack.com/ (accessed 9.6.17).

[25] Wren: The language and rules for the Wikihouse structural system for 1-3 storey buildings, initially developed in the UK for European contexts, 2017. WikiHouse Project (accessed 9.6.17).

immediate needs, change and adapt their design on site by reconfiguring the parts, and use their own building culture and collective knowledge to finish the construction. In that way, the systems enables the dweller to add his experience to the design based on his own culture and different ways of inhabiting.

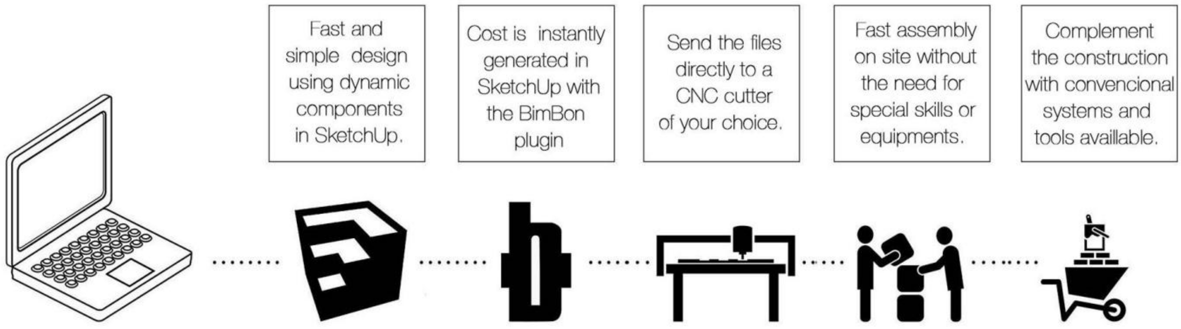

Figure 11 | Illustration of the proposed workflow based on the Wikihouse concept. (author, 2014).

The Wikihouse Wren structure was used to create a fixed module (figure 12) which was transformed into a SketchUp dynamic component[26] to enable the user to alter the organization and number of modules by stretching it in two directions - an arrangement proposed as alternative to the Wikihouse plug-in. The interface in SketchUp was built on dynamic components with simple commands, like stretching, clicking and scaling. The component created a direct correspondence of the representation of the module with the elements to be fabricated. The design of the module was based on the Wren frame developed by the New Zealand group Space Craft[27]. Because the structure proposed by Space Craft was designed and tested to resist earthquakes, it seemed a reliable set to work with. Space Crafts Wren solution was not available online at the time, however, after an email exchange they agreed to send the designs and codes, what shows the potential of open source strategies and networks for collaboration.

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[26] Making a Dynamic Component | SketchUp Knowledge Base [WWW Document], n.d. URL https://help.sketchup.com/ko/article/3000125 (accessed 9.6.17).

[27] Home [WWW Document], n.d. . Space Craft: developing WikiHouse in New Zealand. URL http://spacecraft.co.nz/ (accessed 7.27.17).

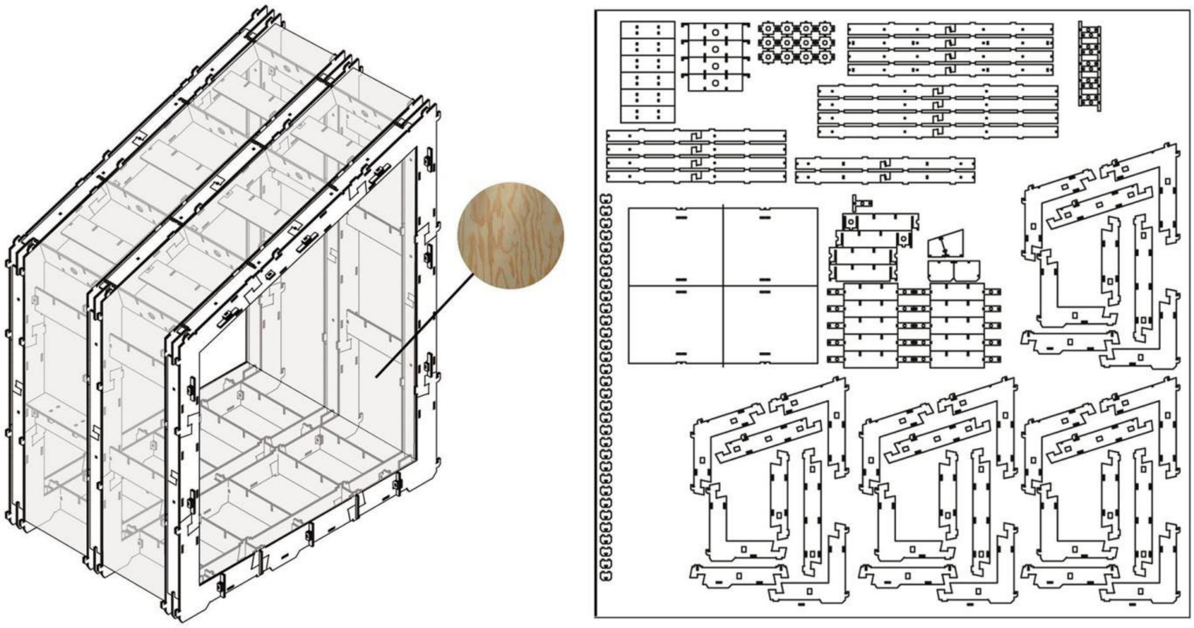

Figure 12 | Two basic modules together with the cut drawings. (author, 2014).

The dynamic component created in SketchUp enabled unskilled users to manipulate the model using simple commands, change the dimension of the house and visualize the results. The Bimbon plug-in was used to automatically generate the building cost and material specification so that with each modification of the original design the estimated cost is recalculated. The proposed fabrication process was based on a three-axis CNC cutter (laser or router) and consists of a rib structure built from plywood sheathed with OSB (Oriented Strand Board) panels . Fittings were added to the structure to enable the use of tile battens at the facade or roof.

Theoretically, the product can be immediately deployable, is easily mounted, dismounted and transported. The possibility to customize the overall geometry, and to fabricate it fast with high quality, enables the inhabitant a different living experience as the modules can be used in diverse situations and possible scenarios. It can be used to build a house, an annex of an existing house or even an office or garden house. The dynamic nature of the system and its low cost enables many solutions to take place fitting different realities.

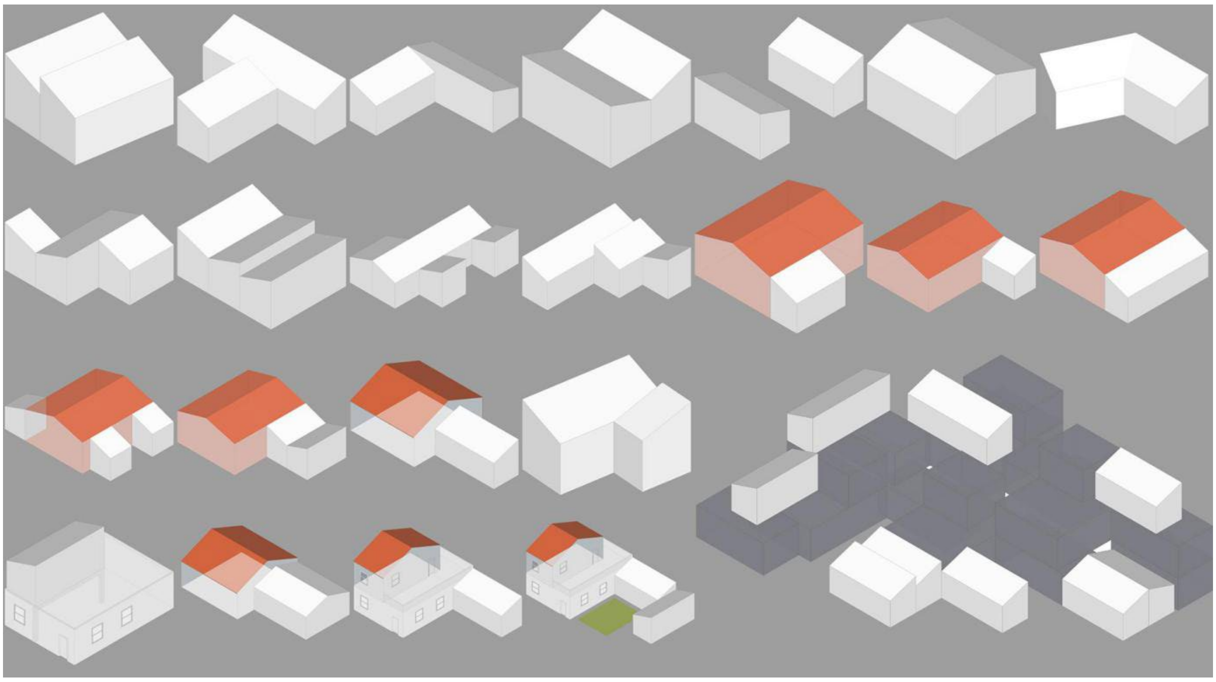

Figure 13 | Variety of possible solution of the WOKA module integrated in different contexts. (author, 2016).

2.2.1.2. Prototype

The first design using the proposed system consisted of a house with one bedroom with balcony, one bathroom, one living room, and a kitchen using in total five modules. The small scale was chosen to keep the design as simple as possible to enable its construction and evaluation with a low budget. An adaptation was made to the roof joints to facilitate the installation of the roof. In the prototype, insulated metal roof tiles were used both on the roof and the facades. Because of the experimental nature of the first prototype, part of the house was covered in glass to expose the rib structure. The interior was coated with OSB panels, including the floor and ceilings. The final cost of the construction calculated with Bimbon was $6000,00, which is still expensive for low-cost housing in Brazil. What increased the cost was the price of the CNC cutting of the plywood plates which is still very expensive. As most of the machines available are used in an industrial context, there are few companies that are willing to stop their production to enable this kind of project.

Figure 14 | First design of Woka system using the Wikihouse concept. (author, 2016).

One section of the house was fabricated in a 1 to 25 scale to test how the joints worked in the actual material. The premise was that if the structure would work on a small scale, it could have a similar effect in a 1 to 1 scale. The prototype proved easy to fabricate and assemble. Although this cannot be said to be true in a 1 to 1 scale, it seems that it will work likewise.

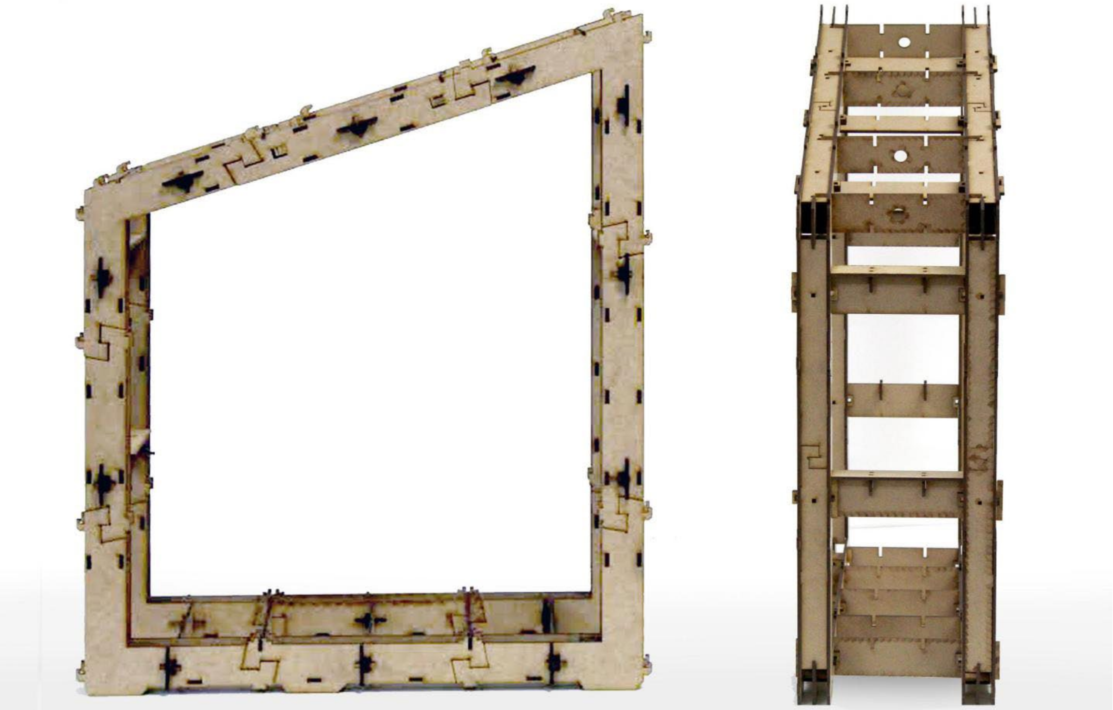

Figure 15 | Prototype of the module in plywood. Scale 1 to 25. (author, 2016).

2.2.2. Preliminary Discussion

WOKA is a design process designed to trigger a building procedure, and not as a finished product. The idea is to establish a continuous process of design, fabrication, and use of the architectural space. The continuity of the design process is possible because the system enables a fast assembly and disassembly of the constructive elements. If needed, people can rearrange the spatial configuration by changing some elements and by fabricating new elements and joints. The joints can be designed by the user or downloaded from the Wikihouse online database. This way, the parameters are open for user's manipulation in the design and fabrication process. In the proposed system, constraints were established to the design parameters of the Wikihouse system so that the core module is immediately deployed, even if the outer shell will take longer if conventional materials are chosen. This way, the user would essentially be able to complete the building without the help of an architect. The proposed system can, in that sense, be seen as a design interface to render architects unnecessary.

The creation of the dynamic component in SketchUp that allows the user to easily control the design in combination with the Bimbon plug-in, is of paramount importance for the proposal. Although it may appear that parametric systems can be difficult to be manipulated, the questions may not lie in the level of complexity of the system, but instead, in the design of the interface. The idea to create design interfaces to enable unskilled users to access complex data is not new. Computers, for example, are several times more complex and faster today than in the early days of their development, but are much easier to use. This has many reasons, but the improvement of the computer interface certainly is an important factor. The many discussions on the Slack forum shows that there are many enthusiasts engaged on further developing the structure with different formal arrangements, however only a few are working with the needed interfaces for users to access the design and building system.

In WOKA, the design interface conformed by the dynamic component of the module significantly limited the possible structural arrangements. The Wikihouse Wren structure enables innumerable different and more complex geometrical possibilities. However, the more freedom to design the basic module, the more complex it becomes to detail and fabricate the structure. This complexity may hinder unskilled users to adopt the system and may demand the participation of specialists. The built Wikihouse structures in Brazil[28], developed by architects and engineers inside academic environments, are an example of this. In WOKA, the choice was made to predetermine the design of the module in order to enable a variety of possible outcomes without technical complexity (figure 15). However, if there is a need for bespoken solutions, the design database of Wikihouse may be consulted and used. In that sense, because the system is inserted in a larger creative network, different levels of interaction with the system may be achieved.

WOKA reinforces that the digital fabrication technologies, when approximated to architecture, open the possibility for the participation of the user in the conception of space, making him co-responsible for the design. In one level WOKA inserts, even in a preliminary way, the user in the process, allowing him to take some key decisions for the realization of each project. In a second level, the user may share his design experience in the database to participate in the cycles of iterations, blurring the distinctions between user and designer.

2.2.3. Findings

WOKA was developed as a dialogical design process to empower self-builders to act in a more autonomous way, expanding the traditional role of design practice and the way buildings are created. The way to produce architecture, as well as the work of the architect, are sensibly modified. The role of the designers shifts from the creation of design notations and objects to design interfaces that only materialize through interaction with the user. The initial experience of the group with WOKA revealed that the creation of design interfaces for an architectural scale is a complex endeavour. First, because of the need of the interfaces to be simple enough to be easily accessed by a non proficient user and as complete as possible to enable the manipulation of relevant parameters.

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[28] The first Wikihouse structure built in Latin America was developed by LAMO3d, Laboratory of 3d Models and Digital Fabrication of the Federal University of Rio de Janeiro. The project was called House Magazine, as the proposal was to freely distribute various house designs to be digitally fabricated. (Passaro and Rohde, 2015).

Second, by reason of the importance of the generative principles over geometry and building form. It is important to enable a real participation of the user in the design process without constraining possible outcomes and use of different materials. Third, by virtue of the need to choose which parameters are left open to be manipulated by the user and which are not. Finally, as a result of the need to create or use an existing database to feed the different cycles of iterations and dialogues between different users and designers.

WOKA is a work in progress and by cause of its nature may never become a finished product. However, the work already developed raised a series of important questions that advance the discussion about the use of parametric design and digital fabrication in architecture towards the creation of a design framework for dynamic architectural systems.

2.3. 13MAY

13MAY was a pedagogical experiment developed in a two months course at the Federal University of Minas Gerais (UFMG) in 2016. The course was developed with the participation of Isabel Amalia Medero, a visiting professor from the Federal University of Paraiba. The objective was to engage the students in the ongoing research, by creating a design exercise that explored the association of parametric design and digital fabrication. The teaching method was based on a radical constructivist approach that invites students to construct their own knowledge through a design task that puts them in contact with real challenges in an existing context. In the sense of von Glasersfeld (1996), the goal of constructivist education is to support students to build their own intellectual competence. Following that understanding, it is important for the student to debate why certain ways of thinking and acting are considered desirable. Education based on constructivist epistemology provides students with opportunities to engage in activities designed to promote their own construction of knowledge.

The course was based on three central aspects: cooperation, (self) responsibility, and (self) interest. In this sense, students direct their own research work and assume a new role in the learning process, shifting from passive receiver to active producer of knowledge. To enable the students to construct their own research and learning process there were no fixed goals, but only the following research and design constraints: (1) explore parametric design; (2) involve the user in the design process; (3) if the outcome is a process it should be implemented, if it is a product it should be built. There were no specific questions to be answered or a precise script to follow. The sole objective was that the students should actively participate in the research and decision process. Von Foerster and Poerksen (2002) observe that to interpret learning as a joint research venture can have astounding results. This experiment represents an attempt in that direction, towards the unknown, by involving students, teachers, and the community in a conversational process where the questions and answers emerge through interaction.

2.3.1. Overview

The learning process was organized in three non-sequential cybernetic cycles - perception, reflection and self-reflection, and action - which interact and overlap throughout the process, with a content that covers research, digital design, prototyping, and digital fabrication. The first cycle - perception - was structured to create a broader understanding of the proposed concepts. It was conducted through a seminar, where the different themes were related to the concepts of interactive architecture, parametric design, and digital fabrication. The goal of the seminar was to foster discussions about the potential of new design practices, new forms of manufacturing, and the role of the architect in the face of these new possibilities. The central question addressed in the seminar was the potential of parametric design to open the design process to the end-user.

At the same time, the design process started with a visit to a community called Guarda de Moçambique e Congo Treze de maio de Nossa Senhora do Rosário (Guards of Mozambique and Congo Thirteen of May of Our Lady of the Rosary) (Figure 16), where the students were able to take measurements of the existing constructions and talk to a representative. The space is maintained by Queen Conga Isabel Casimira together with her sister, brother, and other members of the community. The first construction in the area dates from 1906 and began to house the Guard after its foundation in 1944. Since then, the space houses several functions at the same time, such as residence, chapel, communal kitchen, and space for worship, among others. As the physical space is limited each activity requires a general reorganization of objects, benches, tables and boxes scattered in all corners of the property. The headquarters of the community was under renovation, but because of a lack of funds they were forced to stop the works.

Figure 16 | Headquarters of the Guards of Mozambique and Congo Thirteen of May of Our Lady of the Rosary. On the thirteenth of May the space receives around 2000 followers to have a meal. (Mederos, 2016).

After the visit, the students started the design process with the development of preliminary proposals. They were asked to bring at least three ideas for possible works. In the first presentation, delivered at the design studio, most proposals put forward were aimed at “solving” a problem posed by the representatives, or identified by the students on site. The first ideas, ranged from different furnitures, gardens, and even an event to raise funds for the community to finish the renovation. The many ideas brought by the students were important to trigger discussions related to the concepts of authorship, collective intelligence, and the possibility to involve the user in the design process. During this discussions they showed difficulties in postponing the design solution, and were eager to start working on one of the many designs proposals. They found it hard to shift their focus from the creation of a product, to the development of a process, where they would have no control over the outcome. It was also noticed, that students had trouble to explore the use of parametric design and digital fabrication in the proposed contexts, where many social and spatial issues overlap. Their first impression on parametric design and digital fabrication was that it was related to the creation of complex forms, and they had trouble to envisage another way of using those processes. For most, parametric design was superficial and unnecessary in this specific context. In the end of the first presentation, the students were asked to form pairs, and to further develop one of the many ideas discussed in the group. It was reinforced that students should build a design process that involves the user, and not necessarily a finished product.

The second cycle was developed through a series of workshops where students came into contact with parametric software and fabrication processes - both digital and traditional. Following a process of P2P (peer-to-peer) learning the workshops were led by the students together with co-workers of Oficina.cc, who taught each other. The introduction to parametric design occurred through the deconstruction of the parameters of different elements through a “game” of concepts (Figure 17). This method enabled the students to understand the relationships between various design constraints, such as, form, materials, and structure. The focus was not on a specific software, or design interface, but at giving the students a more general understanding of designing with interrelated parameters and constraints. The idea was that they could build the information flow before starting to work on a parametric model.

In the third cycle, the ideas developed by the groups were presented to two representatives of the community (figure 17). One of the proposals put forward by the students was not a product, but an analogical interface created to trigger conversations with the representatives. The interface consisted on an abstract representation of the elevation of the building, similar to a board game, together with colored pieces of paper that served as representation of various objects. This simple interface allowed a rich discussion among the representatives and the students, who jointly analyzed the design possibilities in the proposed space. With the help of this interface, other students presented their ideas and joined the conversation. During this process, differences between the diverse ideas and expectations of both students and users became visible. Following this conversation, all students chose to abandon their initial design proposals and the group decided to rethink the process. In that moment, issues such as authorship, detachment, and cooperative work were finally worked out, and the students restarted their process working together to develop a single proposal (figure 18). This is not to say that the various design ideas brought by the students were of no importance for the development of the final work. They were necessary to guide the conversation and serve as a base to build upon. Together with the representatives, the group chose to develop a simple modular system where the fittings would articulate different elements. The fittings enabled for various configurations of the ensemble of modules.

Figure 17 | Students and Queen Isabel having a conversation with the use of the interface. (author, 2016).

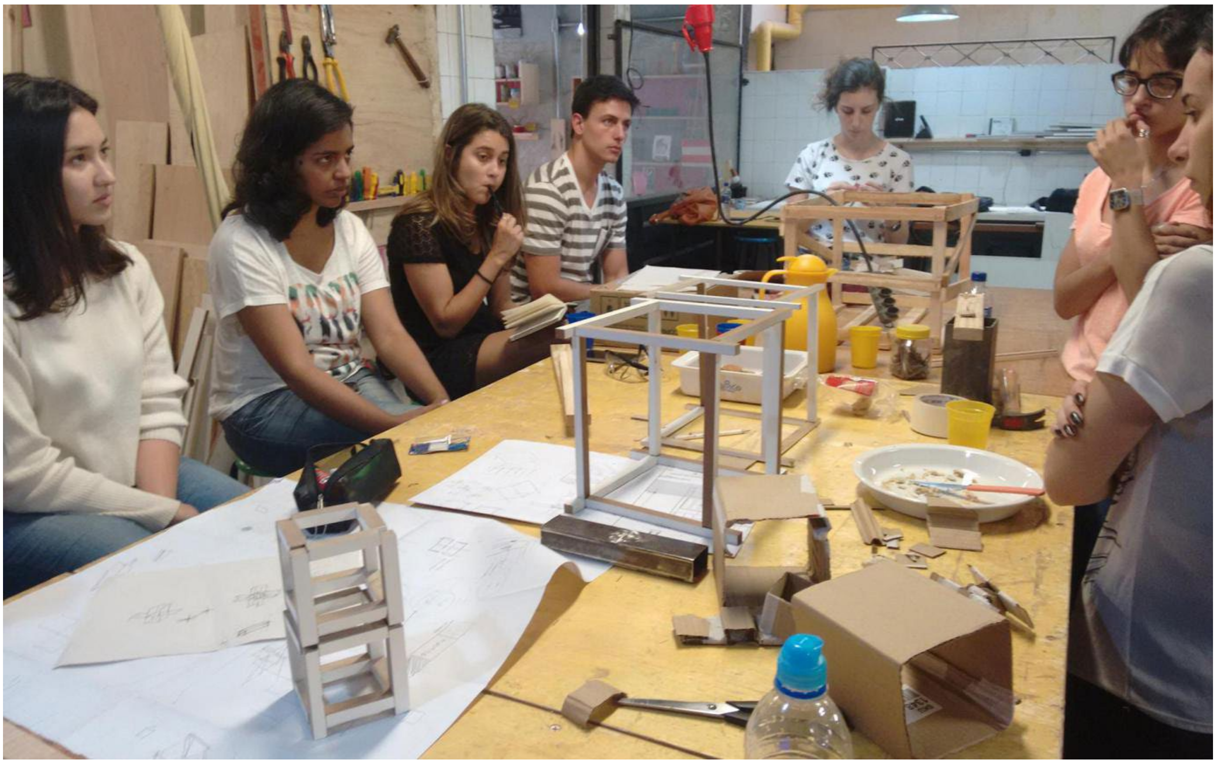

Figure 18 | Students in Oficina.cc showing their different prototypes to debate about the different design strategies. (author, 2016).

The following meetings took place at the makerspace, what facilitated the execution of the prototypes of different ideas and solutions for the module. Queen Isabel followed the initial fabrication and assembly process of the modules and became very interested in woodwork, and with the idea that she could make some objects herself. She later participated in a woodwork workshop with the members of Oficina.cc to learn more about the process. The students had also a rich interaction with the members of the makerspace and learned how to work with carpentry and metalwork. The construction of the prototypes was an important step in the development of the parametric model of the module. In this process the algorithm and the prototypes were built in a circular way, where one informed the other. The knowledge gained by the students by working directly with the different materials served as input to the system.

2.3.1.1. Dynamic Parametric Model

The parametric model, developed in Grasshopper 3d, was designed to adapt the design to various material properties (thickness and strength of the parts), dimensions and positioning of the fittings. The model was created at the same time as the physical prototypes, generating a circular iterative process between physical and digital data. The analyses of the prototypes, built to study the joints, fittings, and connections, was used as an input to the model in order to establish which parameters should be constant or variable.

Figure 19 | The parametric definition was build at the same time as the physical modules. Simple material tests were done to define the constraints of the model. (author, 2016).

The algorithm developed in the grasshopper 3d interface was based on the definition of three groups of dynamic parameters. The first is related to the structural modulation based on the distance between the fittings of the parts. It is this distance that allows the articulation of the parts in a modular system and determines the dimensioning of the modules. The second group is related to the specific dimensions of each unit. The user can change the number of openings and thus adjust the size of the modules. When there is the wish to change the size of the modules beyond the proportion allowed by the fittings a cantilever is created. If the dimension of the cantilever exceeds the distance of the structural modulation, new fittings are automatically generated. The third group, perhaps the most relevant to the development of the work, allows a more active participation of the user. This group of parameters enables the user to change the material to be used in the construction of the modules.

When the material and its dimensions are modified, structural adjustments are made in the design. In this way, when a fragile and poorly flexible material is used, structural reinforcement are automatically added to the assembly. When the material is more resistant, the reinforcements are resized or even removed from the design. This flexibility introduced the possibility of using recycled materials, by adapting the structure to the chosen material. The ability to dynamically change the material specification in real time allows the project to be adapted to a specific context and different external pressures, such as the availability or price of the raw material at the site.

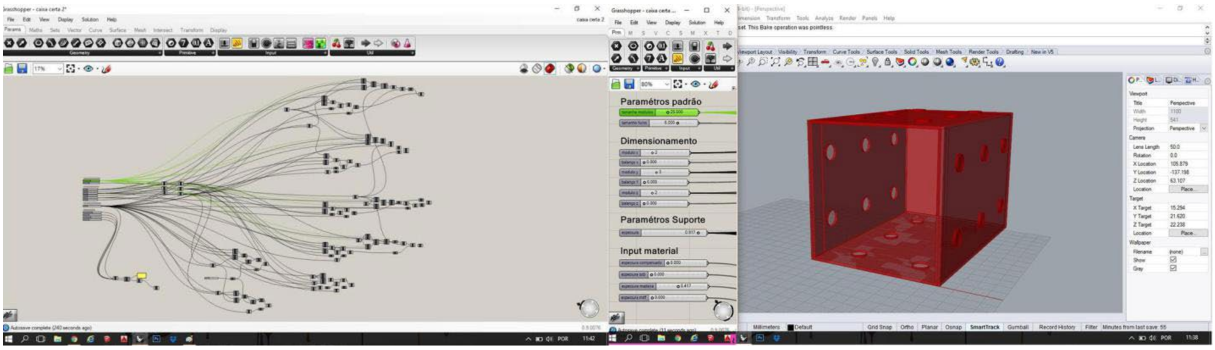

Figure 20 | Parametric definition of the box module where the main variables are: size of the modules and fittings. (author, 2016).

2.3.1.2. The Box

A prototype of the modular system was fabricated by the students to be handed over to the community. Thirteen modules were constructed in three different sizes: small, medium, and large. The students tested different possible configurations of the modules (figure 21 and figure 22) by creating different shelves, tables, benches and a stage. What became explicit in this playful exercise of changing configurations was that, although the module itself was not a dynamic element, a set of modules in the hands of the group became a dynamic system that could be adapted to the different needs.

Figure 21 | Several combinations of the 13 modules assembled by the students (shelve, stage, bench, table, and others). The modules were built in 3 sizes: small, medium, and large. (author, 2016).

Figure 22 | More combinations of the 13 modules assembled by the students. (author, 2016).

The modules were fabricated in 20mm plywood and OSB, and because of the resistance of the material it did not need any additional reinforcements. The round fittings were cut in a CNC laser cutter and screwed into the bottom and lateral side of the box. Two other laterals received wholes to create an exact fit. The use of the CNC laser cutter was important to add precision to the fittings to create a good hold. However, the system does not necessarily demands the use of digital fabrication techniques. The idea of fabricating three sizes of the module was important to enable different configurations. In that way, following simple rules of connections, various sets can be created to enable different uses. The parametric model adapts the design of the box to different materiais, but maintains the basic rules and relations between the parameters. In that sense, the parametric model is not used to generate a variation of forms - as in most uses of parametric modeling in architecture - but to keep a formal constraint and relations fixed, while opening the possibility for different material inputs. In the proposed design system, the design of multiplicities is not related to the number of different sets that can be produced, but to the overall number of nearly identical models fabricated. A larger number of modules enables a larger number of combinations. Following this reasoning, the higher the number of modules, the more dynamic the system becomes. This notion emerged through the making of digital drawings using collage (figure 23) and computational generative techniques (figure 24 and figure 25).

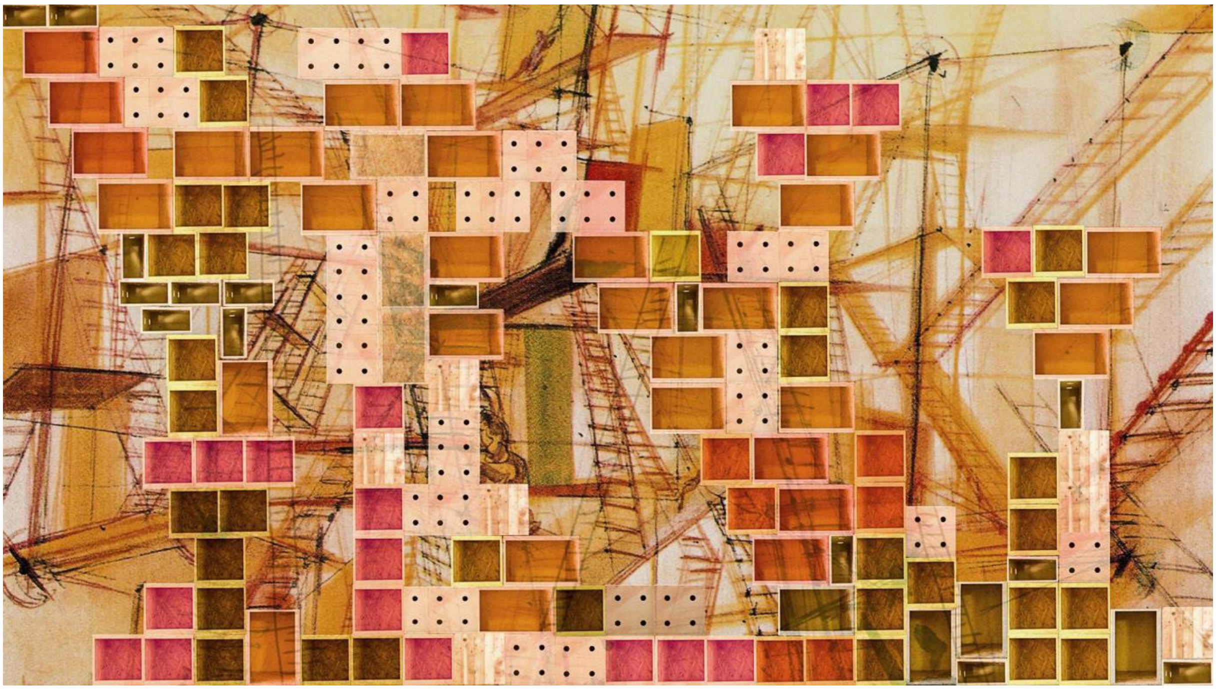

Figure 23 | Digital collage of several modules merged with a sketch of the concept for New Babylon by Constant Nieuwenhuys. The association of this dynamic system to Constant´s painting is not by chance. Both proposals are connected to a political statement that explores new forms of producing space and acknowledges people's creative potential. (author, 2017).

Figure 24 | Computer renderings: exploration of the modules to conform a Dynamic System. (author, 2016/17)

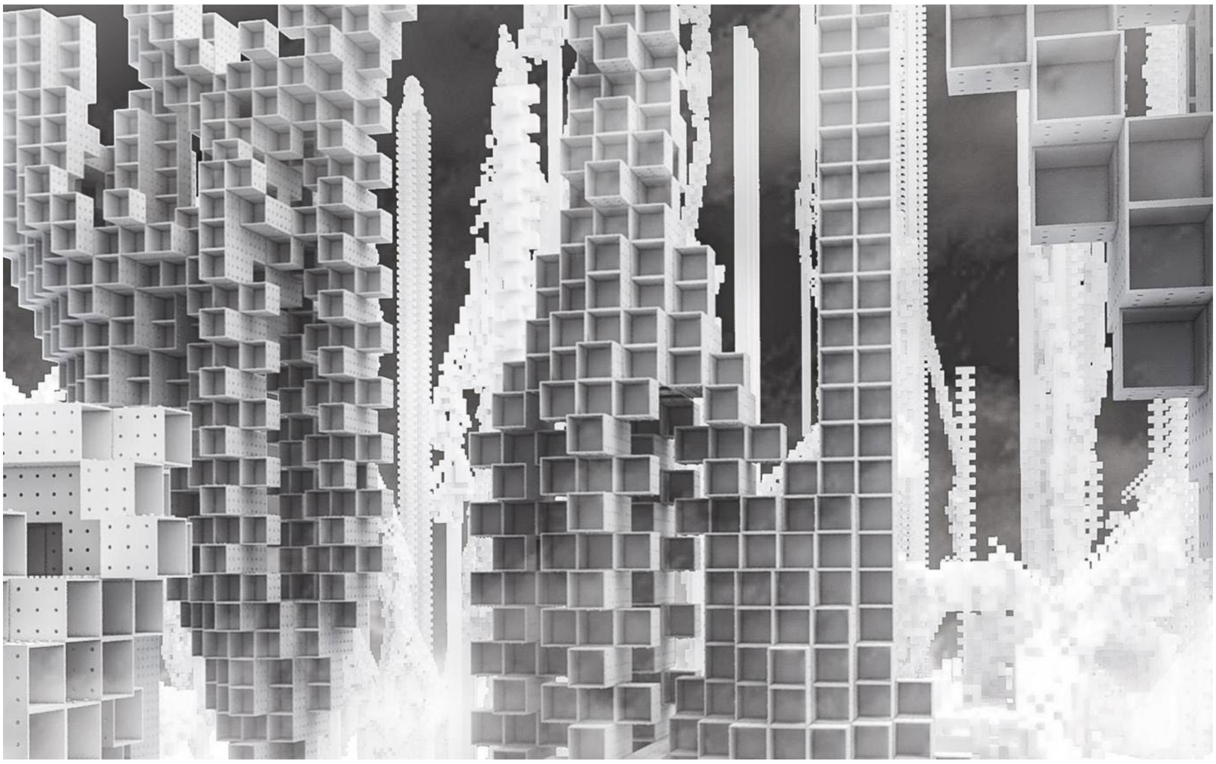

Figure 25 | Exploration of the modules to conform a Dynamic System using the memory of a 2D cellular automata in Grasshopper3d. The original algorithm is called Conway's Game of Life with Memory. (author, 2016).

2.3.1.3. Design Conversations

The result of this learning/teaching experiment was not something that could have been foreseen in advance as it was a consequence of various cycles of conversations between teachers, students, and the community representatives. Throughout the research-sketch, the conversations occurred at different levels and involved different actors at each cycle. The first level, a conversation about having conversations - or metaconversation - was necessary to prepare the students to be open to undetermined goals and to create together before addressing the community representatives. This metaconversation was triggered by the presentation of the first designs made by the students through which they exposed their ideas. In this process, the difficulty they had to create a process that involves the user as an active participant, and their focus on designing predetermined products, was not unexpected. In fact, it is related to a long standing tradition of authorship and control within the architectural discipline. Therefore, some pedagogical inputs were needed to provoke them to reflect upon the issue. The first input was to ask the pairs to choose a design idea created by other student and develop it further. This approach was meant to help them give up control of the process, and overcome the habit of giving straightforward solutions to predefined problems. Another important input was the task that was given to the group to determine the strategy for establishing conversations with the representatives. The need to create a plan invited them to converse about the different possibilities of triggering conversations. This process, the conversation about conversations, was paramount for the students to engage with the community representatives with an open mind and not impose their own will on them.

In the second level of conversation, between students and representatives, the process was triggered by the analog interface proposed by the students. Although it was only a mere scheme of the building, it served to establish a shared language to enable the representatives to talk about their relationship with each part of the house. For the students, it facilitated the presentation of their impressions and understandings about the community. This process encouraged them to use their design proposals for asking questions instead of presenting solutions. Through this conversation, the limits of what could be accomplished within the defined timespan became apparent to the representatives. Because of their many needs, they did not know exactly what to expect from the students. When it became clear that they could contribute with the definition of goals they began to participate more actively. The students, in their turn, decided to restart their work and focus their combined creative potential in developing a solution for a modular system, which could be used to stow objects during normal days and serve different goals during the festivities of the community. This decision was taken together with the representatives, that participated actively in the debate to define the next steps.

In the next phase, the construction of models and prototypes proved to be an important method to enable a creative process within the group. It facilitated them to visualize and test different possibilities in a fast and practical way. Each design iteration was evaluated to observe how it would enable different configurations. This process of test and evaluation of new arrangements did not stop after the fabrication of the set of modules. The articulation of the fittings and connections allows the user to create configurations and to fabricate new modules. As a result, a possibility is created for the user to continue the design process at the level of the object, not because it incorporates dynamic qualities, but by cause of the dynamic relationship between objects. Furthermore, the ability to dynamically change the material specification in real time allows the design notations to be adapted to a specific context, such as the availability or price of the raw material on the site. In this regard, the importance of digital processes is to enable a design to adapt to different external pressures while maintaining the internal relations. Independent of the chosen material and structure, the resultant object will retain its basic configuration preserving the consistency of the whole.

2.3.2. Preliminary discussions

The discussion related to this research-sketch can be divided in three main topics. The first is the potential of establishing different levels of conversation as a strategy to invite the user to take part in the design process. The fact that the outcome of the proposed research endeavour could not be foreseen by the different participants shows that the conversations cycles were effective. However, because many important issues related to design conversations were learned during the process, the potential offered by conversations in design was not developed to its limit. One example was that the need to create design strategies for establishing a shared language with the representatives, so fundamental for enabling their real participation in the design endeavour, came only late in the process. In a more structured initiative, the different levels of conversation can be defined in a framework that favors the creation of a shared language, cooperation, and the building of shared goals. The different interfaces that enable this process to be successful can and should be further investigated. For this to happen, a deeper understanding of the various levels of conversation in design is needed.

The second topic to be discussed is the dynamic system that was product of the conversation cycles. At a first look, the box produced by the students may be regarded by many as too simple or commonplace within a discussion about parametric modeling and digital fabrication. The many books on computational processes are filled with seductive images depicting complex shapes that praises the tools and mediums used in their design and fabrication process. Computational driven processes are largely explored as facilitators in the search for new forms (Iwamoto, 2009), materiality (Kolarevic and Klinger, 2008), managing differentiations (Schumaker, 2009), and generating non-standards (Kolarevic, 2003). In this research-sketch, however, the parametric model was not used to generate a variation of forms, but to constrain the formal relations, while opening the possibility for different material inputs. In the proposed design system, the design of multiplicities is not related to the number of different sets that can be produced, but to the overall number of nearly identical models fabricated. In this system a larger number of modules enables more complex combinations. An analogy may be made with sand, that is soft and malleable when observed in large quantities and hard and sharp when in unit. The box is trivial when observed as an unity but, when in large quantities, it conforms a dynamic system. The proposed systems contrasts to the notion put forward by Kolarevic (2001) that "grids, repetitions, and symmetries lose their past raison d'etre as infinite variability becomes as feasible as modularity and as mass-customization offers alternatives to mass-production". The dynamic notations of the box system associates mass-customization (of materials and structure) with modularity, where what can be customized is the input and not the output of the system.

Another important discussion raised by this research-sketch is the potential of using research as a learning strategy. In traditional education students are regarded as passive receivers of information. However, teaching should not be seen as the transmission of knowledge from one to the many. As acknowledged by Negroponte (1970), "teaching is a joint searching; there can be no distinction between coursework and project work, research and teaching". Negroponte's remarks are important in this context as many of his investigation on architectural machines (1970, 1976) were developed together with students, putting in practice a constructivist approach towards research. Von Foerster (2002) also instigated his students to participate in research as a way of learning. He advocated that time should not be spent by teachers in asking illegitimate questions (were the answers are already known) to the students. By asking legitimate questions teacher and students can evolve into researchers and learning becomes a joint research venture. However, restricting this possibility to *learn by research* only to teachers and students would raise ethical issues. If the user is involved in the design process he should also be given the chance to research and learn together. The fact that Queen Isabel showed interest in learning woodwork after the design process, points that there was a clear will to learn. Sadly enough, this possibility was not fully taken into account during the research and design process.

2.3.3. Findings

The product of this research-sketch is not an object, nor a set of objects, but a dynamic system that associates a modular design principle, an open parametric model, and the user’s inputs. The opening of the design process to the user was explored at least in three levels: in design process, at the level of the parametric notations, and at the level of the object. The experiment showed that it is possible to combine those different levels to form a design system that invites the user to a continuous participation in the design of his environment.

The different levels of conversation were fundamental to enable the development of the proposed dynamic system. The design process made the importance of creating a shared language between the various stakeholders explicit. However, further research is needed to create a design framework that explores the potential of the various levels of conversation in the creation of dynamic systems. The overall design process and the conversation cycles raised issues not only related to design, but also to the possibility of building networks of personal and social relations that endure beyond the design phase. Nevertheless, this possibilities were not fully explored during the design experiment and deserve further investigation.

The research-sketch demonstrated the potential and challenges of new digital design practices inserted into a real context. The contingencies of the everyday life demands a reconsideration on the role of the architect in the face of the complexities of social challenges. The experiment showed that the creation of dynamic systems through conversations and digital processes can be a possible way of dealing with the complex and always shifting social environment.

2.4. Research-Sketches

The three research-sketches presented in this chapter pointed out that the association of parametric design and digital fabrication enable different ways of involving the user in the design process. In MILU, the designed system allows the user to manipulate a digital interface to customize a product within the defined parameters. In WOKA, the user can manipulate a simple parametric model to determine the orientation and repetition of a predetermined module to generate the initial structure of a whole building or part of a building. The module is developed with an open source design system (Wikihouse) that is constantly improved by an online community of designers, builders, and non-professionals. Both experiments have shown that in building open processes, the role of the designer shifts from the design of objects to the design of design systems which includes at least a generative principle, a design interface to manipulate dynamic parameters, and an associated fabrication or assembly method.

13MAY showed a different approach towards the involvement of the user in the design process where conversation takes a major role. It combined different levels (between teachers, students and teachers, between students, and students and representatives) and cycles (perception, reflection and self-reflection, and action) of conversations, the use of dynamic parametric notations, and the creation of a dynamic system that proposes the continuity of the design process. In this process, the user assumes the role of co-designer of the system and the role of designer of his environment. What became evident in the teaching experiment is the importance of the concept of conversation in building the creative process and the need for a shared language for conversations to be effective. Gordon Pask's Conversation Theory (1976) can be of aid in further developing this process by providing a theoretical framework to structure a conversational design process.

The different forms of involving the user in the design process also raise important questions related to the handling of control to the user. Traditionally, most architects make use of digital design processes to create prescriptive digital representations that allow little or no openness for user participation in the design and creation of the architectural space. When trying to control all design parameters, in an attempt to predict possible errors, define situations and configure form, the architect may end up restricting the potential for a more creative architectural appropriation. The presented research-sketches can be framed as different attempts to explore alternative approaches that use digital processes to question the traditional form of control exercised by architects, and invites the user to take an active role in the design process.

MILU and WOKA enable the manipulation of design parameters; however, the two initiatives differ on the level of control offered to the user. In MILU the user is provided control over several predefined formal parameters. The constraints established in the parametric model maintains the structural consistency and enables the user to chose from multiple arrangements to create his design. In this process, the number of possible sets presented by the system is directly related to the generative strategy and number of open parameters designed in the system by the designer. In that sense, the number of possible sets is predetermined within the system. It was observed that to enable the generation of a larger variety of outputs the system has to be exposed to external inputs. The question is, to which degree a system can be opened to external inputs to generate variety without losing consistency.

The same issue is also valid for the WOKA system. The strategy adopted in WOKA was to restrict the number of possible sets offered by the Wikihouse system so that it becomes manageable by non-expert users. The user is given control over a limited number of parameters to design the initial frame. However, because the output of the system is not a finished product the number of outcomes becomes indeterminable. Nevertheless, the different final results will not be a direct product of the design interface, as there is no longer control of what may or what may not be done. After the initial frame is finished, it is up to the user to take control of the process and responsibility for the product. The question that arises is if the handling of responsibility to the users will mean an irresponsible action of the designer, as he will no longer be accountable for the product.

The result of the 13MAY research-sketch offers a different perspective on the design of open design processes, as the control over the main design principles is restrained by the parametric notations. Nevertheless, this restriction of design options in the design notations enables the creation of a system where the dynamic qualities resided in the interaction between the multiple parts and the users, and not in the unitary form. That is to say that the strict control of dimensional features gives the user more freedom to articulate the various modules to serve their needs. Furthermore, because the control of the design process was shared among all stakeholders, the users could not only choose between predefined parameters but were involved in the definition of the initial parameters through a conversational process. What this discussion points out is that control is one of the fundamental issues that emerge throughout the three research-sketches, and deserve further discussion.

A third concept that emerged in the discussion is related to the variety of inputs and outputs proposed by each process. The idea of computational variability is today strongly related to parametric design and digital fabrication. The ability of parametric models to generate a multiplicity of unique designs combined with the potential of digital fabrication to mass-produce variations is seen by many as the starting point for the next industrial revolution[29], where consumers will be able to customize their products. This process, called mass-customization, is defined as the mass production of individually customized goods and services (Pine, 1993). The concept is based on the possibility to increase the variety of products without substantially increasing cost. In the designed systems the effort to create standard objects is equal to generate non-standards. However, if for the machines the computational variability does not represent a challenge, for the designers this capability offered by parametric design and digital fabrication has several implications for practice.

In MILU, the variety of possible sets that could be created were predefined by the proposed system. However, this has proven not be sufficient for people to personalize the object - to give personal inputs. An excessive focus on the digital process as the main interface for interactions and generator of differentiations did not lead to the desired results. A broader understanding of the system, including the possibilities of using a larger array of materials and objects, with an emphasis on the different levels of interactions

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[29] A third industrial revolution [WWW Document], 2012. . The Economist. URL http://www.economist.com/node/21552901 (accessed 5.24.17).

between the various observers, may be needed. To enable this, a different approach is required that expands the system's boundaries beyond the designed interface to invite external inputs. Those inputs can be of essential importance for the user to truly customize the object to fit his needs. In WOKA those external inputs are possible, as the output of the process is not a finished product. However, this may represent a problem for lay users that have difficulty in dealing with the proposed structure and therefore will have to hire a specialist to finish the product.

In the 13MAY process, the use of the parametric model was not focused on generating a variety of outputs, but to enable a variety of inputs. In other words, the parametric model was not used to generate complexity, but, more importantly, to manage complexity so that complexity can emerge in use. This inversion is important if parametric design is to be used in a dynamic context that is in constant change. The potential of developing design notations that is context-aware can not only be used in the design of objects, but also in the development of large-scale projects where external contingencies force changes in the initial design. However, this would leave the designer three choices: (1) try - in vain - to predict all possible contexts; (2) create a system that can recognize and adapt to the different circumstances - using artificial intelligence for example; (3) create a design process that generates a unique design when in conversation with its context. In fact, the third option can be seen as an improvement of the process developed during the experiment. 13MAY showed how a cybernetic process can structure a research and teaching method where there are no fixed goals. The results of the different cycles of conversation could not be foreseen in advance and were meaningful for the various participants.

The three research-sketches presented in this chapter demonstrated that the association of parametric modeling and digital fabrication could lead to the creation of a design process that is more inclusive and acknowledges the user in the process. However, further investigation is needed for the development of a system that enables more profound interchanges between the different stakeholders and invites creative inputs. In the discussion of the research-sketches at least four fundamental concepts emerged: conversation, control, variety, and systems. Those concepts are directly related to cybernetics and a more profound understanding of them may offer important insight in the development of a design framework for the creation of dynamic architectural systems. However, before discussing those concepts in more depth, a broader understanding of the different attempts of designing dynamic systems using digital processes, together with a deeper knowledge of parametric design and digital fabrication, is needed.

3 | ARCHITECTURAL MACHINES

FROM MODERN FLEXIBILITY TO ROBOTIC ECOLOGIES

> “It is evident that the term machine has a general meaning and that it can stand for practically anything related to some temporal process. I mean by this statement that I can consider anything as a machine provided that this “anything” can have subsequent states (even if these states are all identical). A conclusion of this statement could be that a “machine” does not become a “machine” except because of me, who am observing it; I am submitted necessarily to a temporal process: life.”
>
> (Yona Friedman, 1975, p.93)

In the last century, the concept of machine has embodied many perspectives. It expanded from the notion of rational and precise instrument of the industrial age to an intelligent apparatus (Machine Intelligence) of the information age – an “acting and interacting other”(Schuman, 1998). Nowadays, it conforms a whole new ecology of agents that inter-communicate (Machine-to-machine communication). Nevertheless, the above quote by Yona Friedman shows that the concept of machine goes beyond the notion of hardware and necessarily involve the observer. It is he - the observer - who defines the machine. It is with this understanding that the concept of machine is used in this chapter - as a system described by the observer where the subsequent states incorporate change.

Architectural systems that embrace a dynamic nature share key characteristics: nomadic, adaptable, scalable, nonlinear, responsive, interactive, multivalent, polyvalent, etc. Sanford Kwinter (1993) call systems with those qualities "soft systems." "A system is "soft," when it is flexible, adaptable, and evolving, when it is complex and maintained by a dense network of active information or feedback loops, or, put in a more general way when a system can sustain a certain quotient of sensitive, quasi-random flow." (Kwinter, 1993). In other words, what characterizes those systems is the ability to respond to external pressures and evolve in a changing environment maintaining stable conditions. According to Kwinter (1993), "the stability of the system is rooted in its dynamics, in its capacity to handle and process movement, change, difference - in a word, information - transforming all irregular ripples and disturbances in the universe into engines of creation by absorbing these into its own already-existing, and deeply intertwined, internal movements". In that context, change is not only welcome but also necessary in a constantly moving world.

According to Ross Ashby[30] (1960), what characterizes a dynamic system is the possibility to change its states in time within the range of its essential variables. Variable, "is a measurable quantity which at every instant has a definite numerical value[31][32]". "Any arbitrarily selected set of variables" nominated by the experimenter represents a system[33] (Ashby,1956, p.15). The possibility to adjust the essential variables responding to external pressures, and ultimately to reconfigure the variables themselves is what renders a system dynamic and adaptable to change. In design, variable elements can be designed by many means - technological or not. Doors and windows, for example, can be seen as elements with variable states that generate spatial variations. However, the change of states can be more meaningful and profound, and is not necessarily related to kinesis.

The possibility to design dynamic architectural systems has been approached from different perspectives along the past centuries. To contextualize the thesis, this chapter makes an introduction to several discussions related to the theme with a special focus on computational practices. The objective is to situate the research in relation to theoretical discussions and practical works carried out in recent years. A special attention will be placed on understanding the role of the observer in each system.

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30 William Ross Ashby (1903-1972) was a British pioneer in the fields of cybernetics and systems theory. He is best known for proposing the Law of Requisite Variety, the principle of self-organization, intelligence amplification, the good regulator theorem, building the automatically stabilizing Homeostat (1948) called by the Time magazine "The Thinking Machine" and his books An Introduction to Cybernetics and Design for a Brain. In 1948 he built the first automatic homeostat. For a complete biography refer to The W. Ross Ashby Digital Archive. [Online]. Available at: http://wwww.rossashby.info/ [Accessed 17 November 2017].

31 Variables can be measured even if they are absent by considering it´s presence in a zero degree of a chosen scale.

32 Italic set by the author.

33 In chapter 5 the concept of systems will be examined in more depth.

3.1. Modern Flexibility

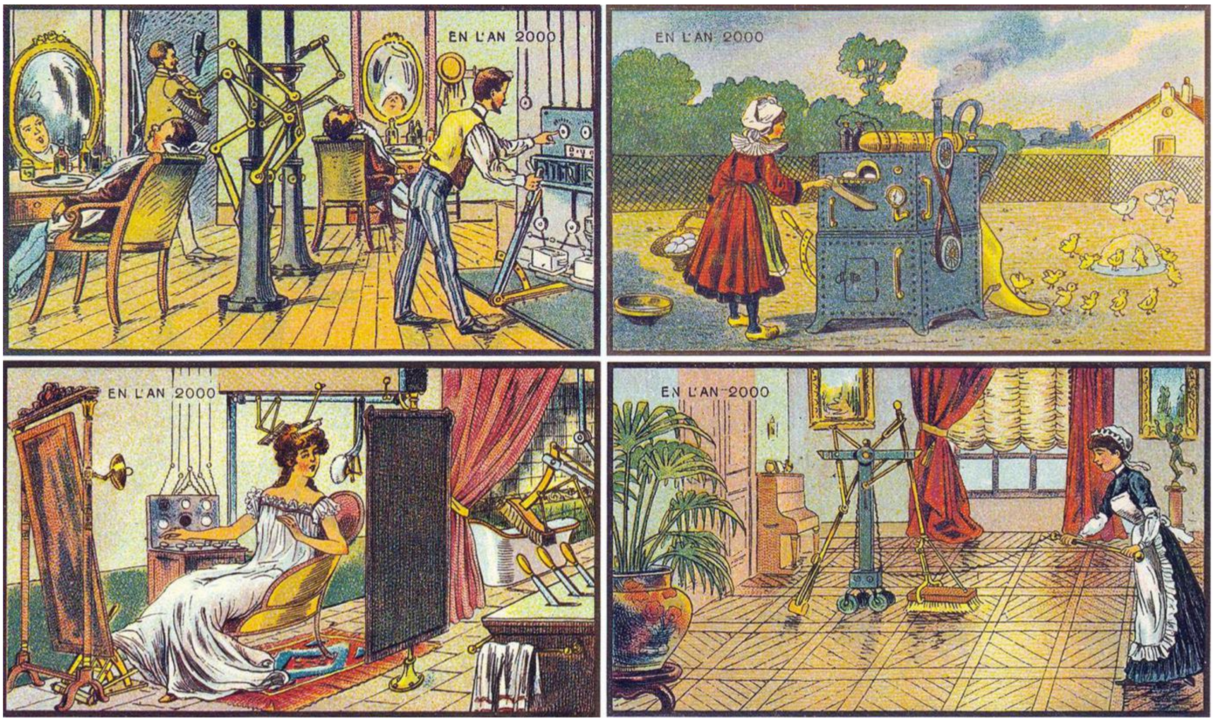

Figure 26 | Four pictures of the series L'an 2000. From left to right, top to bottom: "The new-fangled barber", "Intensive breeding", "Madame at her toilette", and "Electric scrubbing." The pictures were not displayed for the broad public at the time of its making and only gained prominence almost 40 years later, when Isaac Asimov (1986) wrote a book based on them called Futuredays: A Nineteenth Century Vision of the Year 2000. . (Asimov, 1986).

The investigation of dynamic architectural systems that respond to social and environmental changes is a recurrent topic in design. At the beginning of the last century, social movements and artists imagined dynamic buildings and cities, which used the potential of mechanics and automation to rotate, move, expand or fly. In the Italian Futurist movement, Marinetti, Prampolini and Antonio Sant'Elia, clamored for mobile and dynamic cities where buildings resemble giant machines. In Russian Constructivism, artists and avant-garde architects like Melnikov, El Lissitzky, Krutikov, the Vesnin brothers, Gustav Klutsis and Tatlin, among others, drew plans for performing cities, occupied by buildings and structures that rotate, move, and in some extreme cases, float. The several images made by the artist Jean-Marc Côté in 1899 (figure 26), with the theme L'an 2000 (the year 2000), are illustrative of the techno-utopian thinking of that time, where the machine mechanizes several performative processes. Most of the ideas developed by those and other groups at that time dealt with futuristic visions inspired by the constant technological innovations of the machine age - with its idea of movement and automation - and did not reverberate directly into built objects or architectural systems.

From the rare examples built at that time, most were connected to the idea of "flexibility" where architects explored how they could use technology to adapt architecture to new patterns of living and social cultural change. The idea of flexibility became an important modernist term and was implemented to contradict the functionalist notion that all uses could be predicted and quantified. One of the main strategies used to enable the building to adapt to changing conditions was to use dynamic elements such as movable walls, sliding panels, and foldable furniture to allow multiple functions to overlap within a given space. Adrian Forty (2004, p.143) calls this strategie "flexibility by technical means" where space is reconfigured through physical and mechanical elements. Flexibility by technical means is what characterizes projects such as Schröderhuis (1924) by Gerrit Rietveld, and Truus Schröder-Schräder, Maison de Verre (1932) by Pierre Chareau, Bernard Bijvoet, and Louis Dalbet, Maison Loucheur (1928-9) by Le Corbusier, and Kleinwohnung (1931) by Carl Fieger. Although these projects used similar technical strategies to create dynamic elements, they differ on how the user was acknowledged in the architectural system.

3.1.1. The Rietveld Schröder House

The Rietveld Schröder House deserves particular attention in this discussion as it was not designed for an unknown generic user. The design was a result of the conversations[34] between Gerrit Rietveld and Trüus Schröder, who commissioned the work and was credited as co-designer of the house (Overy et al., 1988). In Woman and the Making of the Modern House, Alice Friedman (1998) observes that the house had for them an

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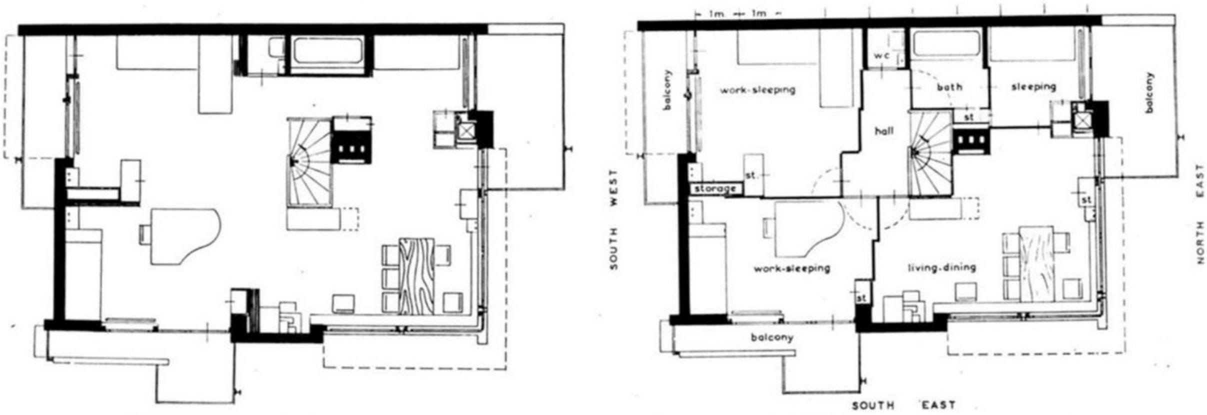
[34] In Schröder description of the design process she stated that: “We didn´t make preliminary plans… Rietveld made a sketch of the plot of land, showing the measurements. The next question was: how do we want to live? Well, I was absolutely set against living downstairs. I've never lived this way, I found the idea very restricting. Rietveld was delighted about this, particularly because of the magnificent view. So we started to map out the upper floor, because you can't do without bedrooms. A room for the two girls and a room for the boy - in fact, that's how we started, with rooms. And where should we put them. All of us together, of course; the children had missed so much.” (apud Friedman, 1988, p.74). In another passage she asks Rietveld: “Can those walls go too? To which he answered, With pleasure, away with those walls!” (apud Friedman, 1998, p.76).

"intense personal meaning" and was used as their laboratory to study the effects of a new way of living. Shröder´s perspectives on a new way of living, together with Rietveld´s expertise and talent[35], resulted in a synthesis of the Stijl movement that reveals personal encounters and conversations in a design process where the distinctions between the role of designer and user are blurred.



53. Schröder House, plan, upper floor, open

52. Schroder House, plan, upper floor, closed

Figure 27 | Architectural plan of the Schröder House showing two different states. The house was designed by Gerrit Rietveld along with Mrs. Schröder in 1924, aiming at a dynamic space that allowed different uses over time. (Overy et al., 1988)

One premise of the design was that there was enough space for the three children to play, study, and be together with the adults[36] during the day, with the possibility of closing the rooms at night. For this to happen, different environments were created that articulated in varying ways employing sliding panels. It was also demanded that all the rooms on the first floor would have a connection with the exterior, besides a heating point and access to water, to guarantee the possibility of independence of the rooms from the house and enable the children to have a more autonomous space when they would grow older. It can be understood that, in this way, the house contains a repertoire of parameters that change according to the resident's interaction at specific moments and over longer time

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[35] "Rietveld´s evolving artistic language found expression in the creation of a total environment, where architecture and furniture shared an emphasis on the isolated and brightly colored elements of constructed form". (Friedman, 1988, p. 80)

[36] "Adults and children were constantly together in the large living/dining room, and the children were encouraged to learn from the frequent discussions among visiting artists and intellectuals. In the end this was one of the most lasting contributions to Shröder´s life and to that of her family" (Friedman, 1998: 77)

spans (either in present time or future uses and family configuration). However, the chosen parameters are not generic and carry a personal meaning for the users. The mutual and dynamic relation between building and observer becomes clear in Rietveld´s own words: “the building is no longer a thing that exists in itself or that stands for something; rather it is in active relationship to human beings and human beings will then have to adopt an active attitude towards it in order to be able to experience its qualities” (Rietveld, 1932, apud Friedman, 1998, p.80). Rietveld puts forwards the idea that dynamic structures requires an active user and points towards the notion that the qualities of space are only experienced through interaction.

3.1.2. Maison de Verre

The Maison de Verre, in different circumstances, reveals another example of close collaboration between designer and client[37]. As observed by Kennedy Frampton (1969), one of the first to recognize the value of the private bourgeois residence, the design was a result of the courage and will of the clients, Annie and Jean Dalsace, to create something new. Pierre Chareau was famous for his modern furniture that incorporated various articulating and mobile elements and made extensive use of those gears and gadgets in the house. The project, fruit of the collaboration between the clients, Pierre Chareau (interior designers), Bernard Bijvoet (architect), and Louis Dalbet (expert craftsman), can be seen as a clear example of flexibility by technical means, by incorporating a complex array dynamic elements, including several sliding and rotating panels, a retractable staircase and elaborate room dividers. Frampton (1969, p.80) states that “the Maison de Verre is the transformable plan par excellence; ‘transformable’ to such a degree that the raison d'etre of its transformation ranges from necessity, to convenience, to subtle poetic variations." However, the use of the many dynamic elements did not seem to be focused on opening the object to indeterminate situations such as in the Rietveld-Schröeder House. Rather, they were used to improve how certain predefined functions ought to be performed by the users. Frampton (1969, p.80) observes that "in contrast

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[37] In a description of the process the client, Jean Dalsace (1954), describes that "the whole house was created under the sign of amity, in perfect affective accord." (Frampton, 1969).

to the Rietveld-Schroeder House (...) the mobile space dividers of the Maison de Verre frequently only modify the basic character of the available space, rather than effect a total transformation". Nevertheless, the house was still the fruit of conversations between designer and user, which had the chance to know each other and engage in dialogue to create the design.

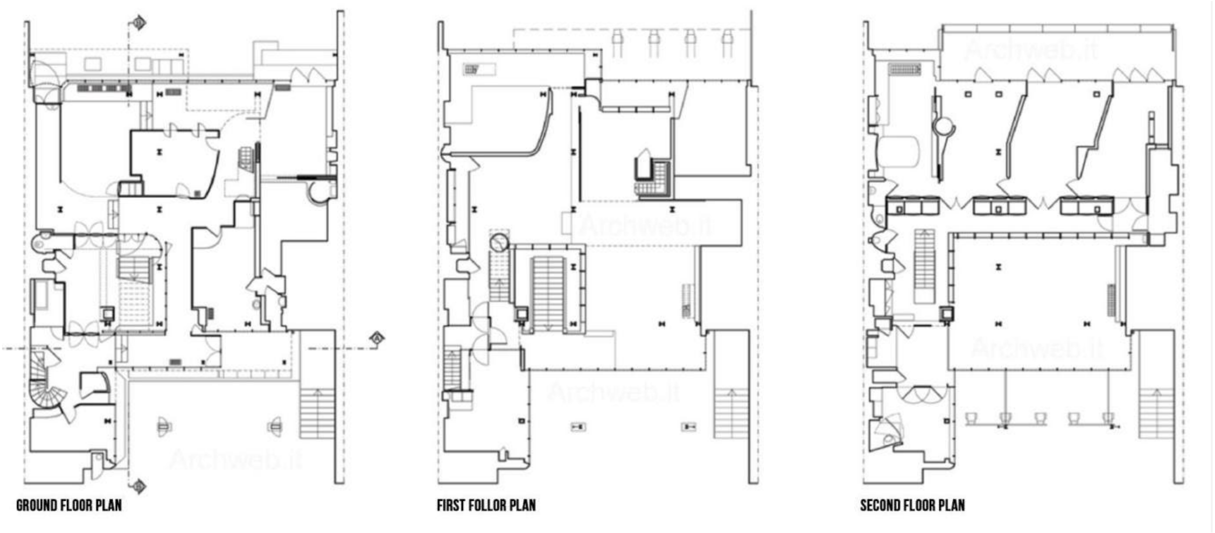

Figure 28 | Floor plans of the MAison de Verre (1931). (Maison de Verre, Paris, France, 1931 – Atlas of Interiors," n.d.)

3.1.3. Maison Loucheur and Kleinwohnung

The Maison Loucheur (1928-9) and Kleinwohnung (1931) represent different contexts because they were designed for generic users with the intent to be mass-produced. Kleinwohnung was a prototype of a minimal apartment of 40m2 developed and built for the Berlin building exhibition in 1931. A central bathroom with doors on both sides articulates the plan by dividing the space into three areas. During the night, folding walls were used to separate those areas to form two bedrooms, and a living room which is connected to the kitchen by sliding screens. During the day, the walls could be opened and the beds folded against the walls to generate a continuous space for the living/dining/studying rooms.

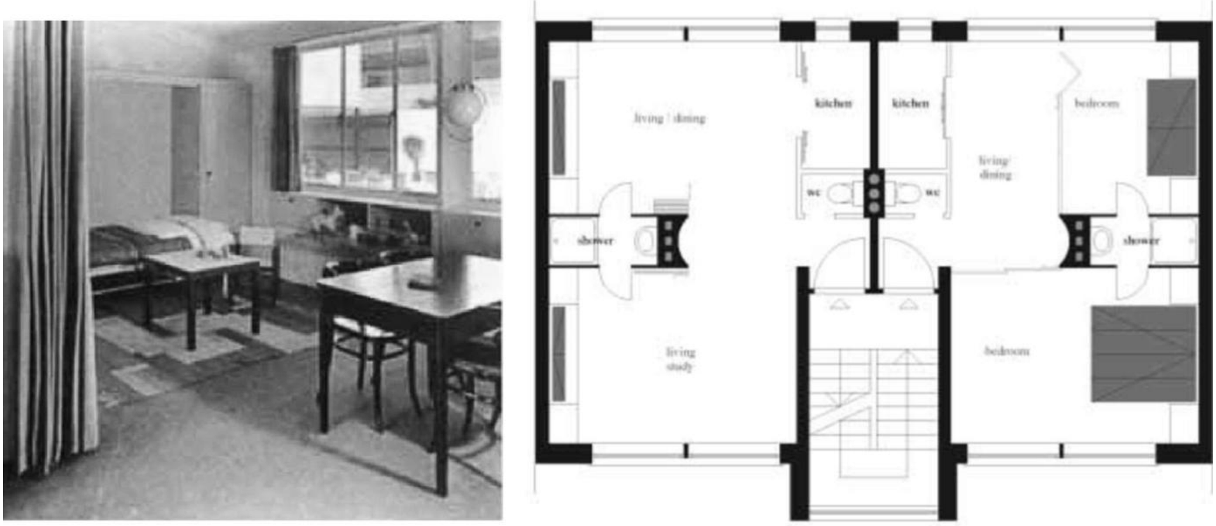

Figure 29 | Kleinwohnung (1931). Night and day configuration. (Till and Schneider, 2016)

Le Corbusier's Maison Loucheur also used sliding screens and folding beds as a strategy to combine multiple functions within a given space. The design was developed in response to the Loi Loucheur, a governmental program created to address the housing shortage. The architect's proposal was to create a "dry-house" that could be prefabricated in a metal workshop and transported to the site with all its elements installed. The design principle departed from a 45 m2 frame that could be used as a single unit or be combined to form, 90m2, 135m2 or 180m2 houses. A stone wall would provide support to the house from one side and could be used as a divider when combining two houses. Le Corbusier's idea was that the stone wall could be fabricated by local craftsman as a form of "opportune diplomacy". (“Fondation Le Corbusier - Projets - Maisons Loucheur,” 1929)

The minimum unit consisted of a two-story dwelling with the living area concentrated on the second floor. This unit was idealized to accommodate a family of six. The different spaces were cleverly organized by a central freestanding bathroom around which all rooms were placed. When the sliding screens and doors were open, a continuous and fluid space was generated. According to Le Corbusier, the design managed to combine the uses equivalent of a 71m2 house in a 45m2 surface.

In both projects, the sliding panels and changing configurations for day and night situations were predetermined by the architects, who envisaged a lifestyle they thought was most appropriate for future users. The number of configurations is restricted to those foreseen by the architect and any deviation from the precise configurations may be seen as a misuse of the proposed design. The overlap of functions within space had strong economic motivations and did not envisage to open space to indeterminacy or to suggest different appropriations. It is important to notice that there is a difference between both designs. Le Corbusier's proposal was not based on a single design but consisted of an architectural system that could generate different configurations with the use of the modular pre-fabricated frames. However, the idea was not to enable the user to intervene in the process and customize the house, but to create a modular design principle for mass-fabrication.

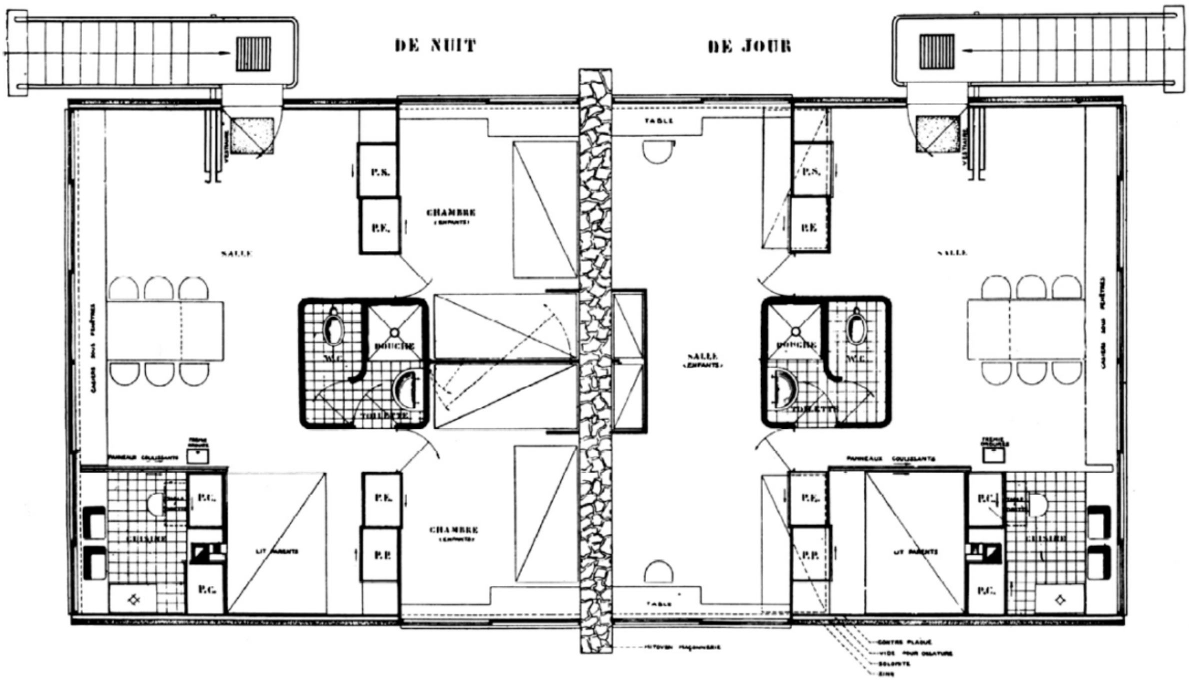

Figure 30 | Maison Loucheur. Day and Night configurations. (Till and Schneider, 2016)

3.1.4. Flexibility by spatial redundancy

Another form of flexibility identified by Forty (2004) was flexibility by spatial redundancy. The concept is related to spaces that are so large that they can accommodate different uses. This idea of flexibility was put forward by Rem Koolhaas in his 1979 proposal for the Arnhem Koepel Prison. The building, designed by Johan Metzelaarthat and built between 1882 - 1883, is organized around a central court covered by a large dome configuring a panopticon. According to Koolhaas (1995, p.240), "flexibility is not the exhaustive anticipation of all possible changes. Most changes are unpredictable ... Flexibility is the creation of a margin – excess capacity that enables different and even opposite interpretations and uses". In this form of flexibility, a generic space[38] is created for a generic user.

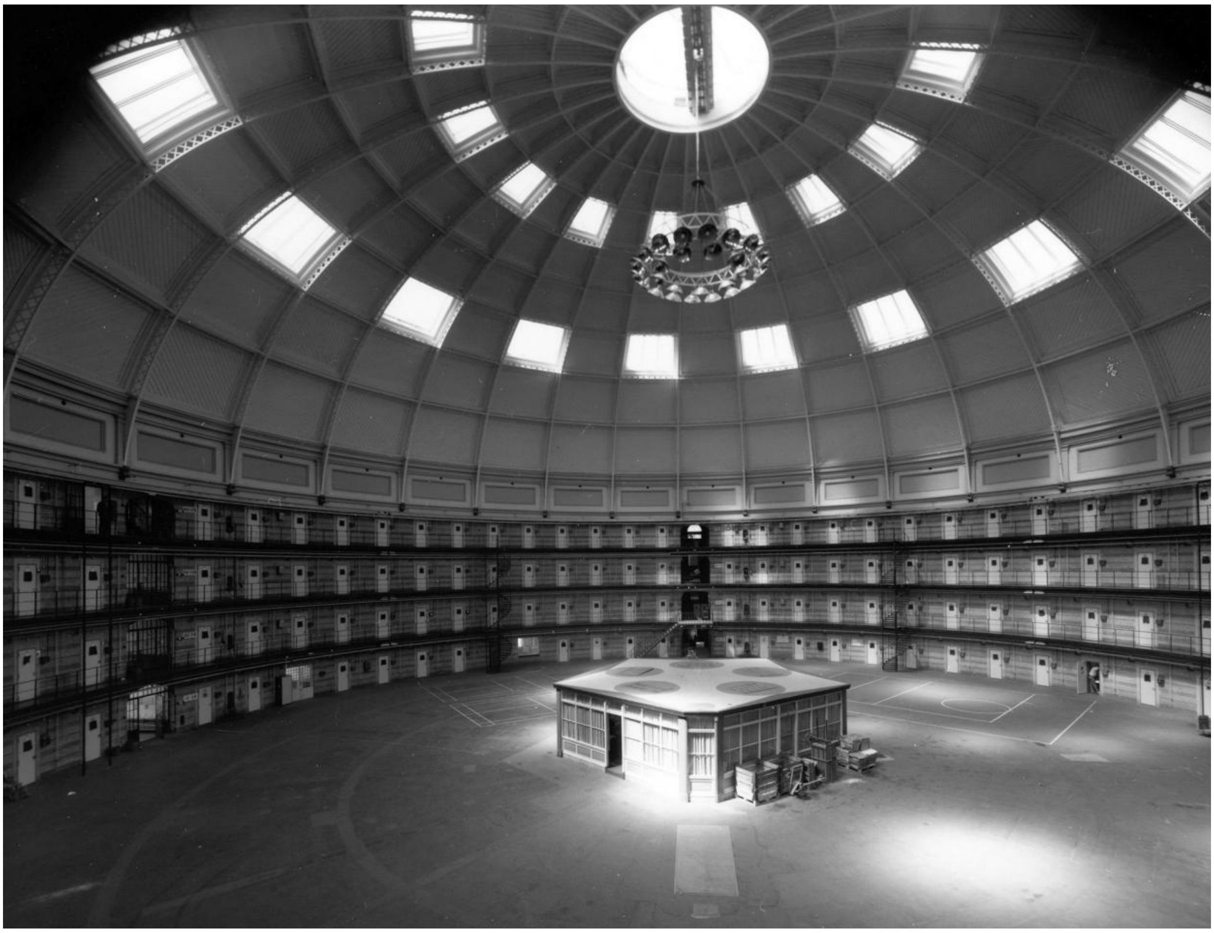

Figure 31 | Interior of the Koepelgevangenis (Koepel Prison) in Arnhem. (Omroep Gelderland, 2017).

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[38] Here the term generic is not related to form, that can be unique, but to how it suggests different forms of appropriation.

3.1.5. Polyvalence

A different approach towards indeterminacy was to make buildings "incomplete and unfinished in certain respects" to be completed by future users (Forty, 2004, p. 142). An early example of such approach is the Hans Hertlein Siemens Factory (1927) in Berlin where all functional spaces were exteriorized to leave a free and continuous open zone. Herman Hertzberger (2005, 2014, 2016) questioned this modern approach towards flexibility and argued for a different strategy to deal with the unexpected and undetermined. For him, flexibility is not about making space to suit multiple functions, nor it is making it as neutral and generic as possible[39]. A multifunctional space is not particularly good at any function, and generic spaces do not invite people to identify themselves.

Figure 32 | Square Hollow at the Montessori School, Delft, 1966. © Architecture Studio. (Hertzberger, 2016).

Herzberger advocates a different strategy called polyvalence, where "design can incite images that lead to personal choices and, consequently, freedom" (Hertzberger, 2016, p.18). A form or space is polyvalent "when it is equipped with what we can call concealed availability, to be discovered by users when they appropriate it. A polyvalent form can be added to, and therefore given another content, without undergoing essential change, the difference in interpretation illustrating its suitability for multiple ends". (Hertzberger, 2014, p.12). In his discourse, freedom is not a question of being able to choose between various options or not having to face with any option at all but to use the space that is given by established parameters to the maximum.

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[39] It is worth noting that Hertzberger did not regard the Rietveld-Schöder House and The Maison de Verre as examples of modern flexibility. (Herzberger, 2005: 219-220, 238–240)

3.1.6. From passive to creative user

All discussed strategies represented a shift of the functionalist paradigm with its notion that spaces - and in consequence people - could be conceived to function in a certain predetermined way. As put forward by Jonathan Hill (2003), the idea that use can be predicted led architects to promote models of experience that suggest what he calls a passive user. "The passive user is consistent, predictable and transforms neither use, space nor meaning, whether performing useful tasks according to functionalist principles, following a sequence of spaces directed by the architect, or contemplating a building as an artwork." (Hill, 2003: 86). However, as pointed by Hertzberger (2014, p.213):

> “buildings unlike artworks are used, abused and, if not spoilt, at all events lived-off, lived-on and lived-out - unlike the everlasting pristine state the architect conceitedly had in mind. And, instead of disappointedly accepting that ‘deterioration’ of our design concept begins when the building is taken into use, we could and should see user input as the completion of our design.”

The idea of opening space for user input expresses the possibility of designing spaces that are only completed by use. This can be related to the models of “reactive user” and “creative user” proposed by Hill (2003). “The reactive user modifies the physical characteristics of a space as needs change, but must choose from a narrow and predictable range of configurations largely defined by the architect.” (Hill, 2003, p.86). The model of a creative user, in its turn, is developed within the understanding that people's creative potential should be acknowledged by the designer. According to Hill (2003, p.86), while the passive and reactive users are dependent upon existing conditions, which they are unable to fundamentally transform, the creative user “either creates a new space or gives an existing one meanings and uses contrary to established behaviour.” Hill´s models are compelling for the analysis of how spaces are related to the model of user constructed by the designers. However, it fails to properly address situations where the notion of user is blurred, such as in Rietveld´s and Truus Schröder´s house, where users become designers.

Although the acknowledgement of the involvement of the user in the architectural system represented, at that time, an enormous potential for the creation of more dynamic architectural systems, most initiatives that explored dynamic systems where not envisioned to foster dialogue between user and space, but were mainly implemented as representations of modernity, progress, and the use of technology in design. As Jeremy Till and Tatjana Schneider (2005, p.159) point out, flexibility was taken for its "rhetorical value as a signal of progressive modernity." According to Forty (2000, p.142):

> “the purpose of flexibility within modernist architectural discourse was a way of dealing with the contradiction that arose between the expectation[40], (...), that the architect’s ultimate concern in designing buildings was their human use and occupation, and the reality that the architect’s involvement in a building ceased at the very moment that occupation began. The incorporation of “flexibility” into the design allowed architects the illusion of projecting their control over the building into the future, beyond the period of their actual responsibility for it”.

The attempt to exercise "control" over "flexibility" led architects to seek to predict the different possible scenarios and determine spatial configurations that could respond to these scenarios. They acknowledged the user as a key node in the architectural system but did not surrender control of the design process. In that sense, although flexibility open spaces for different configurations, most possibilities were already predetermined by the architects. The idea of dealing with indeterminacy with traditional deterministic means and methods proved to be unsuccessful, and cybernetics - as we shall later see - can point to more interesting strategies.

3.2. The post-war technological optimism and user-driven environments

After the Second World War the search for more dynamic architectural systems gained a new push inspired by the scientific and technological optimism and the desire to review and criticise the functionalist approach to dynamic systems. Cedric Price, Nicholas Negroponte, Christopher Alexander, Yona Friedman, Constant Nieuwenhuis, the members of the Archigram group and Nicolaas John Habraken are examples of

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[40] According to Walter Gropius (1954, p.178) "(1) architects should conceive buildings not as monuments but as receptacles for the flow of life which they have to serve, and (2) that his conception should be flexible enough to create a background fit to absorb the dynamic features of our modern life". (Forty, 2004).

an avant garde that envisioned open-ended user-driven environments. They resorted to different epistemologies, theories and methods such as cybernetics, system thinking, structuralism, phenomenology, artificial intelligence, and computer science to investigate how architecture could respond to internal and external forces of social and environmental changes.

One of the main problems addressed by those architects at that time was that the majority of what was being built did not enable a direct interaction between user and designer. The possibility to hire an architect was restricted to a small part of the population that had the necessary financial means. Mass-housing solutions were predominant, and many authors criticised the lack of regard to the end user (Negroponte, 1970, Friedman, 1971, Landau, 1971, Habraken, 1972). In the design of standard houses or apartment buildings, it is hardly possible to know the people for whom it is being designed and built. The dweller is transformed to a statistic, and his participation is deemed to be undesirable (Habraken, 1972). Furthermore, even if it would have been possible to get to know each future user many problems remain as people's behavior and needs change over time. As observed by Royston Landau (1971, p.567), “the acceptance of a behaviour concept which has a potential for continuous change raises the problem of how to devise a house (or a building) to accommodate future changing needs, making the assumption that the programme for the study of existing particular, house-related human behaviour is inadequate". Moreover, as new constructions are expected to outlast its initial occupants who are replaced by new unknown ones, it becomes even harder and ineffective to predetermine solutions to deal with time and change. (Landau, 1971)

3.2.1. Megastructures

A strategy to respond to change and indeterminacy without predetermining solutions was to handle control back to the user. Projects such as New Babylon from Constant

Nieuwenhuys (1959), Ville Spatiale[41] from Yona Friedman (1958) and Plug-in-City (1964) of the Archigram group imagined entire cities based upon spatial structures that created spaces open to uncertainty and enabled their dwellers to constantly change and adapt the environment to their ever-changing needs. Those megastructures - as they would later be known - would serve as permanent and determined frames - each with their own particularities - that provided support for a series of indeterminate modules, pods and events. Forty (2004) also classifies such proposals as a form of flexibility by technical means, where flexibility is perceived as a property of the building. However, their emphasis on the social performance as the motor of change creates a different condition where the focus is shifted from object to the interrelations between users and objects. Picon (2010 observes that "those projects gave precedence to circulations over elementary spatial components in a way reminiscent of the cybernetic approach of complexity in terms of connections between relatively simple elements". Although the concepts of megastructures were eventually criticised by being “a mere illusion of choice disguised behind controlled variations” (Bhatia, 2013), they represented an important critique against traditional architectural practices.

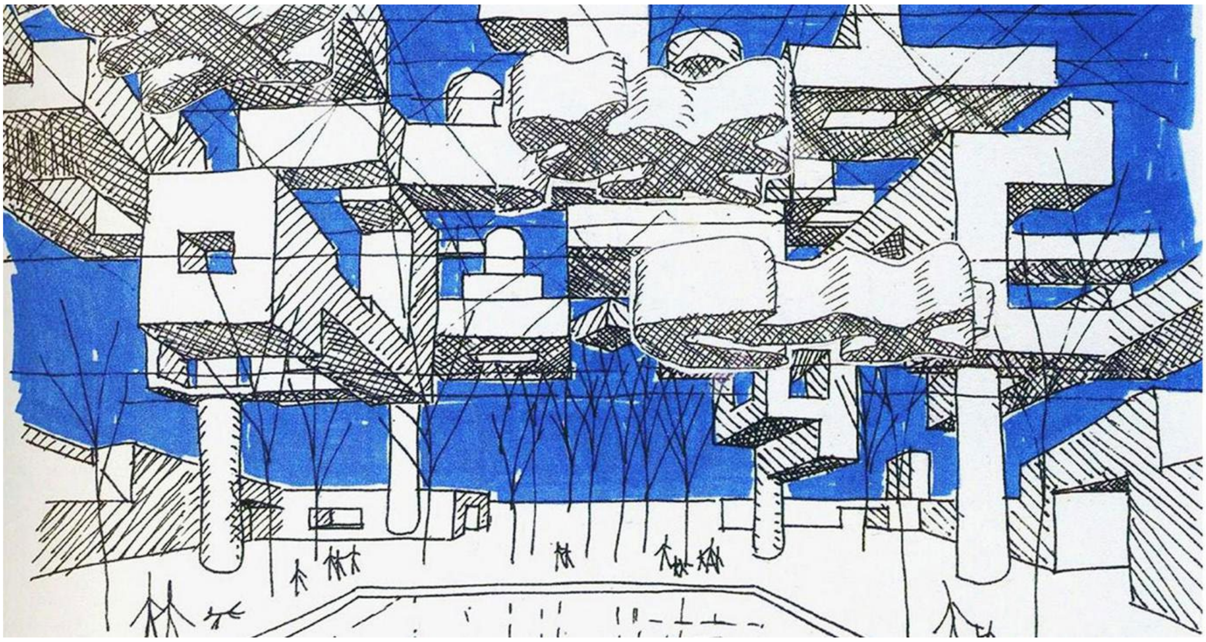

Figure 33 | A Sketch by Yona Friedman of Ville Spatiale. (Friedman, 2007).

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[41] The concept of the Ville Spatiale (1958) was to provide a framework in which the inhabitants could freely construct their homes according to their needs. Freedman believed that automation would liberate man from work and increase the amount of leisure time. He believed that this new society would need a more dynamic city with mobile, temporary and lightweight structures.

3.2.2. Open Building

The idea of a structure that serves as a support for social interactions was also the premise behind the Open Building process originated in Habraken´s (1972) thoughts. Habraken proposed a process based on the concepts of support (drager) and infill. The support system is socially created as a three-dimensional urban planning, whereas the infill can be individually developed. An important aspect of Habraken´s work is the shift from object to process, as for him the most important question was how the different stakeholders could actively contribute to the design process. For Habraken (1972) the task of the specialist is to enable the ordinary person to take control of the creation of his surroundings. Departing from Habraken`s work, the key point in the Open Building approach lies precisely in acknowledging the responsibility to the user, who participates together with other stakeholders (social groups, governments and companies) in the design process according to some methods. The idea of participation was not to involve the user in the architect's design process, but on the contrary, to involve the architect in the age-old process of human settlement that has functioned for most of its time without design professionals (Habraken, 1986).

Open building methods recognize that the built environment is in constant transformation and that control over change is distributed among various stakeholders. It, therefore, proposes a separation of the buildings “long-lasting parts from those that change more frequently, and distinguishing shared (higher-level) and individual (lower-level) agency.” (Kendall, 2017, p.61). Yositika Utida´s Next21[42] mixed-use project built in 1993 in Osaka, Japan, is frequently cited as an example of such separation. The project is an ongoing experimental housing and retail unit that deals with renewable energy sources, adaptable facede components, and the introduction of several gardens in high-rise buildings. The main building elements were divided into “long-life elements with high-degree of communal utility”, and “short-life elements in private areas.”[43] The separation between support and infill in the project would, in theory, allow users control over their own space.

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[42] Kendall, S., n.d. NEXT21, Osaka, Japan [online]. URL http://www.open-building.org/ob/next21.html (accessed 9.22.17).

[43] Idem.

However, the units were not designed by the users, 13 architects were invited to make the project for the infill and determine the interior of each dwelling. Because most people do not possess the necessary means to hire a specialist to design the infill this may represent a problem if the process is to be generalized. The proposed system fails to properly addresse Habraken's call to handle control back to the user.

This critique may be generalized, to a greater or lesser extent, to the several examples cited by Kendall (2017) article Four Decades of Open Building Implementation: Realising Individual Agency in Architectural Infrastructures Designed to Last. The projects show that the concepts developed by Habraken to handle control back to the user and deal with change and indeterminacy have frequently been used as commercial assets associated with the idea of personalization and mass customization. Nonetheless, the concept of support and infill proposed by Habraken is still a powerful idea that involves the user, structures and social systems in a dynamic architectural system. In this context, digital interfaces for participative design based on parametric design and digital fabrication can play a significant role to enable non-specialists to create their own design.

3.2.3. Fun Palace

Another important project that addressed indeterminacy and change was the Fun Palace (1963-67) designed by Cedric Price. The project was put forward by Joan Littlewood[44], who wanted a space where the audience would become actors. This idea was further developed by Cedric Price with the collaboration of Gordon Pask into a cybernetic learning environment. For Price, social interactions were more important than the formal aspect of the building. He argued that architects should not only be concerned with buildings, but more importantly with the "social beneficial distortion of the environment" (Price, 2003). Price (2003) questioned the idea of planning and restrictive control and advocated that agency over architecture and program should be handed back to the user.

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[44] Joan Littlewood (1914-2002) became well-known for her work in The Theatre of Action and The Theatre Workshop. Both had an experimental line of work that encouraged improvisation and invited the audience to participate. For more infomation on Littlewood's contribution to British radical theater, see Howard Goorney, The Theatre Workshop Story (London: Kyre Methuen, 1981)

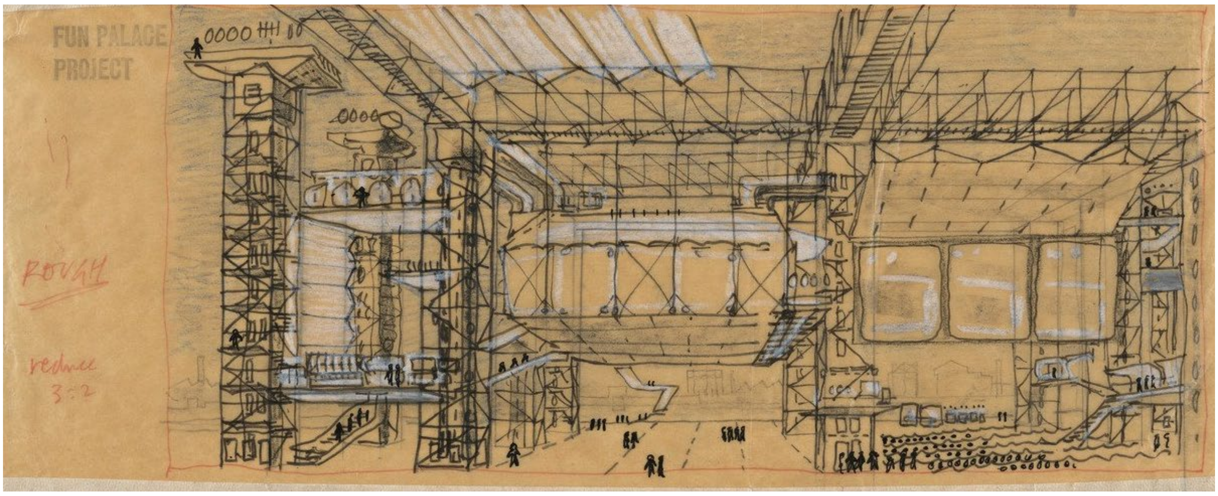

Figure 34 | Sketch of The Fun Palace Project by Cedric Price. (Moma, 2016).

In the project, the automation of mechanical systems, such as movable cranes, would allow the reorganization of a set of modular structures, platforms and ramps enabling the participant to intervene actively in or enjoy passively different spatial configurations created by means of an active dialogue between users and space. For Mathews (2005), the Fun Palace was, more than a conventional building, a "socially interactive machine, highly adaptable to the shifting cultural and social conditions of its time and place". However, as observed by Sweeting (2016a), it is important to notice that the project was not focused on flexibility itself but what was done with it. Flexible and movable means were used to enable interaction and dialogue as a strategy to deal with indeterminacy and the generation of novelty. Therefore, it is helpful to see the design as a cybernetic project in itself, rather than as an architectural project to which cybernetics was applied (Sweeting, 2016a). Following this reasoning, it seems that the central question addressed by the Fun Palace project was not to adapt space to new conditions by technical means, but, on the contrary, to generate new conditions through interaction and conversation.

To help with the development of the project, Pask formed the The Fun Palace Cybernetics Committee in 1963 and invited renowned cyberneticians such as Roy Ascott, Stafford

Beer and others[45] to cooperate. Fundamental cybernetic concepts, such as circularity[46], self-regulation[47] and control were explored to develop the project in different ways. Gordon Pask (1964) wrote a detailed proposal for the system where sensors and cameras would give people feedback of their own actions providing the means for them to learn and for the system to interact with changing conditions. In Cybernetic Theory and the Architecture of Performance: Cedric Price's Fun Palace, Mary Louise Lobsinger (2001) argued that with the inputs from Pask the initial ambitions for the project shifted focus from an "alternative theater venue to a cybernetic learning machine". Sweeting (2016a) questions the contrast between theatrical performance and cybernetic project put forward by Lobsinger. It was in fact, the performative capacity of the system what enabled people to interact and generate novelty. According to Sweeting (2016a), Pask created the degree of novelty parameter, where the goal was not to create something that could be changed, but to offer certain choices to prompt people to explore different things and create new experiences. The Fun Palace represents an early investigation of dynamic systems in architecture and is one of the first cybernetic projects that puts people and environment in a mutual control relationship where both system - human and structure - can change its states.

3.2.4. Generator

The concept of an interactive environment open to indeterminacy was further developed in the Generator (1976-79) project, a retreat and activity center for 1 to 100 visitors at the White Oak Plantation in Florida (USA). The key elements of the Generator system were: (1) a kit of parts consisting of combinable cubes, catwalks, screens and boardwalks that enabled different spatial configurations; (2) a mobile crane to move the different parts

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[45] The Cybernetics Committee consisted of R. Ascott, Ipswich School of Art; C. Beatty, Research Institute; S. Beer, Sigma; A. Briggs, Sussex University; R. Chesterman, Goldsmith's College; R. Goodman, Bristol University; R. Gregory, Cambridge University; M. Young, Institute of Community Studies. See Littlewood, 706-07.

[46] Closed-circuit TVs and surveillance systems by which participants could watch themselves participate, teaching machines and responsive systems are some examples.

[47] People would learn cooperative behaviour by using calculating apparatus (Lobsinger, 2001).

around the site; (3) a game for the potential users to generate different arrangements, or menus as Price called them. Two people would be involved in the spatial dynamics: the "Polarizer" and the "Factor". The first would encourage people to use the Generator in novel ways and the second would be responsible with the logistics operating the mobile crane; and (4) a computer system that could map the current state and "know" where all the parts were and propose new configurations as it became "bored" (the systems would get "bored" if people did not change the position of the kit of parts often). The computer system - a machine readable model - was developed with the help of artificial intelligence pioneers John and Julia Frazer after they were invited to work on the project as consultants. In a letter to Cedric Price they wrote: "If you kick a system, the very least that you would expect it to do is kick you back" underling the active role of the system. Electronics were embedded in every component of the project and connections were made with the foundation pads (Frazer, 1995). Generator was praised to be the first to use Artificial Intelligence (AI)[48] in architecture and served as important reference for the understanding of the potential of computing in design. As advocated by Molly Wright Steenson[49] (2014), Generator represents the nexus of architecture and the nascent ubiquitou or pervasive computing that would flourish in the following decades.

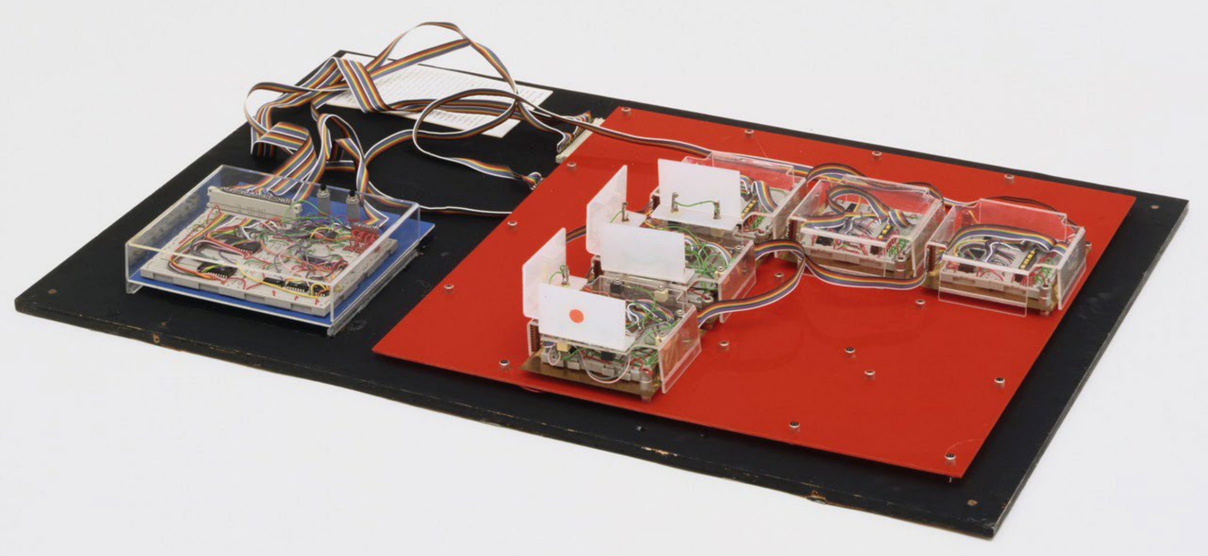

Figure 35 | Computer interface developed by John and Julia Frazer for the Generator Project (Fazer, 1995).

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[48] Verificar a reportagem

[49] Molly Wright Steenson made an extensive research about Generator. For more information about the project or other of Cedric Prices works refer to her dissertation: "Architectures of Information: Christopher Alexander, Cedric Price, Nicholas Negroponte & MIT's Architecture Machine Group.

Projects such as the Fun Palace and Generator by Cedric Price envisioned architectural systems that went beyond the physical and technological aspects and acknowledged the user as a fundamental and active part of the system. In that sense flexibility is not only achieved by technical means but more importantly through interaction. As advocated by Steenson (2014), technology was not the focus of those projects, but was useful for the ways it could "unleash unexpected interactions". From this perspective, Fortis concept of "flexibility by technical means" may be short coming as to properly characterise structures and projects were the dynamic qualities emerge not by cause of their technical and technological properties, but because of the different interactions it enables.

Most of those projects were not built, and because of that they remained immune to different architectural and social contingencies[50]. Nevertheless they serve as archetypes for future development of dynamic architectural systems by providing designers with an alternative perspective of the architectural practice that acknowledges the user-involvement.

3.2.5. Self-builder

After the Generator project, John and Julia Frazer (1995) worked on another machine-readable model (figure 05) conceived as a design interface for Walter Segal's method. The model was an electronic version of Walter Segal's panel model that allowed different panels, door and window combination. Segal's main achievement was to create a set of simple design and construction principles that enabled self-builders to easily design, build, and reconfigure their house (McKean, 1988). In the same way as Price, Segal's focus was not on the final product of architecture, but on social interactions. However, instead of creating a complex structure able to adapt to changing needs, he focused on simplifying the whole design and construction process to enable lay people to design, build and modify their homes. For Segal, architects should be trained to be enablers in

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[50] One exception is the Inter-Action Center in Kentish Town (1973). In the project Cedric Price implemented several concepts developed in the Fun Palace project. The project shows that the ideas for dynamic environments can have unexpected outcomes when realized. Mary Louise Lobsinger (2007) points out that there were numerous complaints and legal threats by the clients who contested the buildings off-the-shelf components.

order to help people who want to build with their own hands (Mackean, 1988). Segal's process handles the user control for both space and the design process, erasing the distinction between designer and user.

To improve the visualization of the design process, John and Julia Frazer (1995) created a board where the panels could be plugged. After a controlling processor scanned the board, plans and three-dimensional views could be displayed by the computer. From that hybrid model a set of data could be extracted, such as area, cost, and drawings of structural frames. According to Frazer (1995), the model incorporated Segal's design rules and much of his expertise, enabling people without any knowledge of architecture or computers to design a house by building a simple model. By cause of Segal's death, the work on the system was interrupted.

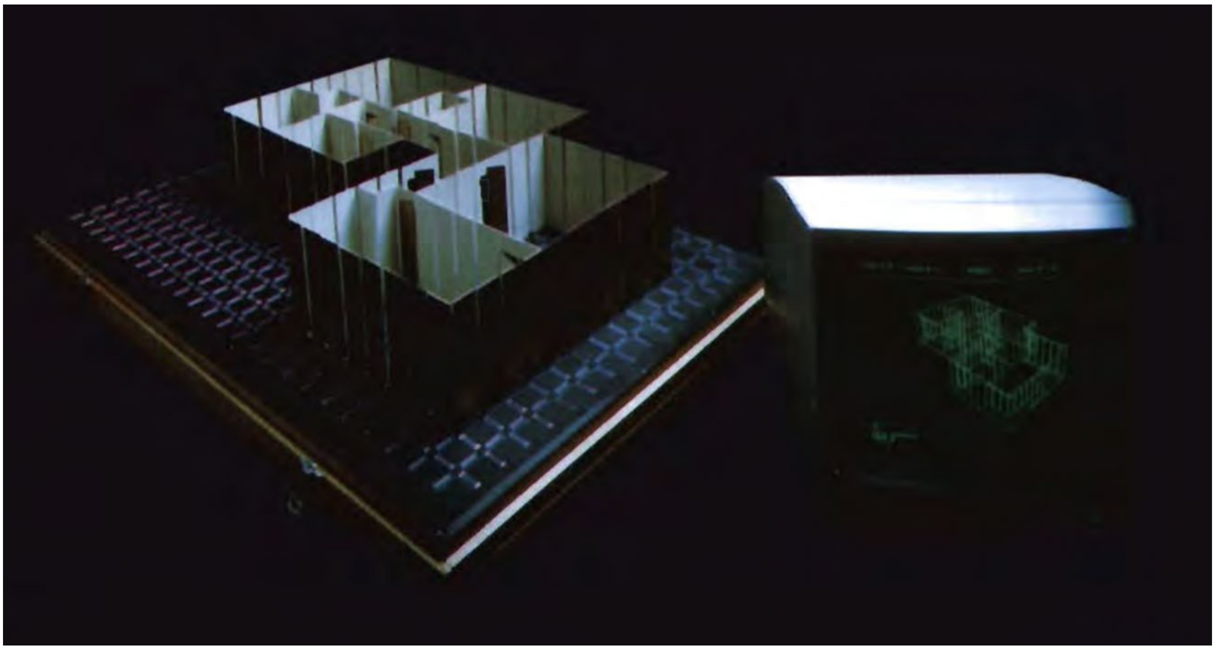

Figure 36 | Self-builder design kit, working electronic system. John and Julia Frazer with John Potter (Frazer, 1995).

Both machine-readable models developed by John and Julia Frazer where proposed as hybrid-interfaces that combined digital and physical features. In the Generator project, the whole building would serve as a design interface enabling a continuous re-design of the layout of the building components. In this new condition, the notion of a user is blurred when he engages in interaction with the system. As observed by Hill (2003, p.34):

> Generator "questions the assumption that it is possible to create a building that meets the needs of its users and suggests, instead, that an animate, unpredictable, ever-changing building may be a more stimulating companion. It suggests that the user may be a passive spectator observing the 'game', an involved but reactive participant, or one of three principal creative agents in a feisty dialogue, the others being the architect and the building." pg 34

Both the Generator project and the Fun Palace invited the user to a conversational process that involves feedback, learning, and the creation of novelty. From that perspective, the projects can be seen as cybernetic designs, where the generation of novelty is not the result of innovative technologies, advanced computer interface, or to the use of dynamic movable systems. Novelty is generated through an interactive[51] process between all spacial actors - man and machines alike. From that perspective, those cybernetic projects can be differentiated from infrastructural approaches such as the megastructures and the concept of open-building that envisages a different relation between support and infill. Open building suggests a hierarchical control structure where the support determines the infill. In the cybernetic approach, support determines the infill, that in its turn determine the support. There is an idea of mutual control - architectural mutuality - where one determines the other.

In Segal's electronic model, the proposed interface could be used to render the traditional involvement of the architect superfluous. It created a direct correspondence between the physical structures and its physical and digital representation which is augmented with relevant data (building cost). This approach point towards the use of digital process in architecture in a way that it integrates digital and physical interfaces in a continuous design process.

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[51] This interactive process can be framed within the concept of conversation as developed by Gordon Pask in his Conversation Theory.

3.3. Architectural Machines

Following a different approach towards technology, architects, and researchers at the Massachusetts Institute of Technology (MIT) explored the potential of digital processes by engaging in open ended experimentations with technological development. Nicholas Negroponte's (1970, 1975) Architecture Machine Group (Arch Mac) became the symbol of this endeavor by creating interchanges between architecture, engineering, and computing to experiment with computation in design process, embedded in the environment, and with the computer as environment. Those experiments had two main focus that frequently overlapped: (1) the design process with investigations of interfaces between man and computers and between computers and the physical world, and (2) the embedment of technological devices in the environment to generate responsive systems with use of AI.

One of the main focus of Arch Mac was to develop a computer-aided architectural design that used the power of computation to empower the user to design his own environment. This would be initially achieved with the help of a machine - a personal architect - that could be installed at each home developed with a “physically adaptive, resilient system of industrialized housing’ (Negroponte and Groisser, 1970, p. 468). Negroponte (1970) advocated for an architectural machine that participates in the design process by emulating intelligent behavior to recognize and understand a specific context to carry out design operations. What characterizes an intelligent behavior, according to Negroponte (1970), is the capacity to give meaning to specific information. It is, as he puts it, the ability of the machine to appreciate a joke, which demands a deep understanding of context and adaptability to new situations. The power to create meaning would enable the machine to deal with large-scale complex situations without ignoring the small-scale problems (looking at the beach without overlooking the specificities of each pebble). Negroponte (1970) argues that the architects lack this capacity and cannot handle large-scale problems because of its complexities, and ignore small-scale problems by cause of its specificities.

For Negroponte (1970), in designing alongside machines with a focus on the particular, without overlooking the general, two directions are possible. The first is DIY, where the dweller becomes designers. "Machines located in homes could permit each resident to project and overlay his architectural needs upon the changing frameworks of the city" (Negroponte, 1970, p. 5). In the second, an architect-machine partnership is established where the architect conciliates physical form and human needs and the machine "exhibit alternatives, discern intercompatibilities, make suggestions, and oversee the urban rights of individuals" (Negroponte, 1970, p. 5). This form of partnership would be developed through conversations between human and machine in a similar way humans converse with each other. However, because machines could not deal with context recognition or missing information, it could not adapt to changing conditions to establish a symbiotic relation with designers and non-professional users. Therefore, the focus of some of the early experiments of the Arch Mac were on the development of a set of sensors and actuators to enable the machine to take information directly from the environment.

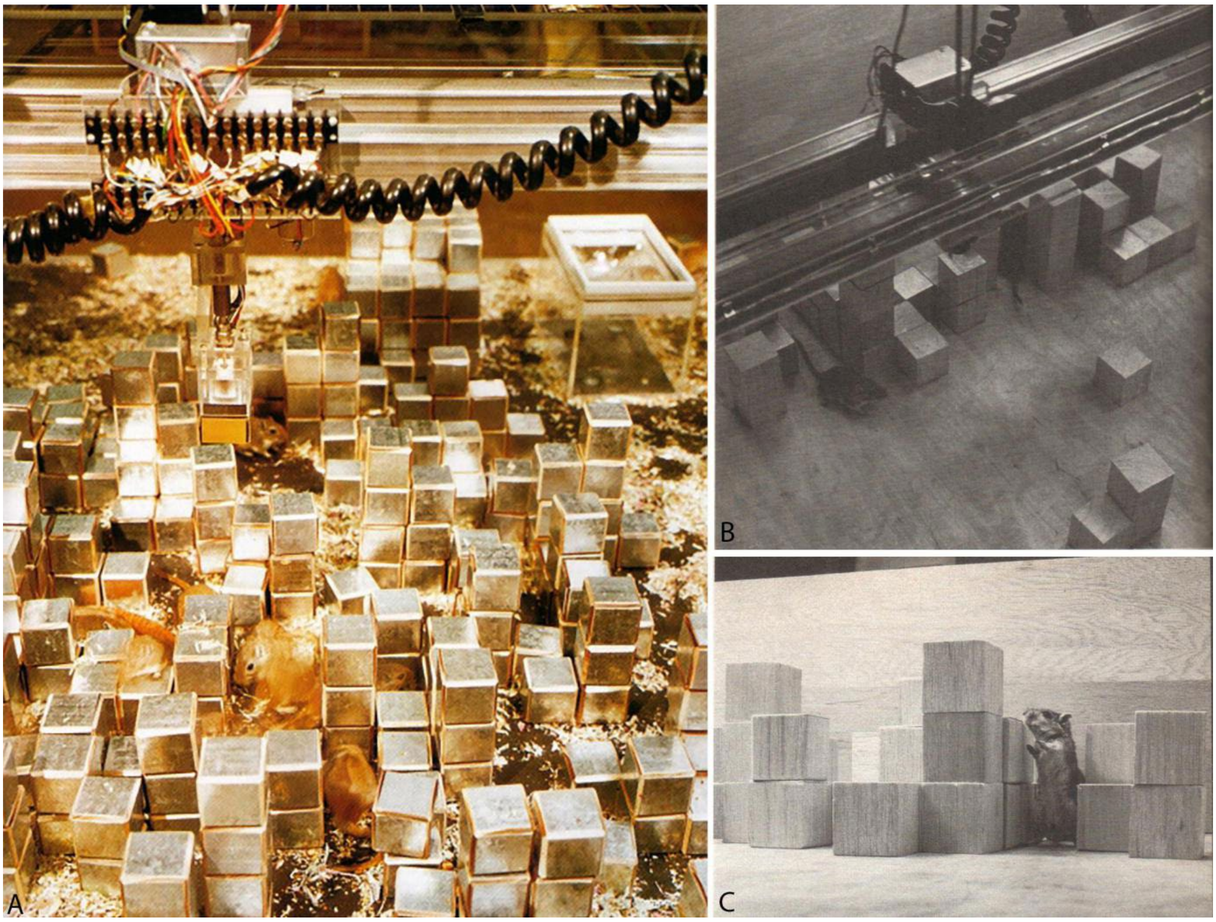

Figure 37 | SEEK (1970), by Nicholas Negroponte with the Architecture Machine Group. (Negroponte, 1970).

An example of such research was SEEK (1970), where a small group of Mongolian desert gerbils were placed in a box full of plexiglass blocks that were constantly rearranged. SEEK was developed to understand how machines can handle changes in context. Its inputs were provided by an array of seven pressure sensors and the outputs implemented by a small gantry system that could transport and rearrange the blocks. The blocks created the environment for the colony of gerbits that brought noise into the system by disrupting its organization in different and unexpected ways. The readings of the inputs were compared with what Negroponte and Groisser (1970) called the "computed remembrances residing in the core memory". What followed was that SEEK tried to correct the alterations by putting the blocks back to their original place or by realigning the block to the grid in its new position. The responsive behaviour displayed by the created open-system could lead to unforeseen situations that were not programmed in the system.

Another objective of the group was to create technologies to enable machines to communicate using the designers own "idiom". Negroponte (1970) advocated that this process would allow non-specialists users to access computer-aided design hardware. Furthermore, "talking" with the machine would enable the designer to better formulate and reevaluate his own ideas within a self-reflective dialogue. During the different interactions, the machine would also learn about the user and adapt to his idiosyncrasies, leading to a personalized symbiotic relation. Within this perspective, Negroponte brings the user to the design process by associating a computational interfaces that emulates intelligent behaviour, with an adaptive industrialized design principle. In this association, he creates a dynamic architectural system that responds to users needs on an individual and collective scale. However, the idea of a machine partner with AI that empowers the user to design his own environment proved not to be feasible due to technological development at the time. Moreover, the focus on the creation of the design interface, brought the user to the background. As observed by Vardouli (2011), the attempt to create a machine that can see, sense, and think brings up the question of who is being empowered, the user or the machine. Following the many problems encountered in the Urban 5[52] experiment in developing a system that displays "intelligent behaviour", Negroponte moved away from the idea of "emulating" an architect through AI and instead argued for removing the architect from the design process.

3.3.1. Soft Architecture Machine

In Soft Architecture Machine, Negroponte (1975) signaled a change of strategy towards computer-aided participatory design from a paternalistic to a non-paternalistic approach. According to Friedman (1975), the partners in computer-aided participatory design are the human and the object to be designed. In this system the computer acts as a translator - an interface - between the two. In the paternalistic organization it is the translator (can also represent an architect, or expert) which establishes preferences, judgments, and after a period of learning about the particularities of the user makes choices for him in his presumably best interests. Although it makes decisions, the risk of potential errors is left to the user - it evokes control, but avoids responsibility. In a non-paternalistic approach, the translator informs the decisions of the user issuing warnings about the consequence and reaction of each decision upon the "real world" - it gives feedback of individual decisions on the whole. As observed by Friedman (1975, p 96) "in the paternalist scheme the computer is associated with the future user, whereas in the non-paternalist one it is a part of the real world." For Friedman (1975), a non-paternalist scheme would be more implementable because learning about structural characteristics of the real world is more feasible than learning about the personality of the future user.

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[52] Urban 5 was a design experiment developed in Arch Mac aimed at the development of a computer system that could monitor design procedures in the context of an environmental design project. The main goal was to create a machine that could conversate with the architect. To this end, the system incorporated features such as the consistency mechanism that signals the user that there is an incompatibility between the designer's activity and the programmed requisites, either allowing the action or refusing to it. Because the requisites are given by the designer, what the machine does is to check if the designer has acted according to what he has proposed. "When Urban 5 finds an inconsistency between what has been said (linguistically) and what has been done (graphically), it states that a conflict has occurred." (Negroponte, 1970, p.87). Although the objective was to develop a machine that displays intelligent behaviour, Negroponte (1970) acknowledged that this was not yet attainable with the technological development at the time.

Building upon Friedman’s critique of a paternalistic organization, Negroponte (1975) proposes the idea of the computer as a “design amplifier” - a personal interface - that would act to elaborate upon and contribute technical expertise to the users design. He makes the assumption that individuals and small groups know, or can come to learn, what they want, and therefore “each individual can be his own architect.” (Negroponte, 1975, p.100). Negroponte proposes a process where the machines would not make judgements and decisions but - different from Friedman's approach - would engage in dialogue and learning process. This relation was based upon Seymour Papert’s work on computer and learning theories, where computer-aided instructions should be treated as the amplification and enlightening of the process of learning and thinking itself (Negroponte, 1975). They envisioned an “architecture without architects” where architects would be progressively removed from the design functions culminating in a scenario where physical environment would be given the ability to “design itself, to be knowledgeable, and to have an autogenic existence”. (Negroponte, 1975). Different experiments were developed to generate design amplifiers[53], but they did not lead to successful results in achieving a human-machine dialogue. Two projects that are helpful to understand and enlighten this discussion are FLATWRITER, by Yona Friedman (1971), and Architecture-by-Yourself by Negroponte and Guy Weinzapfel (1976).

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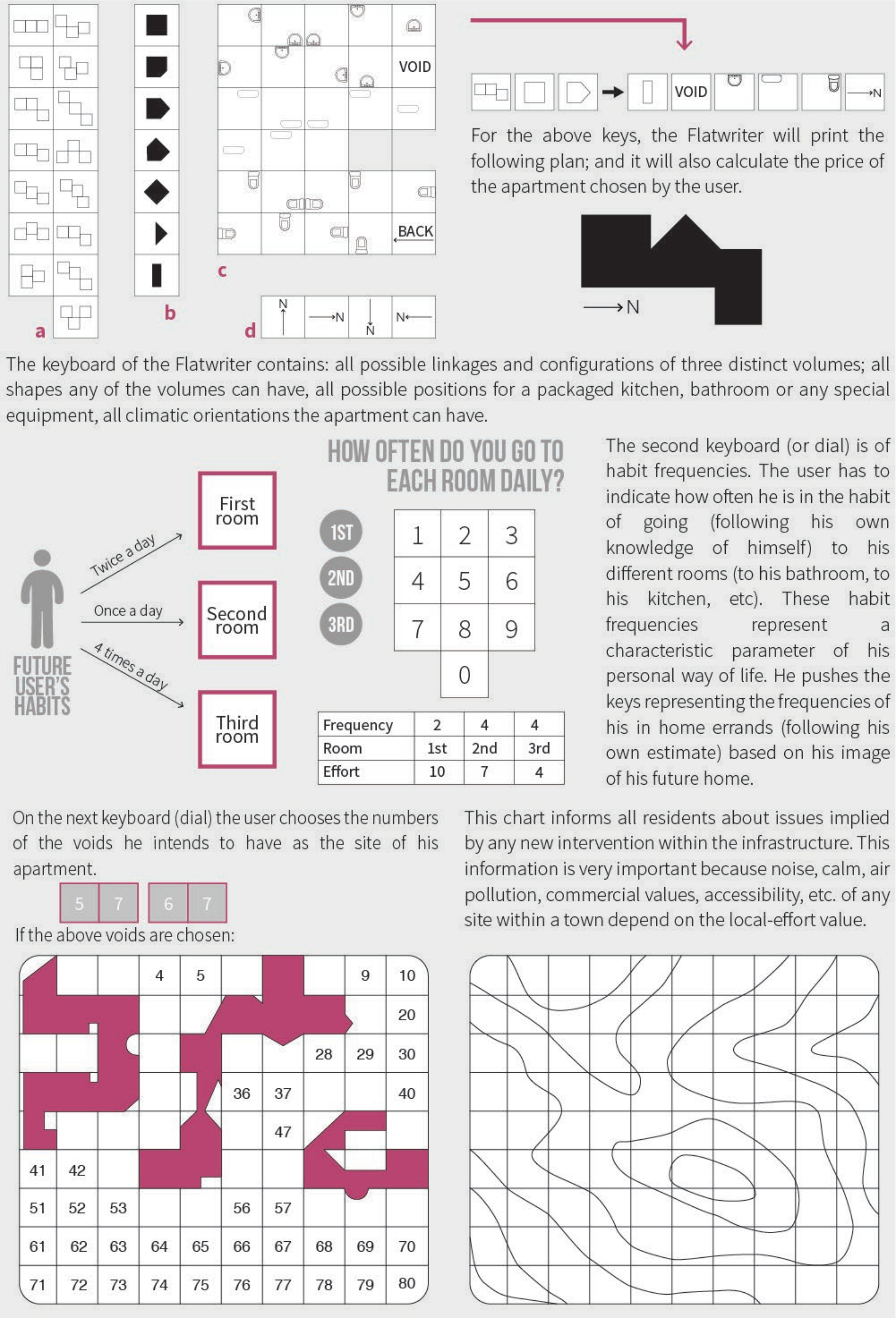
[53] ARCHIT (Negroponte, 1975) for example was extremely prescriptive in the way it dealt with the user and the yes and no answers were not successful in establishing a conversations - it created a machine monologue. The questions asked by the system expressed clear values - values of the programmer and not the user. As observed by Negroponte (1975,p118) “the program has exhibited an illusion of intelligence and "knowingness" and, in this example, done all the talking!”.

3.3.2. FLATWRITER

FLATWRITER was the idea of a design interface where the user could design his house by selecting his housing preferences from a set of 53 keys that represent possible configurations within a given volume. The system was designed around a two loops process - one between user and translator and the other between the translator and the world. The desires of one inhabitant could be compared with the wishes of others by the computational systems, and all incongruencies would be stated. For Friedman (1971:129), "the task of the architect is to warn each user of the effect of each individual act of choice." That is not only limited to the scale of the house, but also at an urban scale, where the construction of a new building can affect a whole community. Therefore people should be given the right to know how the project will repercuss on their way of life and the means to vote for or against any project. (Friedman, 1971). The design system enables the creation of several million plans for possible apartments to be inserted in an infrastructural element of several floors that separates a service network (water, electricity, telephone, etc.) from the mobile elements (walls, partition, floors, ceilings, etc.). Friedman (1971, p. 100) defines the system as “an application of a new information process between the future user and the object he wants to use; it makes individual decision possible within very wide boundaries, and it provides a direct way for anybody to correct his own errors without the help of intermediary professionals”. The overall configuration of the systems is best described in Friedman's drawings reproduced in figure 38.



For the above keys, the Flatwriter will print the following plan; and it will also calculate the price of the apartment chosen by the user.

The keyboard of the Flatwriter contains: all possible linkages and configurations of three distinct volumes; all shapes any of the volumes can have, all possible positions for a packaged kitchen, bathroom or any special equipment, all climatic orientations the apartment can have.

The second keyboard (or dial) is of habit frequencies. The user has to indicate how often he is in the habit of going (following his own knowledge of himself) to his different rooms (to his bathroom, to his kitchen, etc). These habit frequencies represent a characteristic parameter of his personal way of life. He pushes the keys representing the frequencies of his in home errands (following his own estimate) based on his image of his future home.

Frequency	2	4	4
Room	1st	2nd	3rd
Effort	10	7	4

On the next keyboard (dial) the user chooses the numbers of the voids he intends to have as the site of his apartment.

If the above voids are chosen:

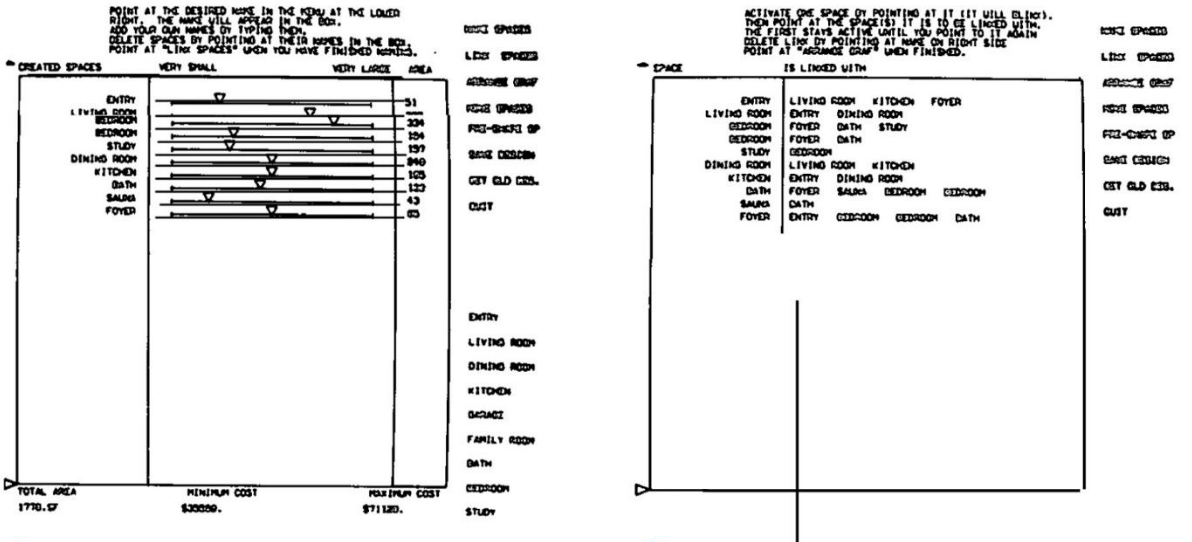
This chart informs all residents about issues implied by any new intervention within the infrastructure. This information is very important because noise, calm, air pollution, commercial values, accessibility, etc. of any site within a town depend on the local-effort value.

Figure 38 | Diagrams depiction how FLATWRITER would funcion. The figures and text are based on Friedman's diagrams published in Flatwriter: choice by computer (Friedman, 1971)

3.3.3. Architecture-by-yourself

Architecture-by-yourself was an experiment concerned with what Weinzapfel and Negroponte (1976, p.74) called a “design aids for do-it-yourself designers". The goal was to allow people to design their homes “without either a middleman or a middle machine creating whole solutions for them” (Weinzapfel and Negroponte, 1976, p.74). In other words, the idea was not to create a finished design for the user, but a design interface to empower the users to make their own design. The points addressed in the system were (a) to create a step-by-step strategy to help to structure the process and (b) to work on visualization techniques to enable feedback. Yona Friedman was directly involved in this project as a consultor and his ideas of a non-paternalistic system were central for the development of the interface.

The design system, called YONA, was created to help a non-expert user to design his own house by giving helpful inputs throughout the design process. In the first of six steps, the user is offered a menu from which he selects the spaces he wishes to include in his home. Spaces that are not part of the menu can be manually added. All chosen spaces are displayed in a list, together with a slide bar that enables the area of the room to be parametrically specified (figure 39A). Because the area parameters are associated with the building cost, the user can measure his actions in relation to the final cost of the construction. According to the authors, users found this feature one of the most useful. In the next step (figure 39B), the user creates a link between each space while the computer checks if the connections are possible in a one level plan. The strategy to create links is based on Yona Friedman's graph theory process where the connections between spaces provide the backbone of the design. If a problem is found the link can be delete or the user can choose between adding a circulation space, or creating a second level. In the following steps, the system creates a graph configuration without any crossing links (figure 39C). The graph enables spaces to be rearranged and moved to new locations (figure 39D).



POINT AT THE DESIRED NAME IN THE MENU AT THE LOWER RIGHT. THE NAME WILL APPEAR IN THE BOX.
ADD YOUR OWN NAMES BY TYPING THEM.
DELETE SPACES BY POINTING AT THEIR NAMES IN THE BOX.
POINT AT "LINK SPACES" WHEN YOU HAVE FINISHED NAMING.

CREATED SPACES	AREA
ENTRY	51
LIVING ROOM	—
BEDROOM	334
BEDROOM	154
STUDY	157
DINING ROOM	140
KITCHEN	105
BATH	133
SAUNA	43
FOYER	85

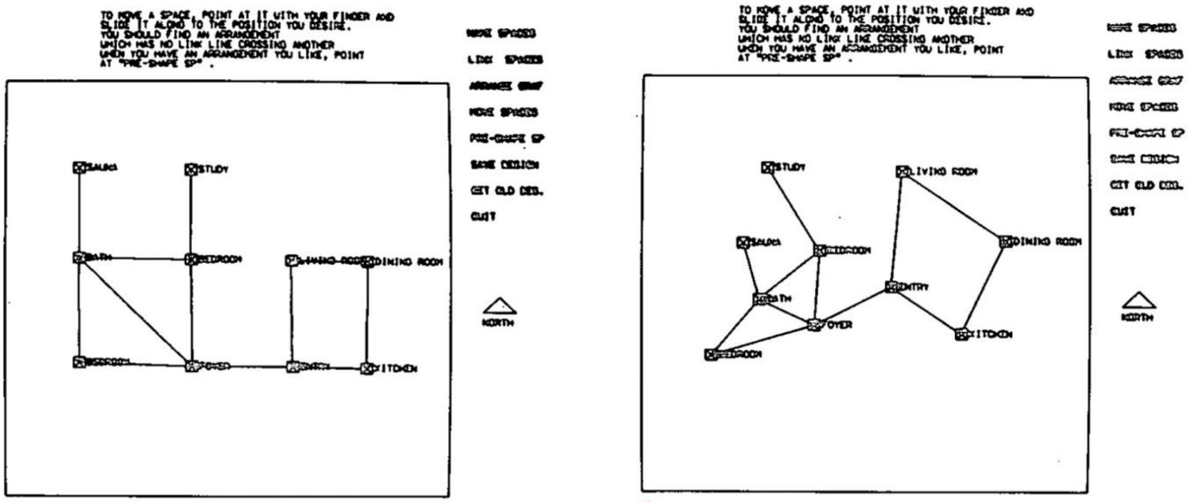
TOTAL AREA	MINIMUM COST	MAXIMUM COST
1770.57	$35550.	$71120.

ACTIVATE ONE SPACE BY POINTING AT IT (IT WILL BLINK).
THEN POINT AT THE SPACE(S) IT IS TO BE LINKED WITH.
THE FIRST STAYS ACTIVE UNTIL YOU POINT TO IT AGAIN
DELETE LINK BY POINTING AT NAME ON RIGHT SIDE
POINT AT "ARRANGE GRAF" WHEN FINISHED.

SPACE	IS LINKED WITH
ENTRY	LIVING ROOM KITCHEN FOYER
LIVING ROOM	ENTRY DINING ROOM
BEDROOM	FOYER BATH STUDY
BEDROOM	FOYER BATH
STUDY	BEDROOM
DINING ROOM	LIVING ROOM KITCHEN
KITCHEN	ENTRY DINING ROOM
BATH	FOYER SAUNA BEDROOM BEDROOM
SAUNA	BATH
FOYER	ENTRY BEDROOM BEDROOM BATH

A. make space

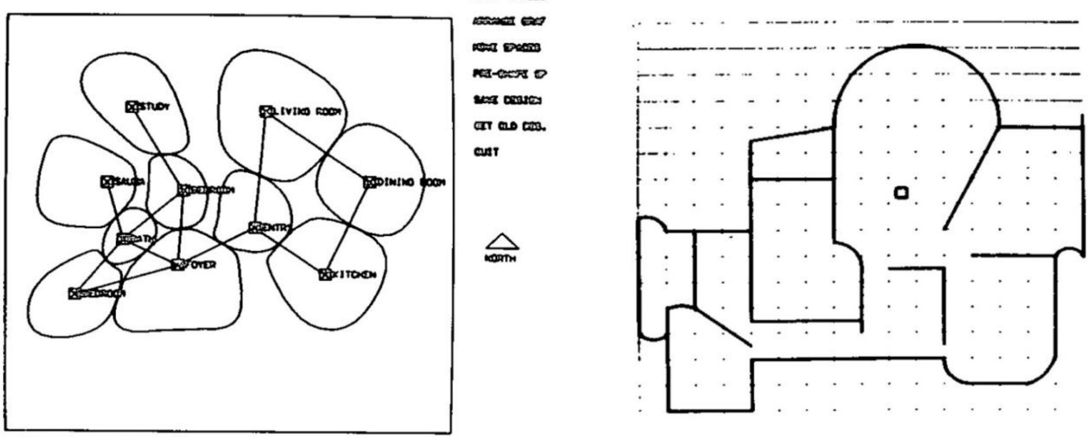
B. link space



TO MOVE A SPACE, POINT AT IT WITH YOUR FINGER AND SLIDE IT ALONG TO THE POSITION YOU DESIRE.
YOU SHOULD FIND AN ARRANGEMENT
WHICH HAS NO LINK LINE CROSSING ANOTHER
WHEN YOU HAVE AN ARRANGEMENT YOU LIKE, POINT AT "PRE-SHAPE SP".

C. arrange graph

D. move spaces



E. pre-shape spaces

F. sketch shape (user)

Figure 39 | Steps of the YONA design interface. (Weinzapfel and Negroponte, 1976)

After the achievement of a satisfactory arrangement, bubbles are created at each node with a size that corresponds to the specified area of each space (figure 39E). The bubbles are then brought together and fitted inside a polygon that determines the outer perimeter and the intersection between each space. This final graph is used as a graphic guide upon which the user can sketch the actual shape of the rooms (figure 39F). In this process the cost is adjusted to the final plan. In this way, Architecture-by-yourself leaves the "soul-searching decisions of personal design" to the user and creates a "understanding, helpful and not paternalistic" man-machine interaction (Weinzapfel and Negroponte, 1976, p.78). In the end, the system did not depict intelligent behaviour, but served as a mechanisms to raise issues that can lead to conversations, and thus design.

FLATWRITER (1967) by Yona Friedman, and Architecture-by-yourself (1976) where experiments on digital interfaces for architectural design that advocated for a non-paternalistic computer-aided participatory design as a way of "democratizing" design. However, as put forward by Vardouli (2011), in those interfaces proposed by Friedman there is "the danger of human paternalism being replaced by a machine paternalism, replacing the architect's preconceived notions with the limitations that the machine's design imposes." Furthermore, the idea that the machine would behave not to establish preferences and make judgments is debatable, as it is the designer (not the designer of the house but the designer of the machine system) with all his preferences and judgments, which gives shape to the system and determines the machine's behavior. The machine may be programmed not to have preferences or judgments and decisions, but the system itself is constructed upon the designer's choices, beliefs, and conclusions.

Those ideas and investigations were bound to specific forums mostly restricted to the an academic avant-garde. Most architects did not foresee any practical use of computers in their day to day process - the ones that did used it as "idiot-slaves" to automate repetitive processes (Negroponte, 1975). Nevertheless the period from 1960 to 1980 marked the introduction of computing to architecture. Although most applications were restricted to the use of the computer as an extension of the drawing board, architects such as, Cedric Price, Nicholas Negroponte, and Yona Friedman experimented with different approaches that explored the potential of computation beyond representation, towards the acknowledgment of the user as an central and active spacial actor in a dynamic architectural system. Through a critical bias, their designs pushed the boundaries of what was considered "architecture" for most architects at that time. Antoine Picon (2010) advocates that it is in those experiences, that are focused on analysis and critique of the design process rather than in their formal results, that lies the key to digital architecture.

3.4. Design Methods

“Building is a form of living and living is a form of building” (Jones, 1991:162)

Negroponte´s attempts to understand the design process in order to design machines to serve as aid in the process - or ultimately to design themselves - can be framed as an effort to deal with complex social problems with technological means. Using a different approach, many architects and researchers explored different non-technological mechanisms to improve the design process. This endeavour has its roots in the design method movement in the early 1960's. According to Cross (1984) this was the period of 'systematic design', in which attempts were made to restructure the design process based on the new methods and techniques of problem solving, management, and operational research which had been developed during World War 2 and in the 1950's.

Cross (1984) distinguishes four stages in the design methods movement: (1) prescription of an ideal design process; (2) description of the intrinsic nature of design problem; (3) observation of the reality of design activity; and (4) reflection on the fundamental concepts of design. The first stage was characterized by the attempts to create a new way of proceeding with design that fused intuitive processes and creative thought with logical, systematic, and analytical procedures (Cross, 1984). They developed a system approach to the design process in order to create methods of systematic design. A common argument for the need of a systematic approach to designing was the increasing complexity of the designers task in consequence of rapid technological and social changes (Cross, 1986).

The second stage involves the attempt to understand the nature of design problems. It was marked by Rittel and Webber's (1973) characterization of design problems as "Wicked Problems", in contrast to tame problems.

> “A wicked problem is a social or cultural problem that is difficult or impossible to solve for as many as four reasons: incomplete or contradictory knowledge, the number of people and opinions involved, the large economic burden, and the interconnected nature of these problems with other problems.” (Rittel and Webber, 1973)

"Tame" (benign) problems, on the contrary, are problems that can be clearly defined and solved in a linear rational way. Rittel and Webber (1973) criticized early systems and cybernetic (First-order Cybernetics) approaches to complex problems (first generation) that tried to transform wicked problems into tame problems. Cross (1986) observes that although many authors at that time agreed that design problems are ill defined, they offered different views on how to cope with those problems. From Rittel and Webber's (1973, p.162) perspective, a "second generation" approach should be developed based on "a model of planning as an argumentative process in the course of which an image of the problem and of the solution emerges gradually among the participants, as a product of incessant judgment, subjected to critical argument."

The third stage was characterized by the attempt to understand how designers deal with complexity within their normal conventional design processes (Shön, 1984, Glanville,1999) - the designerly ways of knowing (Cross, 1982). Cross (1982) points to two general conclusions from the observation of how designers design. The first is architects have a "solution-focussed" approach to design. Early speculations about a solution lead to a conceptualization concerning the problem. In that sense, a problem is understood in association to a specific potential solution. The second conclusion is that systematic procedures are not adequate for conventional design processes. (Cross, 1982)

Finally, one of the most critical remarks about the design methods movement was not of its accomplishments, but concerning its failure. John Chris Jones (1991), most known for his important contributions to the design methods movement, observed that instead of improving design, the design methods turned into itself and became the study of methods. "The fault in method-making was that we made methods as 'products' and handled them on to the designers expecting them to use them, as 'tools,' as means to an end" (Jones, 1991, p.163). The movement proposed changes in the design process, but failed to see the need to transform design from an object-oriented-process to process-oriented-process, meaning a "design-without-product," a "design as process-in-itself." This shift from object to process represents a significant change in how designers work. As Jones (1991, p.162) observes, "designing, making, and using are all processes that are added to, and interact with, the natural processes of the places where this activities occur." If design is seen as a continuous process, a continuous flux, that does not cease when a project is finished or a building built, then all people are designers. (Jones, 1991). The understanding that all people are designers is a crucial one but it is often ignored.

3.5. From reaction to conversation

From the 90's onwards, the development of the internet intensified the rate of change in computational architecture and opened new fronts of investigation. With the gradual adoption of CAD (Computer Aided Design) tools and processes by practice and academia, architects began to experiment with interfaces without the constraints of weight, scale and materials. A new formal complexity emerged from speculative drawings and renderings that explored a new design arena called cyberspace (Spiller, 1999). Architects started to work with the idea that digital environments could be thought of as complement, or in more radical cases, as an alternative to physical space.

Because of the growing gap between fabrication processes that continued largely analog and the designer's vision, the formal complexity of the non-euclidean curves and shapes remained restricted to the digital realm. The change from "atoms to bits" was according to Negroponte (1995) "irrevocable and unstoppable" and new interfaces were needed to access this information. Architects began to explore the idea to merge physical qualities with electromagnetic pulses that spread through the environment to enrich the experience of technological communication (Dunne, Raby, 1995). The idea of ubiquitous computing (Weiser, 1991) and discussions about reactive, interactive and relational systems (Haque, 2007; Dubberly, Haque and Pangaro, 2009) became common ground for computer scientists, designers, and artists working with digital interfaces, tangible computing (Ishii and Ullmer, 1997), physical computing (O'Sullivan and Igoe, 2004), and information spacialization (Cabral Filho and Baltazar, 2006). Designing Interactions (Moggridge, 2007) consolidated as a special field of design inquiry that deals with the design of digital technological devices with a focus on the immaterial aspects of the interaction between man and systems.

Input, output, sensors, and actuators became part of the vocabulary of designers and architects working with electronics and microprocessors to create interfaces for dialogue. Different experiments, such as the Hyperbodies from Kas Oosterhuis (2003), the robotic membranes of Mette Ramsgard Thomsen (2008), Aegis Hyposurface from Mark Goulthorpe et al. (2001), among others, explored the use of such devices to create dynamic systems where structures react to external stimuli and change their shape and configuration. The recurring argument for the creation of these objects and interactive spaces is that, in them, the user is brought to the foreground as the system reacts dynamically to their stimuli. The idea of interaction seemed to push research efforts to a promising path towards the creation of dynamic architectural systems. Built examples, such as Lars Spuybroek (2004) architectural machines effectively merged interactivity in design and use of architectural space. However, through the performative properties that characterize most interactive spaces, it seemed to be the architectural space itself that gained prominence in detriment to the user. In that context, dynamic architectural components with real time behaviour frequently compete with people to be the focus of attention occupying the spatial stage. What appears to be the recurring error in these cases is to design with the focus on the technical and conceptual appeal. They generate visually provocative objects, but contribute little to the spatial quality and more deeply engaging experiences. Many built projects and experiments ended up in museums and fairs and interactivity became a strategy for entertainment industry.

A central discussion related to those projects and processes are the different types of interaction involved in each system. In a dynamic system that includes observer and object, interaction is a way of framing the relationship between both. This relationship can occur in at least three levels: reactive, pro-active and conversational. The first level, reactive interaction, occurs when a system programmatically reacts to the input given by the other system (Dubberly, Haque and Pangaro, 2009). According to Ranulph Glanville (2001, p. 654), "action and reaction are characterized by a simple, supposedly causal connection. When, for instance, I click on an icon on my computer, I expect a particular type of behavior to result. I do this, that results, and so I do what comes next".

The second level of interaction is pro-active. According to Kas Oosterhuis (2008), a pro-active interaction means not only responsiveness to people's interaction but a contribution to present-time changes that take people by surprise. Even if Usman Haque (2007) praises responsiveness as a means to mutually react, Oosterhuis' term pro-active seems more appropriate as the object of interaction is not predetermined and may surprise people. Furthering those two levels presented above, the third level of interaction is conversational. In conversational interaction, the output of a system becomes input for another. In this relation, one system may direct the other without being meaningfully affected by it. However, there is another possibility, when one system gives an output to serve as input to the other and takes the output of the other to serve as its input. (Dubberly, Haque and Pangaro, 2009). This circular relationship may lead to novelty, as one system affects the other mutually. The participation of the observer in a conversation erases the differentiation between user and designer, as both systems - human and machine - participates in the generation of novelty - design. From that perspective they are both designers - or co-designers - that together constitutes the design activity. (Pangaro, 2010).

3.6. Robotic Ecologies

Figure 40 | Kiva robots at an Amazon warehouse. (“Amazon Robotics,” 2017)

Nowadays, the shift from mechanical to digital technologies - now widely available - offer new possibilities and challenges to architects and designers. Robots, drones, microprocessors, and interconnected networks of digital devices are part of our daily lives. The pervasiveness of digital devices is central to understand the transformations of digital processes in design. As observed by Antoine Picon (2010), “digital architecture cannot be separated from the changes that affect the way we plan, design, and, above all, experience our cities using all kinds of electronic equipment: computers, cell phones, personal digital assistants, and GPS.” Currently, that inevitably encompasses the ecology of drones and robots that are spreading throughout our cities. An example is the 30.000 Kiva robots shifting shelves in several of Amazon's warehouses around the globe until June 2016. According to Robert Bogue (2016), a recent market research showed the global warehouse robotics market is forecast to reach $10.34bn by 2020, growing at a compound annual growth rate of 11.5 percent during the period 2015 to 2020. Several other companies, such as, Fetch Robotics, Locus Robotics, Scallog, and Swisslog are also developing similar solutions.

With regard to Unmanned Aerial Vehicles (UAVs), the American Federal Aviation Authority (FAA) estimated[54] in 2010 that there would be, by 2020, perhaps 15.000 of such drones in the United States.In 2016, they reviewed this number to 7 million combining commercial and hobbyist purchases[55]. If we look at industrial robots[56], the numbers also show an exponential growth in the last years. According to the 2016 Executive summary of the International Federation of Robotics[57] (IFR), in 2015, robot sales increased by 15% to 253,748 units, the highest level ever recorded for one year. The positive and negative impact of drone and robotic technologies in design and in the built environment is yet to be measured, and wille "techno-utopianists[58]" and "techno-pessimists" (Picon,2014) battle to contrast their science-fictional narratives of the potential for positive change against the dangers brought by new technologies, several groups of architects and researchers are engaging in hands on approach to explore robotics and drone technologies to generate dynamic architectural systems.

In architecture, research and development with the use of industrial robots and drones at a larger scale started in 2005 with Fabio Gramazio and Matthias Kohler at ETH Zurich (Eidgenössische Technische Hochschule Zürich), where they share the Chair of Architecture and Digital Fabrication and started a multipurpose fabrication laboratory.

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[54] (2015). Welcome to the Drone Age. [Online]. Available at: http://www.economist.com/news/science-and-technology/21666118-miniature-pilotless-aircraft-are-verge-becoming-commonplace-welcome [Accessed 18 December 2016].

[55] *FAA Releases 2016 to 2036 Aerospace Forecast*. [Online]. Available at: https://www.faa.gov/news/updates/?newsId=85227 [Accessed 19 December 2016].

[56] According to ISO 8373:2012 an industrial robot is an automatically controlled, reprogrammable (2.4), multipurpose (2.5)manipulator (2.1), programmable in three or more axes (4.3), which can be either fixed in place or mobile for use in industrial automation applications. Note 1 to entry: The industrial robot includes:

(1) the manipulator, including actuators (3.1); (2) the controller, including teach pendant (5.8) and any communication interface (hardware and software). Note 2 to entry: This includes any integrated additional axes.*ISO 8373:2012(en), Robots and robotic devices — Vocabulary*. [Online]. Available at: https://www.iso.org/obp/ui/#iso:std:iso:8373:ed-2:v1:en [Accessed 29 January 2017].

[57] *Statistics - IFR International Federation of Robotics*. [Online]. Available at: http://www.ifr.org/industrial-robots/statistics/ [Accessed 29 January 2017].

[58] Picon (2014) argues that "techno-utopianism is generally typified by a belief that innovation has an immediate and beneficial impact on society", and the opposing view, "techno-pessimists, condemn new technologies or distrust its capacity to improve the human condition.

They experimented with robotic arms and CNC machines to customise objects (mTable[59]), built complex shapes using traditional building materials (Structural Oscillations[60]), developed on-site robotic construction processes,[61] and ultimately started investigations that used UAVs for construction (Flight Assembled Architecture)[62]. In Robotic Building (RB) ,robots are not only employed in a supportive role in the fabrication and building process, but are also an integral part of the physically built environment (Bier, 2015). The main idea of RB is to generate a time-based process that enables spatial reconfigurations to facilitate multiple uses of the built space within a reduced timeframe.

Nowadays, the robotic trend seem to have reached most western architecture institutions (figure 41), and there are many more explorations with robots in architecture and constructions. If we look at the investments being made by architectural schools on advanced laboratories for computational design - with an array of robotic and CNC machines - it almost appears that robots are indispensable for contemporary architectural education. Institutions such as B-Made at the Bartlett School of Architecture[63], the Institute of Computational Design and Construction at the University of Stuttgart[64], the Robotic Fabrication Laboratory at ETH Zürich[65], the Hyperbody Research Group[66]

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[59] In mTable they explored the possibility for the user to make changes and interferences in the design of a table using a mobile phone. According to Gramazio and Kohler mTable enables people to design their own table on a mobile phone. Once ordered, the table would be produced using direct computer controlled manufacturing.

[60] The project consists of a 100 meter brick wall constructed onsite by a Mobile Robotic Fabrication unit (ROB). "The wall's design was conceived as a system with open parameters. The course of a single, continuous curve carried all the generative information necessary to determine the design. This curve functioned as a conceptual interface, which enabled the needs of the individual exhibited groups to be negotiated. As each group's requirements were modified, the three-dimensional, undulating wall could be automatically re-generated".In "Structural Oscillations, *Gramazio Kohler Research*. [Online]. Available at: http://dfab.arch.ethz.ch/web/e/forschung/142.html [Accessed 11 April 2017].

[61] In the *Mobile Robotic Tiling* project undertaken between 2013-2016 by the SEC Singapore-ETH Centre experiments were done to develop on-site robotic tiling machine that can deliver high accuracy of tiling at more than double the speed of conventional work. (http://gramaziokohler.arch.ethz.ch/web/e/forschung/257.html, visited on 12 january 2017).

[62] Available at http://www.gramaziokohler.com/web/e/projekte/209.html, visited on 11 april 2017

[63] http://www.ucl.ac.uk/robotics/prospective-students/facilities/#bmade, visited on 11 april 2017

[64] http://icd.uni-stuttgart.de/, visited on 11 april 2017

[65] http://gramaziokohler.arch.ethz.ch/web/e/forschung/186.html, visited on 11 april 2017.

[66] http://www.protospace.bk.tudelft.nl/, visited on 11 april 2017

at the Delft University of Technology, and the Institute for Advanced Architecture of Catalunha (IAAC)[67] have technological equipments that would be unimaginable for most architectural schools and research institutes a few decades ago.

Figure 41. International Map of Robots in the Creative Industry maintained by the Association for Robots in Architecture. The maps show that practices that adopt robots in their research and work are highly concentrated in western countries. (Robots in Architecture, 2017)

Numerous projects and built experiments developed in those new high-tech laboratories seem to come out of a science-fiction novel. In their examination of the potential of the new tools and processes, they create possible visions of the future, where robotic arms and UAVs are working in building factories and in construction sites molding and weaving complex shapes and structures (figure 42). Many architects believe that robotics and other automated CNC machines will become a game-changer for the construction industry and will ultimately change the whole field as a practice[68]. Picon (2014) argues that this "science-fiction overtones of robotics may well serve as a convenient transition

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[67] https://iaac.net/, visited on 11 april 2017

[68] See for instance Architectural Design publication *Made by Robots: Challenging Architecture at the Large Scale*. (Gramazio, F., Kohler, M. (Eds.), 2014. Made by Robots: Challenging Architecture at the Large Scale AD, 1 edition. ed. Wiley).

towards one of the key roles of robots these days, namely their supporting part in a narrative regarding the future of the architectural discipline and the rising importance of automated fabrication." He points that this type of narrative dimension is not a recent phenomenon and that "the various attempts to industrialize building activity throughout the 20th century were intimately related to a grand narrative regarding the necessity to adapt architecture to the age of the machine" (Picon, 2014).

Figure 42 | Research pavilion by The Institute for Computational Design and Construction (ICD) and the Institute of Building Structures and Structural Design (ITKE) at the University of Stuttgart exploring building-scale fabrication of glass and carbon fibre-reinforced composites. ("ICD/ITKE Research Pavilion 2016-17 | Institute for Computational Design and Construction," 2017)

Tom Verebes (2014) debates to which extent robotics in architecture has the potential to change design on a global scale. Standardization still plays a significant role in industry and even if seriality is a real possibility, its potential remains untested at a broader scale of the contemporary city. Verebes (2014, p.129) questions if it is the "gang of experimental designers" and "well-funded researchers in a few niche architecture and engineering schools" that will bring robotics to the mainstream. Helen Castle (2014) disputes that if architects want to be significant players when the international construction industry incorporate on-site automated building techniques they have to keep on with the type of research such as Gramazio and Kohler and the Future Cities Laboratory (FCL) are undertaking. However, without a critical and systemic approach to digital architecture, nothing guarantees that this orientation will prevail in practice.

If ultimately the importance of robotic processes in architecture lies within the rise of automated fabrication (Picon, 2014) - where robots and CNC machines have a supporting part - the development of new technologies and processes must be framed in a broader perspective that encompasses the flow of information and networks within architecture, building and society. From that, it seems that a more appropriated approach towards design and research of new technologies is neither within a techno-utopian or techno-pessimist perspective, but a critical and second-order cybernetic perspective research by design that weights and understands actions within a broader and contextualized systemic scope.

A point of departure for a more systemic approach may be to understand how digital processes have an impact on existing building workflows. There was a belief among many architects that digital technology would redefine the relationship of architecture to production. The ability of CAD drawings to drive machines to physically render a design, inspired designers to explore new fabrication tools that offered opportunities for a new aesthetic and performative design. Scott Marble (2012) advocates that the immediacy of file-to-fabrication processes still resonates with new opportunities, but is now positioned "within the broader potential of digital information to form complex communication workflows". He wrote:

> “the assimilation and synthesis of digital communication among architects, engineers, fabricators and builders is dramatically altering how we work and our relationship to the tools we use. New digital capacities are restructuring the organization and hierarchy of design from autonomous processes to collective workflows. The historical role of the designer as an author, a sole creator, is being replaced with semi-autonomous, algorithmically driven design workflows deeply embedded in a collective digital communication infrastructure” (Marble, 2012, p.7).

In his arguments, Marble shifts the focus from the potential of technological tools towards the importance of networks and information flows between design, assemble and industry. In that sense, the ecologie of robots and digital fabrication process can be part of a larger workflow that integrates the different spatial actors. However, even if the shift towards an understanding of digital computational processes as networked workflows represents a potential improvement, it still favors the role of the expert designer. As long as the flow of information is centered on parametric information models, designers will not relinquish their role as controllers of the information flows. Within this perspective, the user is still treated as a consumer rather than as a potential co-author that participates actively in the design of his environment.

3.7. Dynamic Architectural Systems

The review of various possibilities of designing dynamic systems has revealed that it is possible to distinguish at least three fields of inquiry: New Design Strategies, Rethinking the Architectural Practice, and Experimenting with New Tools and Technologies. Different examples of projects, buildings, and strategies for dynamic systems were put forward to contextualize and inform the thesis. The first one is associated with new design strategies and concepts developed to deal with the indeterminacy of use of the architectural space. Either departing from the notion that use cannot be predicted, or that multiple functions had to overlap to improve functionality, designers explored different formal and procedural strategies to design buildings, processes, and cities that incorporate dynamic properties. Various approaches acknowledge the user as an active spatial actor in contrast to the functionalist notion of a passive user that functions according to the designer's expectations. Movable elements that change spacial configuration were employed by many architects to enable space to meet different user demands. However, the application of movable devices seldom resulted in spaces that could accommodate indeterminant uses and were apparently incorporated to bring design closer to the idea of scientific progress. Nevertheless, the examples described revealed substantial differences in how they were conceived and to which underlying purpose dynamic elements were incorporated.

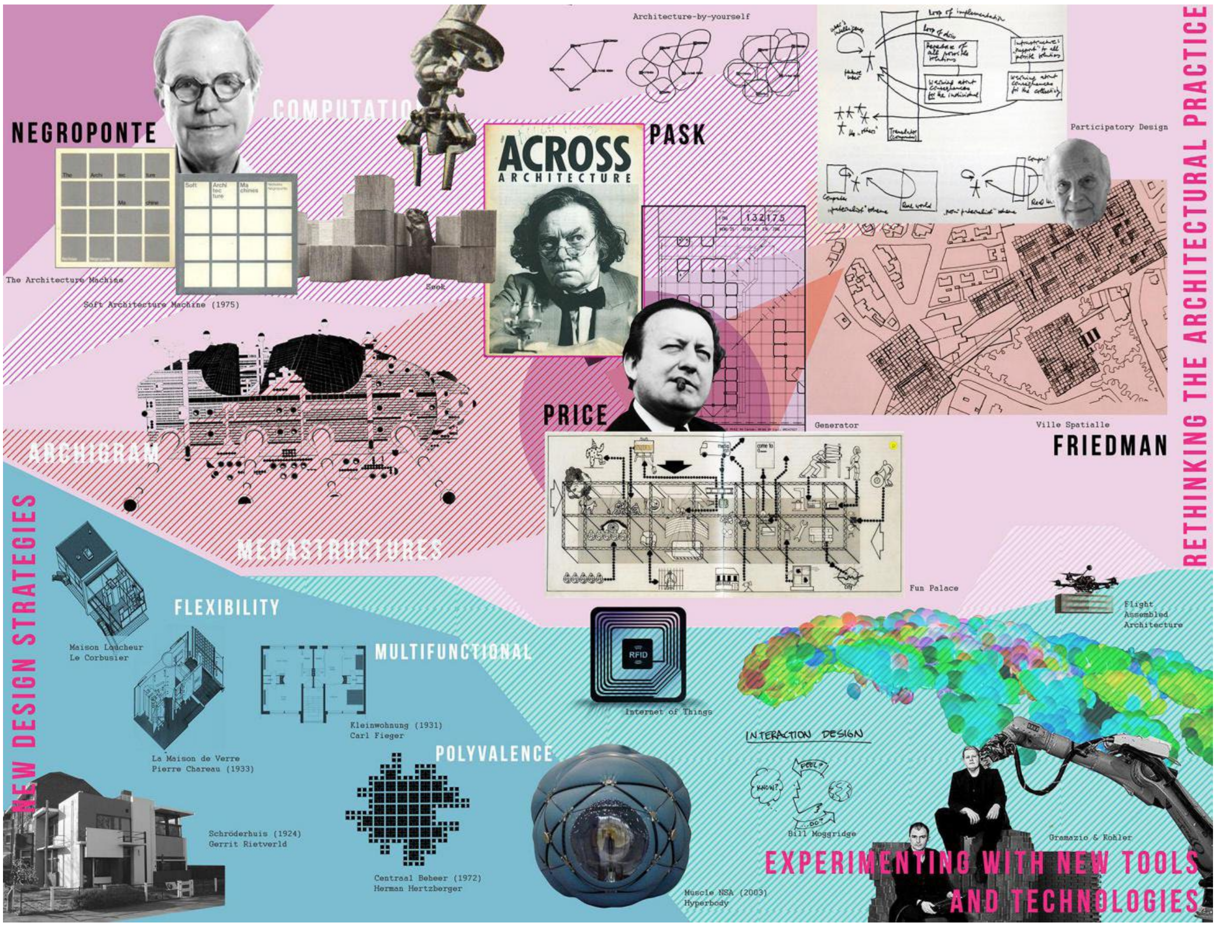

Figure 43 | Three fields of inquiry associated to the design of dynamic architectural systems. (author, 2017).

Maison Loucheur (1928-9) by Le Corbusier and Kleinwohnung (1931) by Carl Fieger were conceived for a generic user, to be mass produced and sold as a product to be consumed according to predetermined instructions of the day and night situation, generating what can be called a hyper-functional space - where technological elements enable the overlap of different functions. La Maison de Verre shows a different circumstance where the user participates more actively in the conception of the design - perceivable in how dynamic elements generate more meaningful transformations connected to the user's way of living. In the Rietveld-Schröder House, the involvement of the user in the process is taken to the point where user/client becomes a designer. In the house, the different spaces defy classification according to determined function and can, therefore, be adapted to various forms of appropriation. The various levels of conversations within the design process and in the everyday use of space were of paramount importance for this outcome. The unique relation between Rietveld and Schröder lead to a unique result that resists generalization.

The second field, Rethinking the Architectural Practice, is associated with the initial use of computation in design and is defined by projects and investigations that sought to rethink the architectural practice by challenging architects to assume a different role in the production of space. Cedric Price, Nicholas Negroponte, Yona Friedman, and Habraken, were at the forefront of this endeavor. Each envisaged a different form of design approach with the shared goal of handling control to the user. They not only acknowledged that the user could make a creative use of space, but also proposed a new relationship between design, use, and space that empowers the user to become a designer. Within this perspective, they envisaged different means to enable the continuity of the design process through the use of mediating infrastructures[69] associated with computational interfaces.

In the Fun Palace and Generator project, the user is acknowledged as a fundamental and active part of the system, and flexibility is achieved through conversational interactions. Technology is not the focus - it is enabling - it serves as a structure to which actions and events are not predetermined. Both projects highlight the importance of interaction - most notably conversational interaction - as a way of dealing with indeterminacy. In Self-builder, the association of a digital interface with Seagal's construction method creates a system where the dynamic qualities depend upon an active involvement of the dweller - it relies on an active user to adapt space. Negroponte sought to overcome this by shifting the responsibility for action - and thus control - from user to machine, and proposed a process based on man-machine symbiosis where the building would ultimately be able to design itself. However, his optimism with a rapid development of artificial intelligence and evolutionary machines did not correspond to the reality. Machines, computers, scripting languages, human-computer interfaces, sensors, actuators, and many other features and process have evolved. However, this evolution was not programmed in the machines. Machine evolution happened because of the continuous - and sometimes erratic - effort of a network of actors (universities, DIY communities, governments, and companies). That is to say that machines evolve within, and in interaction with, a human system. From that perspective, the focus should not be placed on the development of "smart" machines, but on "smart" interactions between users and machines to create

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[69] Movable and demountable structures, cranes, gantries, modular elements, etc.

the right conditions (social, political and structural) for both to evolve. The shift of focus from an architecture machine that plays the role of the architect, towards design aides that gives support to the user's creative process, points to that direction.

Weinzapfel and Negroponte's architecture-by-yourself is an important experiment in that context because the interface was not designed to create a finished plan, but to enable the user/designer to reflect upon his own decisions and choices during the creative process. The YONA interface indicates a possible use of parametric design as a way of empowering the user. In the system, the parametric features were used to inform the process rather than to give form to a specific design. The results of the design process can be seen as a collaboration between the user, Weinzapfel and Negroponte who created the system, and Yona Friedman that offered the design framework upon which the interface was built.

The third field of inquiry, Experimenting with New Tools and Technologies, is related to a wider availability of computational tools and technologies together with the acceptance of the development of digital processes as a field of investigation within architecture and design schools. In a movement that went from atoms to bits and from bits back to atoms, many architects and designers became reference in the development of new technologies. In this context, the works of Cedric Price, Gordon Pask, Nicholas Negroponte, Yona Friedman, and others, serve as theoretical reference to guide practice and research. However, their political stance on questioning the role of the architect as controller of the process and the attempt to handle control to the user is frequently ignored. Therefore, it is not a surprise that many of the built examples of explorations with new technological devices and robots are limited to custom products, installations, facade ornaments, and small pavilions that have a visual appeal but do not seem to lead to a paradigmatic change in the design process and the building industry. Robotic architectures are today more closely related to a pataphysical[70] (Roché et Lacadée, 2014) epistemology were architects contrast their different imaginary and speculative futures

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[70] Pataphysics is a supposed branch of philosophy or science that studies imaginary phenomena beyond the realm of metaphysics; the science of imaginary solutions. Accessed: May 16, 2017. *Pataphysics | Define Pataphysics at Dictionary.com*. [Online]. Available at: http://www.dictionary.com/browse/pataphysics [Accessed 16 May 2017].

in which machines fulfill our desires for total control and instant satisfaction. The need to create a science-fiction narrative to contextualize experiments seems to be a clear symptom of experiments that do not dialogue with real architectural contingencies, and therefore have to build fictional contexts.

Many works developed in that context, argue for the inclusion of the observer in the design process by creating environments that can be reconfigured in real time, such as in Robotic Buildings. At a first look, this seem not to differ from the modern approaches where flexibility by technical means is used to create spaces for a reactive user. However, because of the automation of all process made possible by robots, the reactive user, who was forced to take an active role as to perceive the qualities of space, is transformed into a passive observer of the performative ecologie of robots that now occupy the spatial stage.

Designers should not only be concerned with the physical dimension in designing building systems, but more importantly, they should address the interactive nature of architectural systems that involves conversation and control. The design of design interfaces using computational processes are an important step toward this endeavor. However, digital interfaces alone should not be the focus of attention, as it runs the risk to become opaque and gain prominence in relation to the observer. The connections of design to the human and social systems takes it to the scale of extremely complex systems. System thinking is an alternative to reductionist thinking for dealing with complexity. The idea should not be to develop isolated methods, but to create a more holistic perspective where the primary properties of a phenomena derives from the interactions of their constituent parts. Designers should therefore focus on the design of systems which include interfaces, machines, users and designers in a network of conversational interactions.

4 | INFORMATION FLOW

PARAMETRIC DESIGN AND DIGITAL FABRICATION

> "Technology is the answer, but what was the question?" (Cedric Price, 1979)

In the first generation of digital design, architects experimented with new design possibilities offered by three dimensional modeling and renderings. Non-euclidean geometry became the new hype and topological possibilities were explored in a weightless and scaleless digital environment. Most formal explorations of that time remained on the digital realm because they were not bound to any material and assembly logics or production methods. Marble (2012, p.108) observes that "a common process from this period was a sequence of linear steps, in which the architect would generate a formally complex design that would subsequently go through various stages of translations, rationalizations and optimizations by engineers, fabricators, and other digital specialists in order to be realized as a building". This complex process restricted a wider adoption of digital processes in design and building industry.

With the popularization of digital fabrication methods, the idea of a continuous "digital workflow" has fostered a great deal of expectations because of the apparent possibility of transporting the information from the designer's idea to a physical materialized result (Scheurer, 2012). Although the seamless physical rendering of the designers idea has not yet been achieved, the possibility to unite design to fabrication encouraged architects to enter in an open ended exploration of the convergence of computational processes and material properties. Parametric design, associated with digital fabrication, is at the center of this transformation by enabling a new bi-directional flux of information between design, fabrication, and use. This chapter explores this new flux of information and discusses the association of parametric design and digital fabrication as a strategy to create dynamic architectural systems that involves the user in the design process.

4.1. Design and Computation

Since the first use of computers in design during the sixties, two main attitudes can be mapped of how computers are explored. The first is represented by the attempt to improve existing procedures with the use of computers. This process is related to what Negroponte (1975) and Terzidis (2006) distinguishes as *computerization*. The concept is defined by Terzidis (2006, p.XI) as “the act of entering, processing, or storing information in a computer or a computer system.” *Computerization* is the dominant mode of the use of the computer in design today, where “entities or processes that are already conceptualized in the designer’s mind are entered, manipulated, or stored on a computer system” (Terzidis, 2006p.XI). Glanville (1992) refers to this as “the computer as illustrating”, an approach that is associated with CAD, where computational power is used to represent or simulate a design. This approach may also involve more advanced CAD tools that can use databases to extract cost, structural analysis, etc.

The second attitude concerns the exploration of new creative paths to where computation may lead. According to Terzidis (2006), computation “is the procedure of calculation i.e. determining something by mathematical or logical methods”. It is related to the inner - cybernetic - logic of computers that is reachable through scripts and algorithms. In agreement with Glanville (1992), this logic can be brought to architecture following two approaches to the use of computers: (1) the “computer as”, and (2) the “computer as making”. The first approach is related to the embodiment of computation through digital devices in the architectural space to the point they are no longer distinguishable from one another. As Glanville (1992) observes, it is “a use of the computer in architecture, such that it is the architecture itself.” This approach is the case of experiments in Interactive Architecture (Oosterhuis, 2003), Generative Architecture (Frazer, 1995) and the lately Robotic Building (Bier, 2015). In the “computer as making” approach, the computer is used to “generate (novelty) to, from and with us [...] through proper use and improper abuse of the computational environment” (Glanville, 1992). It is an approach that invites open experimentations with the computer in ways that may lead to novelty.

Most architects are contented in using CAD software to operate data inputs and outputs without knowing the inner workings of the computer. However, by doing so, they may end being restricted by the limitations of the tool. By “programming architecture” (Terzidis, 2016) - exploring parametric and algorithmic processes - architects can operate beyond the control imposed by software and enter into some of the computers “black boxes”. This characterizes a shift of the use of the machine on a representational level towards a dialogical one, where novelty can arise (Cabral Filho, 2013). This shift represents a change from using the computer as a tool to using it as a medium. As Glanville (1992) advocates, “ (...) we treat the computer as a tool—a slave. We need, rather, to treat it as what it is, a medium in and through which our imaginations and our imaginings are extended, collaboratively, instead of perverting it so that it perverts us.” In the same direction, Negroponte (1970, 1975) advocates for a human-machine partnership where the computer is no longer treated as a idiot-slave that encourages repetition in task and in product, but engages in a symbiotic relation with the designer (an expert or non-expert one).

Parametric design, where algorithms accommodate interrelated variables, enables the designer to work with the computer in both ways, treating it as a tool to improve existing processes, and as a medium by exploring new creative paths and processes. It is the attitude of the designer that determines the degree of “toolness” - the quality of being a tool - or “mediumness” - the quality of being a medium - of the process. In this thesis, it is advocated that by entwining the user in the process, parametric design can be used as a medium to expand the possibility for novelty by embracing indeterminacy, sharing, playing, association, collage, change, and other strategies[71] that deal with the indeterminate.

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[71] Those strategies are part of Glanville’s (1992) list of possible ways to treat the computer as a medium.

4.2. Parametrics

Parametric is a general term used in a variety of disciplines and means something that "relates to or is expressed in terms of a parameter or parameters[72]." In design, there is no precise definition of the term, and its use often varies according to the context. The original use of the term parametric has its roots in mathematics where a parametric equation is defined in *Concise Encyclopedia of Mathematics* as a "set of equations that express a set of quantities as explicit functions of a number of independent variables, known as 'parameters'" (Weisstein, 2003, p.2150). Different from cartesian equations, parametric equations incorporate change in the form of parameters. An example[73] is a definition of the unit circle, (figure 44) where the position of a given point (x,y) can be expressed by a cartesian equation $x^2+y^2=1$. Although this equation correctly describes the circle and offers the values of the "x" and "y" coordinates at any given point on the circle, it does not reveals what establishes the relation between the two. The coordinates "x" and "y" have no direct correspondence with each other but are controlled by a third independent variable that connects the two: angle "α" - the parameter. If the equation is parameterized the relations in the system are made explicit by the parametric equations: $x = \cos\alpha$, and $y=\sin\alpha$. Those explicit functions reveal that any change in "α" will change "x" and "y" accordingly. The parametric function makes the relations explicit.

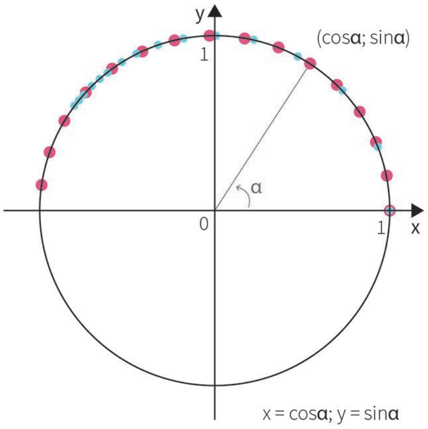

Figure 44 | A parametric circle.

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[72] Oxford Dictionaries (oxforddictionaries.com) Accessed 17/01/2016

[73] For more examples refer to A quick intuition for parametric equations available at: *A Quick Intuition For Parametric Equations – BetterExplained*. [Online]. Available at: https://betterexplained.com/articles/a-quick-intuition-for-parametric-equations/ [Accessed 23 April 2017].

Following the mathematical definition of parametric equations, Luigi Moretti (1907-1973) developed during the 1940s' the concept of *Parametric Architecture* (Moretti, 1971, p.205). Regarded as the first use of the concept of parametric in design (Davis, 2013), Moretti advocated the adoption of a scientific approach to design and proposed that "form (...) must be derived by identifying and quantifying the parameters that interfere with the thesis of a work" (Bucci and Mulazzani, 2002, p.21). At the 1960s' Milan Triennale, Moretti presented the application of his concept of parametric architecture with the design of stadiums (figure 45) and other sports facilities (*Progetti di strutture per lo sport e lo spettacolo* – at the *XIITriennale di Milano*). According to Moretti (1971, p.205), certain structures displayed in the exhibition "could change the forms in which they were projected, based on certain conditions, or parameters, that the observer could choose to select." This process was enabled with the help of a 610 IBM computer that - in the case of the stadiums - would change form according to different parameters. Moretti's method for *Parametric Architecture* involved three steps: (1) identification of the theme; (2) identification of the parameters involved with the theme; and (3) definition of the analytical relationships between dimensions dependant on the various parameters (Moretti, 1971, p207).

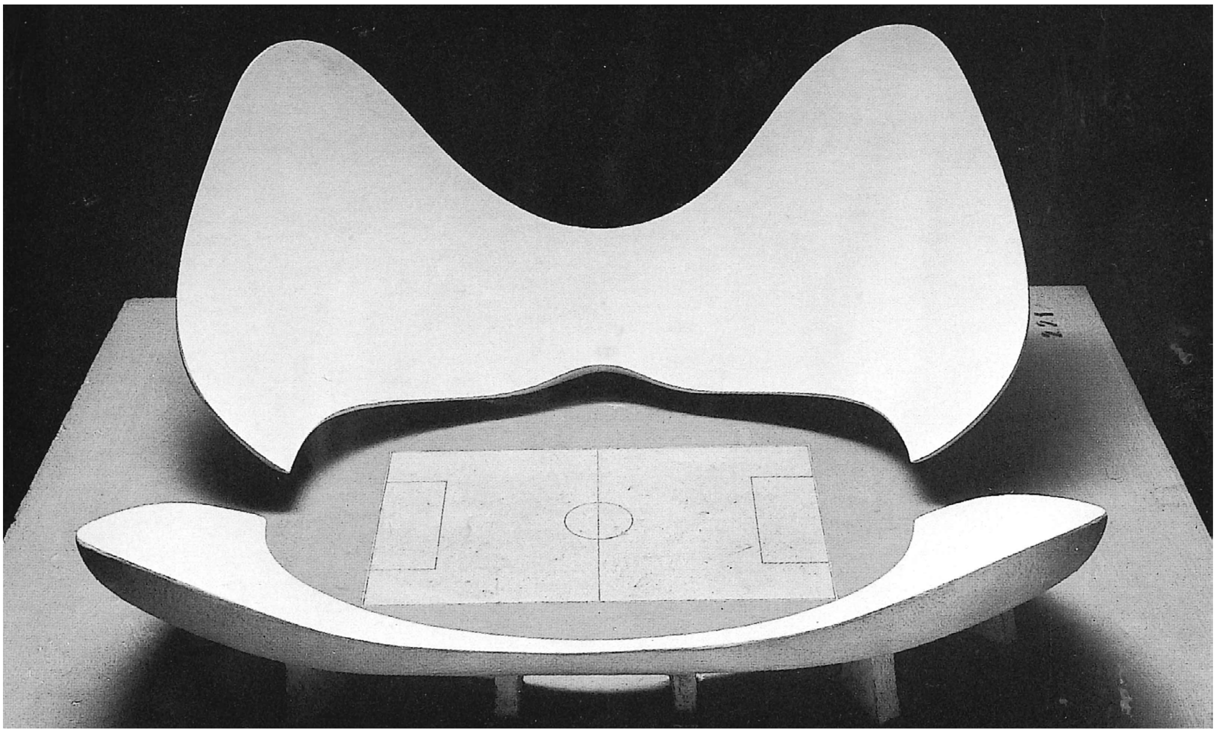

Figure 45 | A model of stadium N by Luigi Moretti. Exhibited at the 1960 Parametric Architecture exhibition at the Twelfth Milan Triennial (Bucci and Mulazzani 2002, p114).

In Moretti's parametric models there was an explicit connection between the established parameters and the geometrical relationships. In his endeavor, Moretti was probably the first to create three-dimensional architectural forms using parametric relationships resolved by digital computation (Davis, 2013). However, the use of flexible models that enabled the change of parameters precedes the digital era. Antoni Gaudi (1852 - 1926) and Frei Otto (1925 - 2015) are regarded by many as the forerunners of parametric design because of their use of hanging models that allowed them to change design parameters without the need to reconstruct the model (Burry, 2016, 2011, Menges, 2012). Both made use of inverted hanging models that automatically adjusted the shape of the model after each change of parameters, functioning as an analogue computer (Davis, 2013). According to Davis (2013), "this method of analogue computing was enlarged by Frei Otto to include, amongst other things, minimal surfaces derived from soap films and minimal paths found through wool dipped in liquid" - a process Otto called *form finding.* Mark Burry (2016) calls Gaudí and Frei Otto "proto-parametricists" because of their use of gravity as a parametric input to "inform rather than plan architectural form as an essential physical determinant within the design process". What their models did was to incorporate dynamic properties in the design process, as changes could be made within the established constraints without losing the consistency of the whole. It is this ability to change the parameters in a dynamic manner that represents an important distinction of parametric design from other approaches.

Mark Foster Gage (2016) goes further in history and claims that the Greek Temple of Hera at Olympia (590 BC) was architecturally parametric, as a change in the diameter of a column would require an update of a series of associated components. He adds that the majority of Vitruvius Ten Books on Architecture (1t century BC) along with Leon Battista Alberti's De Re Aedificatoria (1452) "are largely recipe books of these parameters that intricately and algorithmically link components to each other proportionally in order to produce predictable yet variable wholes" (Gage, 2016, p.130). In the same direction, Mario Carpo (2016) argues that because Vitruvius and Alberti's treatises were manuscripts meant to be hand-copied without any images or illustrations they had to resort to verbal rules and instructions similar to what is called today procedural algorithm. Because there was no visual reference, the outputs differed one from another, generating a variety of outcomes. According to Carpo (2016), this went on through the medieval until the rise of matrix-based reproductive technologies that replaced verbal rules with printed images, leading to standard copies. He argues that "with the Industrial Revolution, mass production spread from pictures to 3D objects, and the modern culture and technologies of identical copies replaced the ancient and medieval culture of scribal and artisanal variations" (Carpo, 2016, p.29). Following this reasoning, Carpo (2016) advocates that the ability of parametric notations to generate variations, coupled with the use of machines that can mass-produce variations, represents a revolution.

The idea that ancient and medieval cultures used parametric notations that generated variations, points to the notion that every design is parametric. Indeed, because all design use parameters, several authors correctly adopt this view (Aish and Woodbury 2005, Gerber, 2007, Hudson, 2010). However, parametrics as computational method expands this notion with the use of parametric models. Through the use of algorithms and relations, changes and variations can occur in real time. Despite the fact that verbal rules of the medieval and renaissance architecture may resemble parametric or algorithmic instructions that generated a multiplicity of forms, they do not incorporate flexibility in the design process in such a way that parametric models do. Multiplicity and flexibility occur in verbal rules because they are open to different interpretations as meaning cannot be transmitted (see the difference between communication and conversation in chapter 6), and that is not different with printed images. In parametric models, multiplicity and variations are generated in a process where there is no ambiguity in the model - a result of the explicit relations (constraints) established by the designer within the digital model.

4.3. Parametric models

The two main approaches to 3D design are *explicit* and *parametric modeling*. In explicit modeling the designer interacts directly with the model with visual and physical interfaces (mouse, pen tablets, keyboard, etc.). Generally the model does not embed easily retrievable information. In parametric modeling approach, the parameters, relationships, and constraints are embedded within the model. In constructing a parametric model, the designer establishes the relationships by which each part (component) connects, creating an interdependency between them and the whole. By doing so, he operates directly with the flow of information that corresponds to the model. According to Davis (2013), the way in which a parametric model is created - "by a designer explicitly stating how outcomes derive from a set of parameters" - is what distinguishes it from other processes and representations. Davis argues that a parametric model is not unique because it "has parameters (all design, by definition, has parameters), not because it changes (other design representations change), not because it is a tool or a style of architecture, a parametric model is unique not for what it does but rather for how it was created". Following this reasoning, he draws from the mathematical characterization of parametric equations to define a parametric model as "a set of equations that express a geometric model as explicit functions of a number of parameters" (Davis, 2013, p.31).

The ability to change parameters in a model is thus associated with how the designer relates functions, parameters, and geometry. However, a look at how parametric models are constructed and used in practice reveal that the possibility to make changes in a parametric model is not easy as it may seem (Davis, 2013, Scheurer, 2012, Hudson, 2010). Changes in parametric models can be hindered by the hierarchical structure of parametric tools that encourages the user to develop long chains of geometrical dependencies that makes a model computationally heavy and slow (Hudson, 2010). Long chains of geometrical dependencies take time to construct and to update. In some cases the model structure can become so complex that even the designer who has create the model may find it troublesome to change the model. As Davis (2013) observes, sometimes it is easier to remake the whole model than to change a specific part of the model.

In a research on strategies for parametric design in architecture, Hudson (2010, p.165) indicates that restructuring of models is "an integral part of the design process and that it should be considered as an essential procedure when creating any parametric model." He advocates that the model can be structured to provide users with control of progressive levels of detail, and by doing so it minimises update time cost by preventing unnecessary complexity (Hudson, 2010). What Hudson indicates is that parametric models can be built to enable change. However, the challenge to create, what he calls, *reusable models* differs from that of developing *one-off models*. It requires extension of the functionality, more accuracy, more time to develop, and involvement of more people both in development and when the model is in use. From his analysis, Hudson (2010) concludes that *reusable models* should be considered as a parametric design task that could cover a wide range of processes in design offices, alike to parameterizing standard building types such as apartments, offices, or internal spaces. However, he does not put into consideration the possibility that those reusable tools could be adopted and designed for other stakeholders and laypeople.

In a parametric model, inputs are interwoven to specific outputs through an encodement model of communication (refer to chapter V, section 5.4). If information is changed in one part of the model this affects the whole model. Because the encodement model of communication does not involve meaning, many authors regard parametric models as neutral tools. However, as Woodbury (2010) points out, “the way in which data flows deeply affects the designs possible, and how a designer interacts with them.” The choice of inputs and outputs and how they relate to one another is a design decision. In the same direction, Benjamin (2012) advocates that the “process of evaluating a parametric model reinforces the need for clearly defining design objectives (also called fitness criteria). Design objectives are values: they are the goals and desires of a project that involve judgment and beliefs, outside of efficiency and computation.” Benjamin (2012) acknowledges the potential of opening the parameters to users and states that “if the values of a project could be exposed and stated in plain language, then the digital model could become a platform for debate and discussion.” This debate can go beyond the traditional cycles of design professionals and involve a broader audience with, for example, people who are going to feel the impact of a given building in their context. In this sense, parametric models could become a “platform for an open and inclusive process of design” (Benjamin, 2012).

4.4. Parametric Software

> [The Analytical Engine] might act upon other things besides number, were objects found whose mutual fundamental relations could be expressed by those of the abstract science of operations, and which should be also susceptible of adaptations to the action of the operating notation and mechanism of the engine...Supposing, for instance, that the fundamental relations of pitched sounds in the science of harmony and of musical composition were susceptible of such expression and adaptations, the engine might compose elaborate and scientific pieces of music of any degree of complexity or extent. (Ada Lovelace, 1843[74]).

The first documented computer program, written by Ada Lovelace in 1843, was formulated with Charles Babbage's algorithms for his *Analytical Engine*, which was based on varying parameters (Frazer, 2016). Her notes about the *Analytical Engine* Lovelace (1843) foresaw that "objects found whose mutual fundamental relations could be expressed by those of the abstract science of operations" could be used as an input to the Analytical Engine. In a famous quote, she stated that "the Analytical Engine has no pretensions whatever to originate anything. It can do whatever we know how to order it to perform. It can follow analysis; but it has no power of anticipating any analytical relations or truths." In her notes about the Analytical Engine, Lovelace anticipated the open and indeterminate nature of computers. The functionality of a computer is not solely determined by its hardware, and can be changed according to the software it is running. Although the idea of varying parameters was already present in Lovelace and Babbage's works, it took more than 100 years before it was effectively used in a CAD software in a way that the designer could easily access and manipulate those parameters.

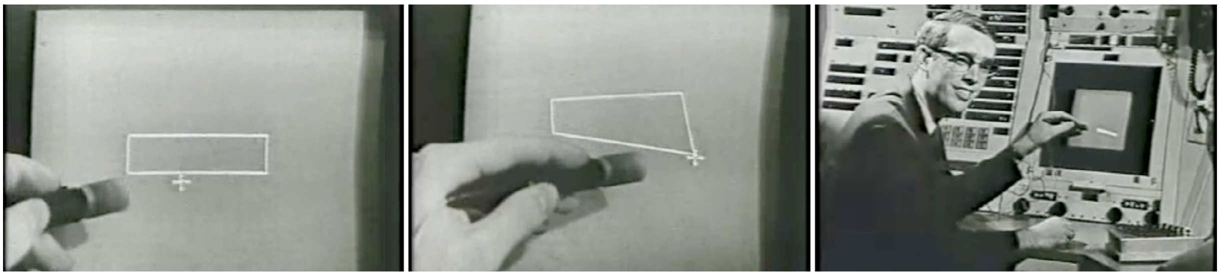

Figure 46 | Timothy Johnson operating the Sketchpad System. After a giving a command Sketchpad corrects the lines drawn by Timothy to a parallel position (Davis, 2013).

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[74] Analytical Engine :: Museum of Imaginary Musical Instruments [WWW Document], n.d. URL http://imaginaryinstruments.org/lovelace-analytical-engine/ (accessed 5.15.17).

In design, the concept of varying parameters in architectural representation came with the development Ivan Sutherland's *Sketchpad System* (1963) during his doctorate at MIT. The system enabled the user to change the drawing without breaking the chain of geometrical relationships. In a famous presentation of *Sketchpad*, Timothy Johnson drags a pen across a small screen of a room-sized computer. The video shows that the user could sketch the general topology, and by establishing relational constraints the engine could adjust the drawings within pre-established criteria. Geometries could be changed, copied, and manipulated without losing the initial constraints. For Steven Coons (1975, p.53), the system made "modest but seemingly intelligent responses to (graphical) actions of its human companion" and therefore "did not behave like a complete idiot". Sutherland (1963) went further to suggest that computer drawings could index different layers of information - anticipating what is now called Building Information Modeling (BIM).

The idea of associating geometry with an underlying database was later further developed in software like Radar CH[75] or REVIT[76]. Although both software made significant advances in architectural representation, they were built based on standard building workflows that normally do not leave much space to different approaches to design. Most software developers were more focused on the improvement in productivity and the automation of repetitive tasks, than to enable novel creative forms of exploring data, algorithms, and variables in the model. The developers draw their decisions from economic considerations leaving behind novel approaches.

The possibility to build parametric models was present since the first CAD systems. However, the feasibility to access and operate with interrelated variables and algorithms was restricted to those who were proficient in scripting languages. The majority of the main CAD software were built for expert users, and most do not explore the possibility of creating interchanges between designer and user. As observed by Sweeting (2017, personal communication, 24 June), "there is a tendency for technological development to

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[75] Radar CH was created in Budapest by Gábor Bojár in 1982, later known as ArchiCAD and the first BIM software made available on a personal computer.

[76] Revit, now one of the most popular BIM software, was conceived by Parametric Technology Corporation (PTC) and later purchased by Autodesk

support aspects of the professional role of the architect, such as information management and production information, but not the disciplinary role of design.” In this context, the work developed by Negroponte (1975) at the Architecture Machine Lab discussed on the previous chapter (section 3.3.) is still relevant to indicate different approaches towards the development of new design interfaces that collaborate upon and contribute technical expertises to the designers design intentions. Negroponte sought to amplify, or even completely change, the design process exploring the use of digital devices beyond computerization.

Because most software only reproduced and automated conventional design processes, architects and designers wanting to explore digital processes further in their praxis could either recur to software, design methods, and specialists from outside the design field[77], or to develop their own digital tools and processes. From this experiences, new companies were created with a focus on translating design intentions to executable digital notations. Companies such as Gehry Technologies at Gehry Partners, Specialist Modelling Group at Foster and Partners, Advanced Geometry Unit at Arup, CODE at Zaha Hadid Architects, began to offer their service to other architects and stakeholders. More recently, this expanded to a new specialization within digital design, where design professionals are specialized in developing design solutions and algorithms for geometrical definitions, form-finding processes, facade design, and structural engineering. Examples are Knippers Helbig Advanced Engineering[78], Design to Production[79], Balmond Studio[80], Programing Architecture[81] and One to One[82].

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[77] A recurring example in literature is the use of CATIA in the design of the Barcelona Fish by Gehry Partners, with the consultancy of Rick Smith from Virtual Building Technologies.

[78] Knippers Helbig Advanced Engineering. [Online]. Available at: http://www.knippershelbig.com/ [Accessed 9 November 2017].

[79] Design-to-Production. [Online]. Available at: http://www.designtoproduction.com/en/ [Accessed 9 November 2017].

[80] Balmond Studio. [Online]. Available at: http://www.balmondstudio.com/ [Accessed 9 November 2017].

[81] Programming Architecture - Automating Building Industry. [Online]. Available at: http://www.programmingarchitecture.com/ [Accessed 9 November 2017].

[82] ONE TO ONE. [Online]. Available at: http://www.1to1-design.com/ [Accessed 9 November 2017].

During the first decades of the exploration of digital processes, there was a dependency on a profound programing knowledge. Nowadays, the dissemination of new design environments that enable algorithmic techniques have visual programming interfaces that facilitate the construction of parametric models. Those visual programming systems enable designers, with little knowledge of software engineering, to build custom design tools and mediums using algorithm building blocks, bringing them closer to the inner logic of computers. This is the idea behind parametric software, such as Grasshopper 3D and Generative Components, which offer an open canvas with a wide array of parameters and components that can be linked together using graph structures. As observed by Frazer (1995), "the computer is a device with the power and speed to meet the requirements of the limits of our imaginations." In that sense, parametric software opens an enormous field of possibilities, where everything that can be digitalized and parameterized, can be used as input in parametric models. However, Veloso and Pratschke (2014) also warn that parametric modeling tends to be restricted to the expansion of formal geometrical operations and run the risk of simplifying architectural problems. Furthermore, Celani and Vaz (2012) observe that, from a pedagogical point of view, the use of visual programming may be adequate for introducing students to general programming concepts, but can be restrictive for more advanced users, who can benefit more from scripting languages.

The wide range of possibilities offered by parametric software to create and modify definitions and CAD processes, lead many authors to associate parametric modeling with digital toolmaking. Mark Burry (2011, p.8) states for example that "we are moving rapidly from an era of being aspiring expert users to one of being adept digital toolmakers." Thomas Fischer (2008) explores the idea of designing digital tools for designing digital tools for designing digital tools in a recursive manner. In his thesis, the term design tools is taken as synonymous of the term design systems that encompasses all that support the production of design outcomes. Frazer (1995, p.24), in his turn, writes of a "toolbox" that the designer has to build to assist and explain formative processes. Along this lines, the idea of digital systems as tools, and of parametric modeling as toolmaking is a recurrent one, notwithstanding it is not unanimous.

Davis (2013, p.27) questions the idea that parametric modeling is analogous to toolmaking, and argues that this view - unintentionally or not - is connected to the perspective that designers "become fixated on what 'completed' parametric models do, often leaving out details of how parametric models are created and changed". The term tooling suggests a distinction between tool production and application. Davis (2012, p.27) stresses that the implied division between tool use and tool making leads to the belief that the creation and use of a parametric model is temporally separated. He urges that the focus should be placed in the process and not in the final parametric model.

4.6. Parametric Design

Parametric design represents an approach to digital design that explores constraints and variability in models, objects, and systems. Parametric models and software are essential elements in the parametric design process. However, the notion of parametric design can not be restricted to the mathematical definition of parametric equations, nor limited by the use of a specific software. The focus on the geometrical topological possibilities without considering a wider opportunity offered by parametric design, may restrict the possibilities offered by the concept. Understanding parametric design from a broader perspective, beyond models and software, can lead to a design logic that associates material systems, computational processes, and human systems.

Oxman and Oxman (2014) distinguish three important domains of parametric design: (1) differentiation; (2) informed tectonics; and (3) continuities from design to digital production. Differentiation can be defined as "the local distortion, or unique modulation, of a continuous tectonic model in order to accommodate local requirements." (Oxman and Oxman, 2014, p.138). Parametric modeling enables form generation techniques to design modulations and patterns where each component can have unique attributes. Informed tectonics is a concept that identifies the singularities of new tectonics developed with the integration of design, materialization, and fabrication through information. It is related to the combination of tectonic design, performative evaluations, and generative procedures within parametric mutations as the operative basis for performance-based design (Oxman and Oxman, 2014). Continuity from design to production highlights the bi-directional flow of information between design and production. Parametric models can be continuously updated with empirical data in a circular design process. Within this particular logic, the parametric model can be informed with material and fabrication constraints.

Most conventional design processes prioritize the elaboration of form over performance where shape is forced into matter. As observed by Achim Menges (2014), "in today's practice digital tools are still mainly employed to create design schemes through a range of design criteria that leave the inherent morphological and performative capacities of the employed material systems largely unconsidered." This is the case in a construction process of a conventional concrete structure. A concrete beam may be made according to various concrete mixtures specified according to certain external parameters such as the span or the load applied to the structure. Normally, the mixture will be distributed homogeneously along the beam, even when the load acts heterogeneously along the structure. This form of using materials may generate waste because only part of the material will be employed efficiently. Oxman (2012) points to a different approach that combines computation and material behavior and argues that it is possible to program the variation of the material properties through digital manufacturing with functional gradation. In the same beam, concrete can be denser where stresses are higher and gradually thinner where they are smaller, decreasing their weight and improving structural performance. This process demands from the designer a new set of skills and strategies that bring them in close contact to material behavior.

What underlies those principles is the ability to control the information flux and variables within and outside the model. Within this context, Neri Oxman (2012) discusses the possibility of programming physical matter as a design strategy associated with new digital manufacturing processes, such as the 3D printer and robotic arms. In many materials found in nature, certain physical properties of the same object vary according to the direction in which they are measured. This feature, called anisotropy, is explored by several designers to be used as a design strategy based on material properties and the programming of physical matter with digital fabrication techniques. By programming how the material properties are organized it is possible to improve its performance. The idea of programing matter is not new in human history. Damascus blades, for example, were made with an ancient art of forging that informed metal by rearranging its molecules making it stronger. What changes today with computers is that information can now go both ways in shorter feedback cicles.

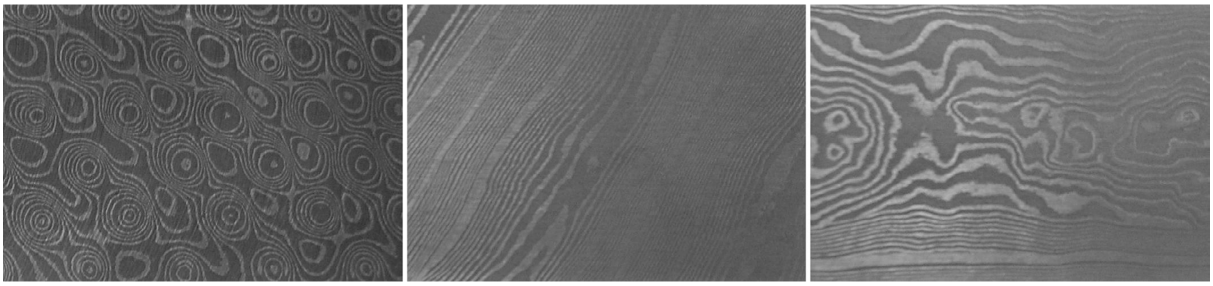

Figure 47 | Damascus steel with different patterns. Source: Admiral Steel - (Knife & Sword Blade Steels, 2017)

Similarly, Menges (2014) proposes an alternative approach to design that interrelates formation and materialization processes to generate morphological complexity and performative capabilities. Parametric models are used to create complex interrelations between form, material, and structures. Menges (2014) calls this process "computational morphogenesis," where the design constraints are established by the constraints of material systems. Material systems are defined as "the complex reciprocity between materiality, form, structure and space, the related processes of production and assembly, and the multitude of performative effects that emanate from the interaction with environmental influences and forces" (Menges, 2014). Within this frame, computational design processes can be used to explore a system's performative capacity within the material constraints. Design is then a result of the interaction between the material system's behavior and the designer's intentions, in a process mediated by computation. The material behavior is parameterized and used as design input in parametric models, which in turn defines the behaviour of the output of the material system, creating a circular flux of information between material systems and computational systems. When those behaviors are dynamic, it enables the creation of responsive architectures, where the design parameters remain variable within the finished system. HygroSkin (2013), a project coordinated by Achim Menges, Oliver David Krieg, and Steffen Reichert, exemplifies this potential by using inherent behavior of wood as design variables (Krieg et al., 2014).

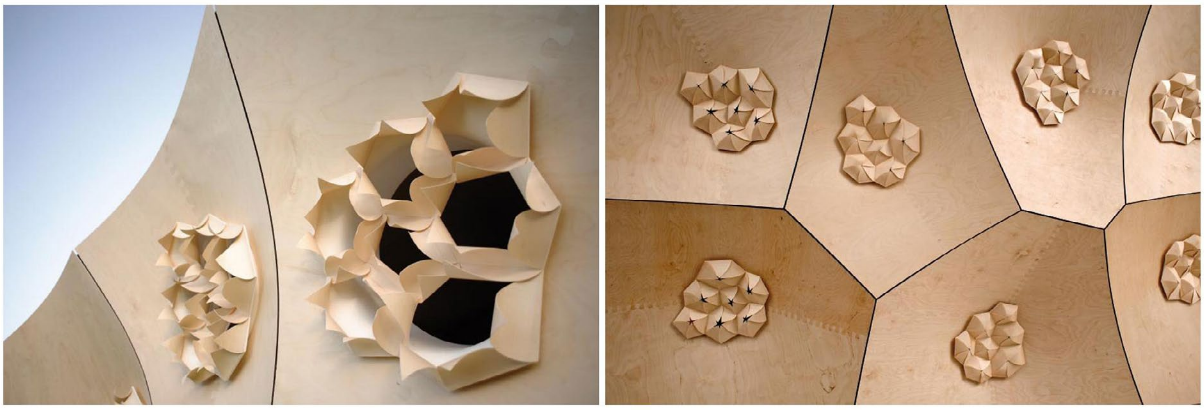

Figure 48 | HygroSkin: Meteorosensitive Pavilion. Details of the hygroscopic apertures. (Krieg, et all, 2014).

The project explores the combination of material behavior and computational processes to create a dynamic system that responds to climate changes without the need for any technical equipment. It is a "no-tech strategy" to interactive systems that explores hygroscopic[83] and anisotropic dimensional changes where "the responsive capacity is embedded in the structure of the material itself" (Menges and Reichert, 2012). Menges and Reichert (2012) explore the idea of physically programming matter by regulating its performance. Because the dimensional change of wood is directly proportional to changes in moisture content, the swelling or shrinking dimensions can be mapped and parameterized. In combination with synthetic composites, this changes can be programmed to compute different forms. Computational design is integrated to generate and simulate various forms and behaviors. As Menges and Reichert (2012, p.57) observe, "in this process, the surface geometry is algorithmically generated and controlled through a number of parameters and constraints based on the material's anatomy, characteristics, and behavior."

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[83] Hygroscopicity "refers to a substance's ability to take in moisture from the atmosphere when dry and yield moisture to the atmosphere when wet, thereby maintaining a moisture content in equilibrium with the surrounding relative humidity" (Menges and Reichert, 2012:54).

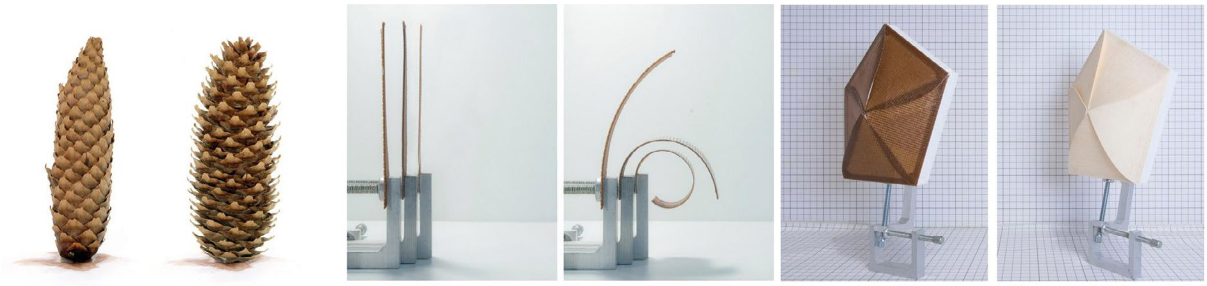


Figure 49 | Transfer of the biological principle of shape change induced by hygroscopic and anisotropic dimensional change. (Krieg, et all, 2014).

Achim Menges and Neri Oxman concepts of material computation and programming matter point to the notion that parametric design is not limited to the digital realm of computational processes, but can be further explored by integrating material systems and generative techniques within a parametric system. In that sense, parametric design can be understood as a design process that employs parametric models to establish explicit relations between variables and constraints within and outside the model. One key technology that enables an informative process that integrates conception and production of material and structures is digital fabrication.

4.7. Digital Fabrication

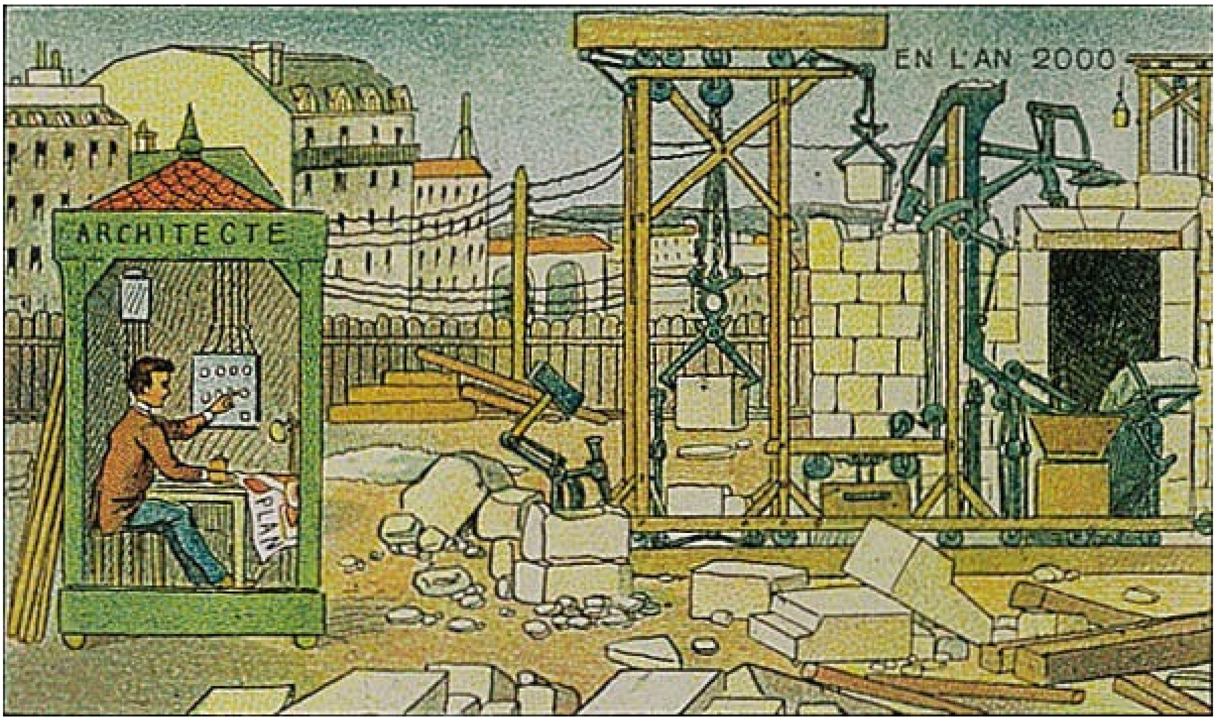
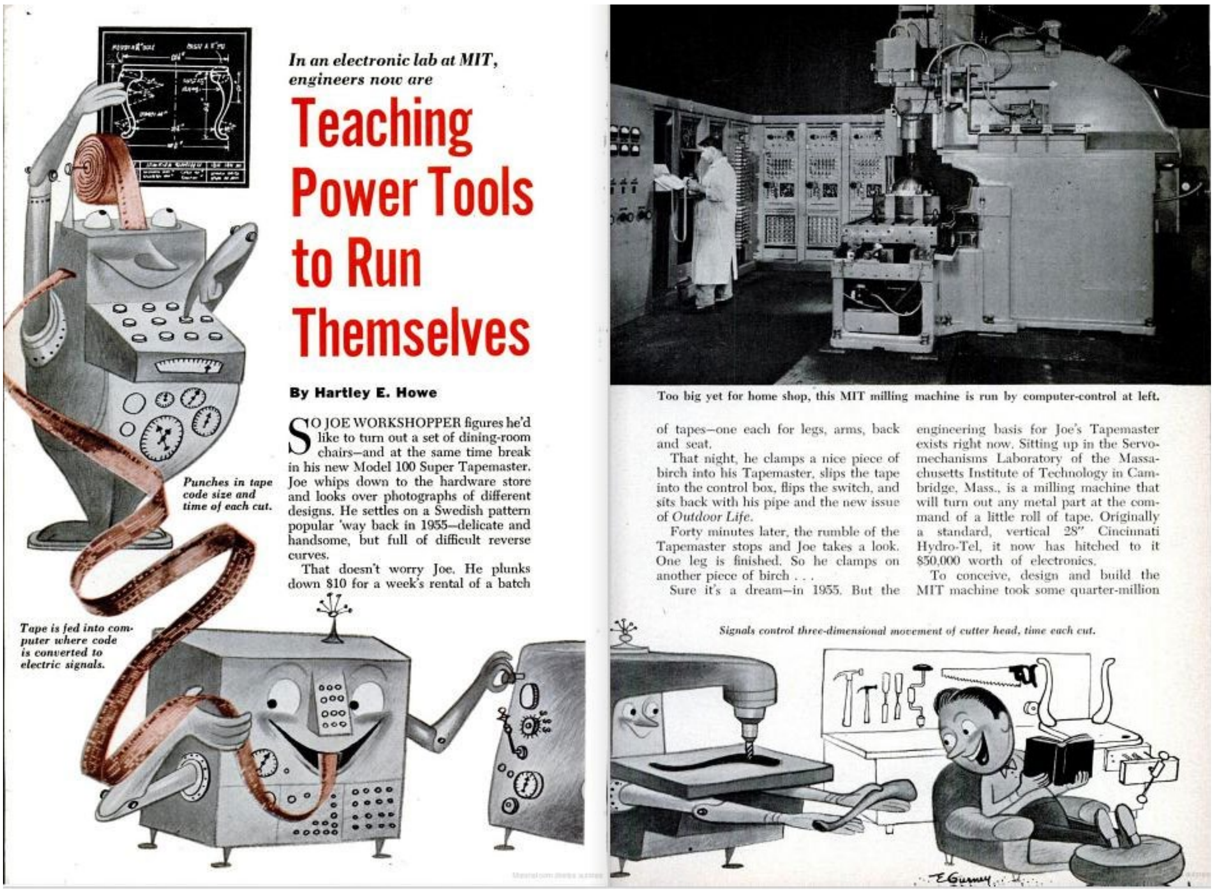


Figure 50 | In this figure of the series En L'an 2000 Architect in control of a construction process. (Asimov, 1986).

In the 1955 August edition of Popular Science, an article by Hartley E. Howe (1955) was published with the heading: Teaching power tools to run themselves" (Figure 50). The article starts with the story of Joe, who wanted to make a new set of dining-room chairs. Instead of making one manually, he rents a batch of punch-card tapes containing the codes for the design of the chair and runs them on a Numerically Controlled (NC) machine. While the machine does the job to fabricate the parts of the chair, he leans back to smoke a pipe and read a magazine. The milling machine that inspired this exercise of futurology was developed by the Servomechanisms Laboratory of MIT during the 1950s. At that time, such machine did not fit in a workshop and needed a roof of its own to house its 270 vacuum tubes, 170 telephone-type relays, and 300 germanium diodes (McDonough and Susskind, 1952). The NC machine operated with a paper tape punched card that coded size and time of each cut. The tape was fed into the computer (called the machine director) where codes were converted into electric signals that controlled the three-axis movement of the cutter head.

The developers expected that such machine would bring substantial changes in the industry. Howe (1955) predicted that it could be remotely controlled by radio transmissions of codes, enabling several machines to be controlled from one central headquarters. Little machine shops would be capable of tackling big jobs by buying or renting control tapes. However, the main advantage of the Numerically Controlled Machine was the ability to rapidly make different objects and parts without changing its general configuration - in other words, it could be used to make custom objects. Furthermore, another advantage was that the design codes could be recorded magnetically so that a machine owner did not have to own a computer - he could buy, rent or share each design.



In an electronic lab at MIT, engineers now are

Teaching Power Tools to Run Themselves

By Hartley E. Howe

SO JOE WORKSHOPPER figures he'd like to turn out a set of dining-room chairs—and at the same time break in his new Model 100 Super Tapemaster. Joe whips down to the hardware store and looks over photographs of different designs. He settles on a Swedish pattern popular 'way back in 1955—delicate and handsome, but full of difficult reverse curves.

That doesn't worry Joe. He plunks down $10 for a week's rental of a batch of tapes—one each for legs, arms, back and seat.

That night, he clamps a nice piece of birch into his Tapemaster, slips the tape into the control box, flips the switch, and sits back with his pipe and the new issue of *Outdoor Life*.

Forty minutes later, the rumble of the Tapemaster stops and Joe takes a look. One leg is finished. So he clamps on another piece of birch . . .

Sure it's a dream—in 1955. But the engineering basis for Joe's Tapemaster exists right now. Sitting up in the Servomechanisms Laboratory of the Massachusetts Institute of Technology in Cambridge, Mass., is a milling machine that will turn out any metal part at the command of a little roll of tape. Originally a standard, vertical 28" Cincinnati Hydro-Tel, it now has hitched to it $50,000 worth of electronics.

To conceive, design and build the MIT machine took some quarter-million

Punches in tape code size and time of each cut.

Tape is fed into computer where code is converted to electric signals.

Too big yet for home shop, this MIT milling machine is run by computer-control at left.

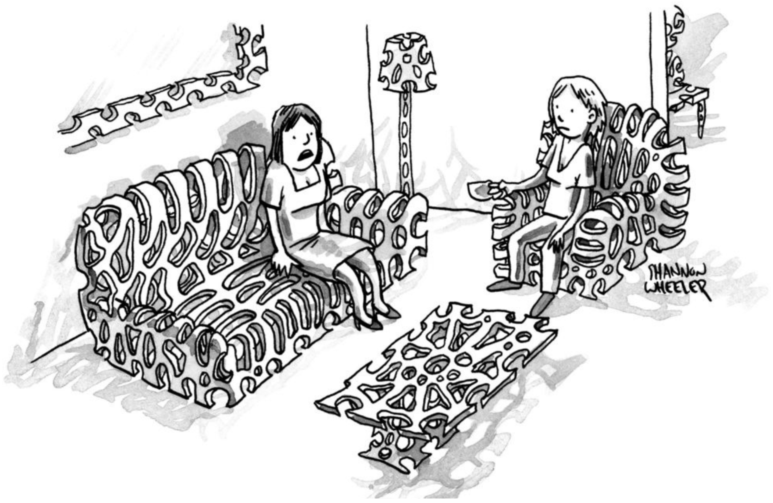
Signals control three-dimensional movement of cutter head, time each cut.

Figure 51 | Two pages of Hartley E. Howe (1955) article published in Popular Science about the Numerically Controlled Milling Machine named Mass. (Howe, 1955).

During the first years of development, those machines were not envisioned to be used by or for designers, and most explorations were directed towards aerospace engineering. It would take a few decades before it could be integrated into a building workflow. Although there were significant technological developments during the following decades, such as the evolution and integration of computers in the process, the main concepts, potentials, and expectations did not change much since the 1950s. The now called *Computer Numerically Controlled* (CNC) machines have passed from room-size scale to desktop proportions. It adopts digital coding instead of radio transmissions and can make use of the internet to send or download digital files from all over the world. Designs are shared on various websites, and many can be freely downloaded. The idea of customization is taken a step further where people can download a design, make adaptations and "print" it at home. Machine workshops, frequently called maker-spaces, have many different CNC machines at their disposal and can produce complex objects. CNC tools enable to translate data almost directly to physical objects, materials, and structures in such a way and speed that would have been impossible without computational capabilities. In a CNC machine, making several copies of an object is almost the same effort as making several different objects. Therefore, they are proper tools to custom-produce objects. It not only provides a medium for creating different iterative cycles with rapid prototyping techniques, but also enables the creation of innovative design methods, assembly, and fabrication processes. In some sense, Howe's predictions were fulfilled and even surpassed.

Curently, the various CNC technologies are delineating an emerging body of concepts associated with computer aided fabrication processes that can be defined as *digital fabrication.* Digital fabrication is "a way of making that uses digital data to control a fabrication process" (Iwamoto, 2009). The main operations associated with the concept are cutting, forming, adding, and subtracting. The aforementioned processes are frequently associated with other traditional fabrication techniques. *CNC cutting*, also called *two-dimensional fabrication*, consists of a cutting tool operating in a two-axis motion in relation to a sheet material. The most common cutting technologies are laser-beam, plasma-arc and water-jet. *Formative Fabrication* are processes where materials are reshaped or deformed by the application of mechanical or thermal forces to a material to give it a predetermined shape. CNC bending or Thermoforming are the most common formative processes. (Kolarevic, 2003)

Additive fabrication is today one of the most popular digital fabrication processes. The term refers to a range of different technologies that generate physical objects by adding layers of material. Because of the wide range of technologies, it receives different labels, such as *layered manufacturing*, *solid freeform*, and *desktop manufacturing* (Kolarevic, 2003). Most technologies consist of the breaking down of a digital model in 2D slices and in rebuilding it physically layer by layer. The fascination with the ability to have an idea materialized almost instantly, have brought much attention to additive manufacturing technologies in the last years[84]. Although the technology to "print" objects was already available in the last decades, they were monopolized by large companies such as Stratasys that did everything they could to prevent the technology to be disseminated. Nowadays, a portable 3D printer can be as cheap as $100,00 (ONO[85]), and open source blueprints for 3D printers are freely available online enabling small companies and people at home to build their own additive manufacturing machines. In addition to having an increasingly affordable cost, additive fabrication offers the possibility of reusing materiais by means of different recycling techniques[86].



"I wish I'd never bought Harold that 3-D printer"

Figure 52 | The cartoon by Shannon Wheeler, "I wish I'd never bought Harold that 3-D printer", depicts the ubiquity of 3D printers with the associated idea that it can be used to do anything. (Wheeler, 2016).

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[84] A third industrial revolution, 2012. . The Economist.

[85] ONO 3D Printer and Resins [WWW Document], n.d. . ONO 3D, Inc. URL https://store.ono3d.net/collections/all (accessed 8.12.17).

[86] Make New Filament From Old 3D-prints (Recycling) [WWW Document], n.d. . Instructables.com. URL http://www.instructables.com/id/Make-New-Filament-From-Old-3D-prints/ (accessed 10.8.17).

Although all digital fabrication techniques are considered CNC processes, additive manufacturing is treated by some as *rapid prototyping* (Oxman and Oxman, 2014). However, with the latest developments on concrete printing, additive manufacturing cannot only be used in prototypes but also in full-scale construction. Initiatives such as *3D Print Canal House* from Dus Architects[87], *Contour Crafting* by Behrokh Khoshnevis, Stroybot concrete printer by Andrey Rudenko[88], MIT's Robotic Printer from the Mediated Matter Group[89] and Apis Cor[90] mobile 3D concrete printer are evidence enough that scale is no longer an issue.

Subtractive fabrication consist of the removal of matter from a given material using electro-, chemically- and mechanically-reductive processes. The most common technology is CNC milling, which has been used in architecture and design since the early 1970s (Kolarevic, 2003). There is a wide range of CNC milling machines that vary in size of the milling bed, number of axis (from 2 to 7), and degree of automatization of the tool. Because the tool can operate in several axis, defining an appropriate "tool path" is not a trivial task, and generally involves skilled operators. The instructions of how the machine is going to execute a given task is called G-code.

The latest developments in digital fabrication are being achieved with the combination of CNC tools with industrial robots, in what is called *Robotic Fabrication* (Oxman and Oxman, 2014). Robots can perform additive fabrication (brick laying and 3D printing),

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[87] Dus Architects developed a additive manufacturing machine called The KamerMaker in an effort to build the first house using additive technologies. The Canal House is made of different elements that are printed separately and mounted on site. The process was estimated to take three years. According to DUS Architects (2016) the 3D print Canal House is a "publically accessible Research & Design by Doing project focused on four main directions: (1) software tools and global online user interface development; (2) smart parametric design and engineering; (3) development of extra large (XL) 3D printers and print networks; (4) development of new bio-based, sustainable and recyclable materials and product innovation. 3DPRINTCANALHOUSE by DUS Architects [online], n.d. URL http://3dprintcanalhouse.com/ (accessed 5.23.17).

[88] Andrey Rudenko is one of the first to build an entire house using additive manufacturing. In 2014 he printed a miniature castle onsite in Minnesota. In 2015 he went further and printed a 100m2 Hotel Suite at the Lewis Grand Hotel in the Philippines in 100h (excluding stops to install plumbing, wiring and rebars). Rudenko 3D Printer [WWW Document], n.d. . Andrey Rudenko. URL http://totalkustom.com/rudenko-s-3d-printer.html (accessed 5.23.17).

[89] 3-D printing offers new approach to making buildings [WWW Document], n.d. . MIT News. URL http://news.mit.edu/2017/3-d-printing-buildings-0426 (accessed 5.24.17).

[90] Apis Cor | We print buildings [WWW Document], n.d. URL http://apis-cor.com/en/ (accessed 5.24.17).

subtractive fabrications (when combined with routers - see figure 53), and formative process (weaving and folding). Thomas Bock and Silk Langenberg (2014) argues that the introduction of robotics in construction is part of an ongoing process of industrialization and automation of the building site that started in the industrial revolution. Flexible industrial robots are being more widely used in the prefabrication of building elements and in architectural research institutions. However, before real change occur, design, management, and engineering will have to comply with the robot as a new tool, going beyond the attempt to merely copying and perform long-established construction and fabrication technologies. (Bock and Langenberg, 2014). The crucial question seems to be an approach towards digital fabrication and robotic fabrication beyond computerization, towards computation, where design and fabrication tools become mediums.

Figure 53 | AA Design + Make » (Woodchip Barn, 2015)

The seductive nature of digital fabrication is encouraging designers to explore the creation of innovative design processes with specific digital tools and methods. In *Digital Fabrications: Architectural and Material Techniques*, Lisa Iwamoto (2009) brings together and classifies various “works designed and built by emerging and newly defined practices that, with a do-it-yourself attitude, regularly pioneer techniques and experiments with fabrication processes on a small scale.” In those experiments, the architectural project represents a form of design research were the design aesthetic is a product of the association of digital representation and digital fabrication methods. It shows the architect in full control of the design and fabrication process using different digital fabrication techniques to produce small scale interventions. Those investigations can be associated with a process called *Fabricating design* (Oxman and Oxman, 2014, p.300), that reverse the traditional design process into a new design workflow that goes “from tool to process to form”. As Oxman and Oxman (2014, p.300) observes, “tooling design by fabrication means that the *form generative potential of the tool to materialize form*[91] can be exploited as a generative paradigm.” In the same direction, Barkow and Leibinger (2012) observe from their practice that speculative explorations with digital fabrication processes may lead to novel approaches. They explore how new technologies can inform the design process and outcome.

Although CNC tools are widely used in industry, the integration of Computer-Aided Manufacturing (CAM) in construction industry requires the development of new production approaches in parallel with an understanding of traditional means and skills (Menges, 2006). Each custom project demands a custom fabrication and assembly process. Industrialized production follows standardized processes with standardized interfaces between the different specialists where each can remain within their own domain. In a non-standard project, there is no standard procedure (Scheurer, 2012). New processes have to be developed with the different craftsman’s involved in the fabrication procedures, and because they are custom-made, after a project is finished the whole process is discarded. Furthermore, in a design and construction process, constraints are not only imposed by design choices, but are defined also by fabrication and assembly contingencies. Components have to be stacked, transported, and lifted. In a non-standard building it is difficult to think that the designer alone will have the capacity to adjust the parametric model to cope with all those contingencies (Scheurer, 2012).

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[91] Italic by the author

Tibbits (2016) argues that the challenge of fully integrating computing into construction, assembly, and manufacturing, requires "bottom-up processes for construction and manufacturing whereby the materials are not only programmable in behavior but can collectively self-assemble and error-correct to collaborate with humans and machines and achieve far greater results than when operating individually." Tibbits (2016) points to a future where structures can compute and adapt on demand and systems can build/repair/reconfigure themselves. In other words, he points to the development of systems where digital fabrication is explored in a more dialogical way.

Tibbits (2016) proposal may be promising, but nowadays it is still far from being achieved. One of the many difficulties in the integration of digital workflows is the multitude of incompatible standards in software and hardware (Scheurer, 2012). Different software uses different file formats that restrict the interchange between platforms and digital processes. If there is a problem in communication between two people because of different languages, this does not hinder the success of the conversation. In this case, ambiguity in communication may even lead to novel and funny situations. Machines on the other hand, generally require communication without any ambiguity. One error in a line of code may lead the system to fail. Those and other difficulties in integrating a digital workflow points out that, in an architectural scale, the continuity between digital design and digital fabrication is not as fluid as many authors depict. From an empirical perspective offered by designers working within digital processes, such as Fabian Scheurer (2012), Daniel Davis (2013), and Roland Hudson (2010), it becomes clear that the digital workflow is not as continuous as it may appear and involve many gaps. It is perhaps within those gaps, where ambiguity emerges, that novelty may arise in its fullest potential.

4.8. Mass customization, personalization and design democratization.

Mass customization is currently one of the main concepts associated with parametric design and digital fabrication. The promise to deliver variety and personalization with efficiency and economy of scale is seen by many authors as a response to the Fordian paradigm of mass production and standardization. (Pine, 1993, Kolarevic, 2015, Nielsen et al. 2015). Nowadays, many companies are adopting parametric driven digital interfaces that enable the user to change design parameters in order to personalize a product. Some see the potential of product personalization as a possibility for democratizing design. (Kolarevic, 2015).

From a market perspective, consumers have become more demanding for variety, uniqueness, and personalization. The strategy "a few sizes fit all", from mass manufactures, leaves many users dissatisfied with products they buy because users needs are heterogeneous (Hippel, 2005). To address these issues companies began to focus on understanding and fulfilling the needs of individual customers. In this context, the concept of mass customization was put forward as a process that combines mass production and customization to comply with different needs without sacrificing efficiency and cost. (Noguchi et al., 2016). In architecture, several companies offer the possibility of configuring houses using online digital interfaces. Those systems are generally associated with specific design strategy that combines standard mass produced components to generate a non-standard personalized design. For Noguchi et al. (2016, p.112), the design interface is part of a service (S) that combines designing, producing and marketing a product. The housing components are labeled as products (P) covering production techniques - such as modularization. Mass customization (MC) can thus be modeled as: MC=f(SP) (Noguchi et al., 2016). In this system the degree of control offered to the user frequently depends on the design constraints determined in P.

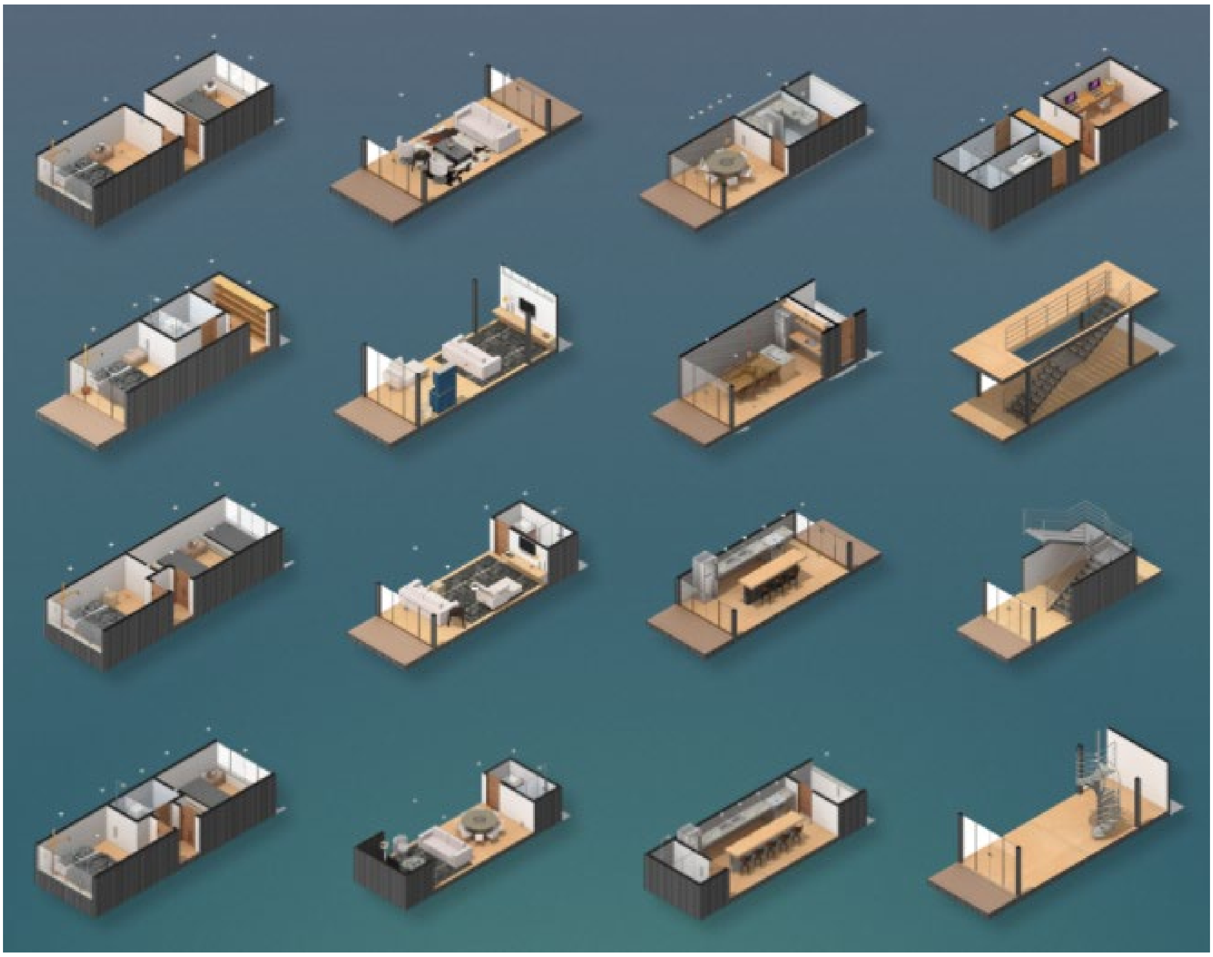

Figure 54 | 16 modules of CASA CHASSIS. (Hometeka, 2014).

An example of a customizable house system developed within this logic is CASA CHASSIS[92] (figure 54), the winner of the Binbom design competition held in 2014. The architects developed 16 initial modules that can be recombined to generate spatial variations and different plans. The modules can be prefabricated and transported to the site. Other examples that use modular processes for mass customization are Resolution: 4 Architecture's (RES4) prefab homes[93], and BluHomes[94] with its 3D configurator interface. For Kolarevic (2015), this kind of process offer ways to customize predefined house designs, but do not offer dimensional customization with the possibility to manipulate

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[92] CASA CHASSI : Projeto para casa container modular pré-fabricada : Hometeka [WWW Document], n.d. URL http://portfolio.bimbon.com.br/casachassi (accessed 10.7.17).

[93] Prefab [WWW Document], n.d. . RES4 | Resolution: 4 Architecture. URL http://www.re4a.com/prefab/ (accessed 10.7.17).

[94] Blu Homes | Modern, Green, Premium Prefab Modular Bay Area Homes. [Online]. Available at: https://www.bluhomes.com/ [Accessed 7 October 2017].

the house's overall geometry online. To enable "true" customization, he proposes that a mass customizable house should be "parametrically defined, interactively designed (via a website or an app), and digitally prefabricated, using file-to-factory processes." (Kolarevic, 2015, p.52). In this way, custom houses would be available for a broader segment of society, where users could make design decisions based on open-parameters defined by the architect. This would lead, according to Kolarevic (2015), to a democratization of the design process.

Figure 55 | Gramazio and Kohler's mTable. (Gramazio and Kohler, 2012).

Nowadays, there are many examples of design interfaces that associate parametric design and digital fabrication to enable people to customize designs and products. These interfaces can be differentiated according to the degree of control they offer to the user. At least three groups can be distinguished. The first group is characterized by design interfaces that offer a certain number of open parameters for the user to customize a given product. Those interfaces are frequently called "configurators", as they offer the possibility of configuring a predefined design by changing some attributes. Examples of this first group are Gramazio and Kohler's mTable (2002), Assa Ashuach Co-design[95] objects, Nervous Systems design systems, and Hermit Houses. mTable (2002), is a customizable design system where the user can make holes by placing deformation points in the tabletop of a parametrically variable table design (size, dimension, material, and color). (Figure 55)

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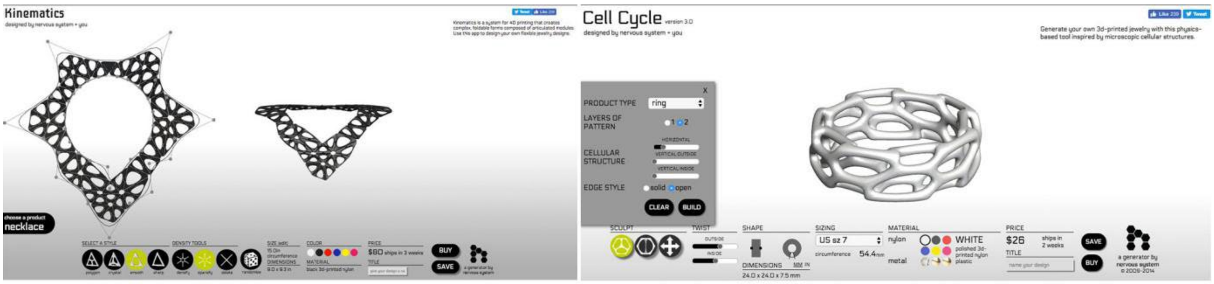
[95] ASSA ASHUACH STUDIO © [WWW Document], n.d. URL http://assaashuach.com/ (accessed 6.6.17).

a.Heliz Bracelet b. Openpen Pattern c. Loop Light Table

Figure 56 | Assa Ashuach (2017) design interfaces: Heliz Bracelet, Openpen Patter, and Loop Light Table. (Ashuach, 2017).



a.Kinematics - necklace b.Cell Cycle - Ring

Figure 57 | Nervous System design interfaces. (Nervous system, 2017).

Assa Ashuach Co-design is based on his concept of Digital Forming, a design system that involves software for customizing products and additive manufacturing method. This system allows product personalization and reconfiguration within an online interface, connecting the user, designer, and manufacturer. Each object has different open parameters, but in general most designs available online involve the change of color, pattern, and size. Likewise, Nervous System[96] offers several online design apps (figure 57) where users can change the design parameters and customize different products such as jewelry and puzzles. Some design interfaces created by the group offer the option for the user to download the product and print it at home using additive manufacturing (3D printers).

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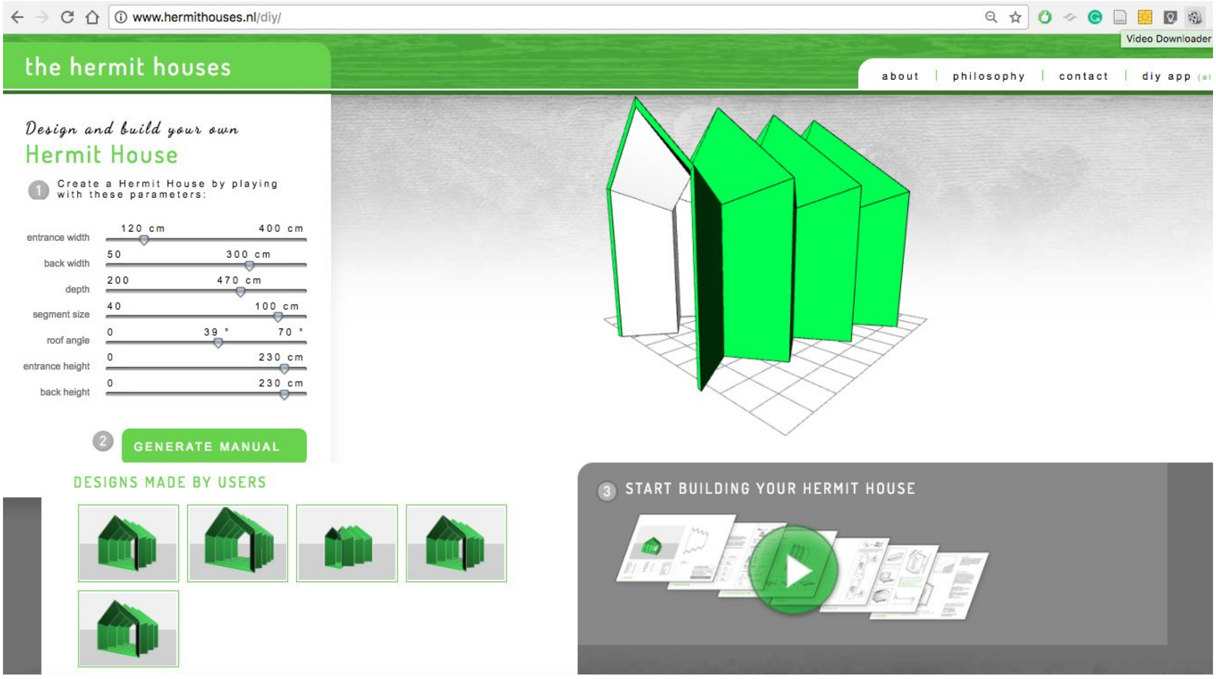
[96] Nervous System [WWW Document], n.d. URL http://n-e-r-v-o-u-s.com/ (accessed 5.6.17).

Hermit Houses, from The Cloud Collective, is an example of the possibility of designing custom houses using dimensional variation. The project associates an online interface (S) where the user can configure different dimensional open-parameters (figure 58) with a digital fabrication process (P). The interface generates 3D drawings for visual feedback, construction documentation and files for the CNC fabrication process.



1 Create a Hermit House by playing with these parameters:

entrance width 120 cm 400 cm
back width 50 300 cm
depth 200 470 cm
segment size 40 100 cm
roof angle 0 39 ° 70 °
entrance height 0 230 cm
back height 0 230 cm

Figure 58 | Hermit houses online configurator. (The Hermit houses, n.d.).

The second, and more promising, group of custom design systems is related to design interfaces that enable technical feedback between system and designer. Those interfaces can be seen as a simplified version of "design amplifiers" put forward by Negroponte (1975, p108) where the system contributes with technical expertise to the designers intentions. Those design systems do not only offer a choice of open-parameters to the user, but more importantly, empowers him to act.

Sketchchair is an example of a design interface constructed to facilitate the design of chairs intended for digital fabrication. The open source system enables the user to control, in a simple manner, the whole process, from design, evaluation, detailing, and manufacturing. The interface consists basically of a 2D work plan with drawing and editing tools. The design principle is based on 2D sections, where the object is sectioned in the longitudinal and transversal directions forming interlocking planes. The user can easily draw the profile of the chair and later adjust the layers and sections to determine the final shape. The software also includes a system that enables to test the ergonomy and to simulate gravitational forces. The ergonomy test is done with a figure that represents the human body and can adopt different measures. To check the proportions of the object, the software dispose of several reference images like tables, other chairs, etc. The product is a vector file with all the pieces of the chair that can be sent to a CNC cutting machine or even printed as a mold and cut by hand. The system was tested in a design workshop that revealed that people express preference for their own design rather than those sold in stores, and indicated that they would consider their chair less disposable (Saul et al. 2012).

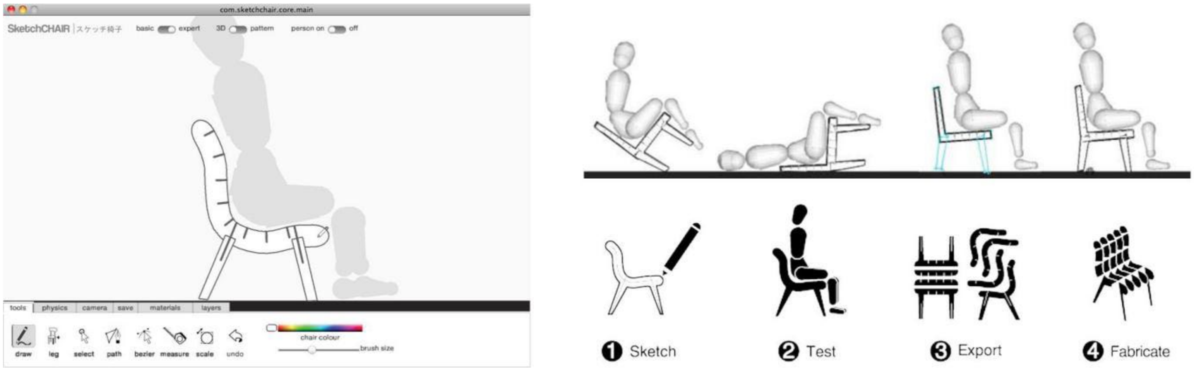
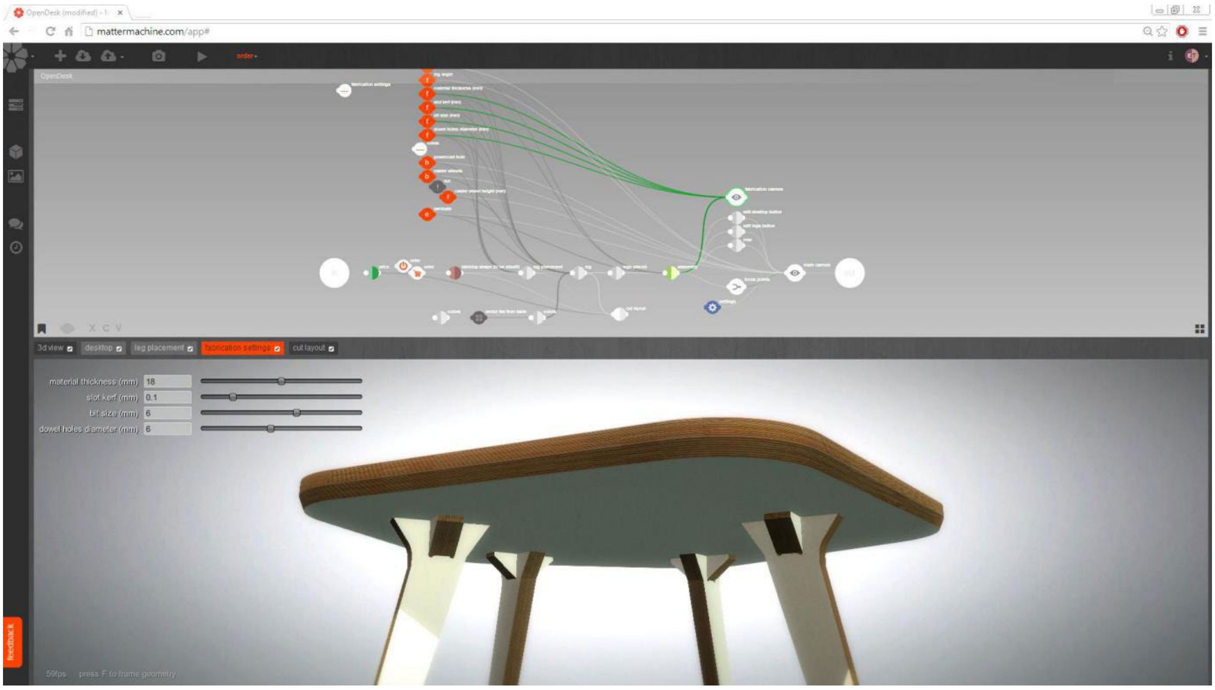


Figure 59 | Sketchchair Interface, and gravity simulation (Saul et al. 2012).

The third group is characterized by design interfaces developed to enable the creation of design interfaces. *Mattermachine* is an example of such interface that offers a parametric design platform to allow designers to create and provide customizable products over the internet. The design interface consists of a node-based editor where one component can be connected to another to form a parametric definition. The designer can create open-parameters for the user to customize the object according to his need. In this way, the design can be constructed dynamically, where the user defines the final parameters of the object. In this process, the degree of openness of the object to the intervention of the user is stipulated by those who establish the initial parameters. However, the user can also opt to make more profound changes in the design by assessing the parametric chain of constraints. The online design platform enables both forms of interaction with the use of two different interfaces, one with the open parameters called presentation mode and the other with the parametric definition of the object. Mattermachine stores a database with all designed objects which the user can access, change the parameters, and make the product available again generating a collaborative process and enabling dialogue between different designers. A designer can choose to distribute his designs for free or charge an access fee to the cut layout or codes for 3D printing. The program also allows different people to work simultaneously on the creation of the same model, allowing a greater collaboration between designers, engineers, manufacturers, among others.



material thickness (mm) 18
slot kerf (mm) 0.1
bit size (mm) 6
dowel holes diameter (mm) 6

Figura 60 | Mattermachine Interface with the node-based design programming environment above and the open parameters below. (Mattermachine, 2017).

The second and third groups of design interfaces can be associated to database design (Mul, 2011), where the designer creates a drawing space for inexperienced users. The creation of these metadesigns may represent a possible alternative to the growing control exercised by architects of the whole process of design and construction, made possible by the association between digital design and digital manufacturing technologies. However, if the number of open-parameters is not enough to create complex interactions and meaningful changes, the design process will be likely condemned to be what Negroponte (1975, p115) calls a “menu-picking activity”. In this process, objects can fit better, but this does not guarantees emotional attachment (Norman, 2004). “Things do not become personal because we have selected some alternatives from a catalog of choices. To make something personal means expressing some sense of ownership, of pride. It means to have some individualistic touch" (Norman, 2004, p220). Kolarevic's (2015) perspective on design democratization can be framed as such menu picking activity, and instead of a real democratization of the design process by transforming the user into a designer, the user becomes a consumer.

In a different perspective, Eric von Hippel (2005) credits the democratization of design to the radical and rapid improvement of the user's ability to innovate as a result of improvements on the quality of digital tools (hardware and software), access to easy-to-use tools and components for innovation, and access to a rich network of innovation commons. In architecture, for example, digital tools for design and prototyping were expensive assets frequently restricted to large offices. Nowadays, a 3D printer can be constructed at home using Lego[97] and many CAD software based on explicit and parametric modeling are open source [98]. Furthermore, as discussed in section 4.8, there is a large array of websites and design forums where designers share knowledge, designs, and codes. Within this context, Hippel (2005, p 1) observes that, "users that innovate can develop exactly what they want, rather than relying on manufacturers to act as their (often very imperfect) agents."

The idea of a "innovation user" relies on the fact that users have more information about their specific needs and use-context and as a result "tend to develop innovations that are functionally novel" (Hippel, 2005, p.8). The author therefore argues that companies and government fundings should shift from a manufacture-centric development system to a user-centered innovation process where "*need-related innovation*" tasks are outsourced to users. To enable this, users should be equipped with appropriate toolkits, defined as "integrated sets of product-design, prototyping, and design-testing tools intended for use by end users" (Hippel, 2005, p.8). Hippel and Katz (2002) question product configurators used by producers of mass customized products as it only offers a list of

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[97] LEGObot 3D Printer [WWW Document], n.d. . Instructables.com. URL http://www.instructables.com/id/LEGO-bot-3d-printer/ (accessed 10.8.17).

[98] FreeCAD: An open-source parametric 3D CAD modeler [WWW Document], n.d. URL https://freecadweb.org/ (accessed 10.8.17).

options that have been predesigned by the mass customizer. Instead of choosing from a list, the idea of user-based customization via toolkits is to enable non-specialist designers to design high-quality, producible custom products that exactly meet their needs. The concept of toolkit put forward by Hippel and Katz (2002) involves trial-and-error learning, user friendly interfaces, libraries that can be incorporated into custom designs, the creation of solution space that encompasses the designs they want to create, and direct communication with the manufacturer's production equipments. This set of principles can be valuable for designers to design for design empowerment and democratization of the design process using parametric design and digital fabrication. However, some caution is needed, as the concept of *innovation user* and *toolkit design* were developed in order to offer a viable model for companies to adapt to a new context where users are already creating, sharing, and customizing their products and objects. If those processes already exists, it is important to understand how to potentialize it, instead of investing on another bias where large companies outsource the creative endeavor yet maintain added value of the creation to centralize profit.

In this context, the Wikihouse.cc project can offer valuable lessons. If Wikihouse is compared to other systems such as Hermit House, many differences become clear. Wikihouse defines design principles while the Hermit House defines a shape. Although most of the principles of Wikihouse are essentially formal, there are concerns with user input in the design process, which opens possibilities for dialogue through the creation of communication channels. At the same time, it reveals the potential of parametric systems to trigger dialogues, especially if their basic assumptions include the user as co-responsible for the production of space. Wikihouse is not a product configurator, nor it is a toolkit for housing design. It is not a finished idea to be applied nor a specific method for constructing a house. Wikihouse can be seen as a self-replicating system with organizational closure that involves design principles, design interfaces, companies, engineers, architects, lay users, researchers, and others, in a creative network. Understanding this systemic perspective may be key for designing dynamic architectural systems.

4.9. Digital Conversations: from digital continuum to circular information flows

According to Kolarevic (2003), one of the most profound aspects of contemporary architecture is the new found ability to generate construction information directly from design information through new processes and techniques of digital design and digital fabrication. He observes that "much of the material world today, from the simplest consumer products to the most sophisticated airplanes, is created and produced using a process in which analysis, representation, fabrication, and assembly are becoming a relatively seamless collaborative process that is solely dependent on digital technologies." He stresses that the digitally-based convergence of representation and production processes represents the most significant opportunity for a profound transformation of the profession and, by extension, of the entire construction industry. According to Kolarevic (2003, p.10), "when applied to architecture, the use of digital technologies raises not only the question of ideology, form or tectonics, but also the question of the significance of information, and, more importantly, who controls it." If parametric models become the primary source of information in design, analysis, fabrication, and construction, it would put the designer in a central position in the building process. The architect would perhaps even regain the absolute powers of the medieval master builder - becoming a "digital master builder" (Kolarevic, 2003). From that perspective, it seems that computational processes are interweaving bits and atoms in a continuous workflow of digital information.

The idea of a digital continuum may be attractive to many architects, as it gives them apparent control over the whole process. It suggests that the design process is flattened into a linear continuum, connecting the initial idea to product, which can be parametrically differentiated and digitally fabricated, which enables, among other things, mass customization. However, this perspective can be misleading and may diverge the focus from what can be a true paradigm shift in the design and fabrication process. Looking from the outside, the product of the digital process that combines parametric design and digital fabrication techniques can indeed suggest a continuous and linear process from design to production. Notwithstanding, an inside look reveals that both parametric design and digital fabrication are subjected to different contingencies inherent to the design process.

The design endeavor is a circular active conversation (with oneself or with others) where novelty is generated (Glanville, 2009, Schön, 1983), and that is not different with digital design processes. Glanville (2000) relates this distinction between a linear and circular perspective of the design with the image of a wheel leaving tracks in the sand. In this metaphor, someone looking from the inside will see that the wheel is the active design (research) process that is in a constant dynamic move, whereas someone looking from the outside may only see the linear trace left in sand - the product. Glanville (2000) points out that the problem is when the trace is taken for the wheel, becoming distortive and potentially prescriptive[99]. Following this reasoning, from the outside the digital continuum may give the impression of a linear process, but an inside look reveals a process that involves circular conversations between the different craftsmen and stakeholders that are part of the design and building endeavor.

Effectively, that seems to be the case when looking beyond the product of experimental design processes that combine parametric design and digital fabrication. Most authors do not report on the problems and difficulties involved in the design and fabrication process. As Thomas Fischer (2008, p.245) observes, "failures and dead-ends (…) seem to be rare and overshadowed by the significant number of post-rationalised, outcome focused reports on digital design toolmaking." The ones that do report (Davis, 2013, Scheurer, 2012, Hudson, 2010) show that most processes involve different iterative development cycles in which digital computation is used in parallel with analog processes. Some of them even question to what extend digital processes should be used in the creative process (Reiser and Umemoto, 2012).

From that perspective, the notion of a linear and continuous digital process at an architectural scale gives a false idea of control that eliminates contingencies. In that sense, the digital continuum may not be much different from the perspectival paradigm that suggests a linear causal continuum between representation, making and use. Both notions disregards the social, political, and technical circumstances that frame architectural production - that is, as Jeremy Till (2013) puts it, ignores "the contingent nature of the

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[99] In this passage Glanville (2000) refers to science and doing. However, as Glanville sees science as a design activity his arguments are also valid for a discussion of the architectural design process.

architecture discipline". However, even if parametric design and digital fabrication does not eliminate contingencies, the notion of a digital workflow put forward by Scott Marble (2012) creates a different condition that favors the flow of digital information and the creation of networks within architecture, building, and society.

In parametric design, codes are being copied, edited, multiplied, and shared online in architectural forums and social media platforms. Because digital information can be copied without suffering losses and used for different purposes, designers explore digital collage to adapt the various algorithms to their goals and needs. This "copy-and-modify" strategy, as it is called by Woodburry (2010, p.38), is typically used because designers find it easier to change code that works than to build it from scratch. Sometimes those copies gain their authenticity and enable a creative appropriation, but frequently they represent almost identical copies of the original code or process with small parameter changes. If it is said that frequently architects only build what they could draw, but in the new information environment that characterises many parametric software, designers run the risk to only design what they can copy and modify. An example is the proliferation of "waffles" and "slices" in furniture and architectural design that frequently use the same original code. Leach (2016) points out that in digital culture "it is not the original that is important, but the number of times it is replicated. Originality has given way to replication and repetition".

However, there is a positive side to it. In his seminal article *Variety in Design*, Glanville (1994, p.98) already acknowledged that "the making of perfect copies, the seamless collaging of elements from different sources, and the processes and actions of image transformation" were some of the particular strengths of digital processes. The ability to clone the original puts ownership in doubt, as any copy has the status of the original. What follows is that it is possible to originate things, but no longer own. The removal of significance of ownership enables any part of anything to be shared, copied, cut, pasted, and transformed (Glanville, 1994). In a world of digital workflows, the sharing, copying, pasting, and editing of code can be seen as an opportunity for design conversations that embrace contingencies in the generation of novelty and can be seen as a true possibility for democratizing design.

4.10. Parametric design and Digital fabrication towards design democratization.

In this chapter, parametric design and digital fabrication were explored as possibilities to create systems that involve the user in the design process. It was observed that in a design process involving parametric models, the designer designs the flow of information that affects how the designer interacts with the design outcomes. This circularity between designer and designed can be especially important if the potential for change of parametric models is taken into account. Change is not necessarily a unique attribute of parametric models, but it is designed into the model by the designer. Designing for change requires different design frameworks where various stakeholders should be taken into account. The choice of variables that conforms the parametric models is not a neutral one, as every variable may represent values. Clearly stating those values is a fundamental step to open the design process to the user.

The possibility offered by many parametric software to create definitions that can be reused in different projects suggests a toolmaking process. However, this concept fails to address the fact that the process of creating a parametric model is in itself a design process that affects the outcome of the final design. In that sense, the focus should be placed on the process and not in the final parametric model. The designer of the parametric model cannot be seen as detached from the design process, such as is implied by Hudson (2010) and should be acknowledged as an active participant in a design conversation that is mediated by code and parameters.

The chapter discussed that parametric design should be understood from a broader perspective, without restricting to a mathematical definition or limiting to the use of specific software. Projects such as Hygroskin show that an expanded perspective on parametric design that encompasses material systems can lead to novel outcomes that manifest dynamic behavior. However, it should not be restricted to that. The creation of performative structures that explore material properties within self-organizing and generative models cannot only be used for form-finding processes, but also for conversational processes where form emerges through conversation. The prerogative to choose from within the multiplicities of variations resulting from computational processes can and should be handled to the user. The possibility of opening the parameters in design and use can point to the creation of dynamic systems that are adaptable to different conditions, where the designer is responsible for determining the system's constraints within which the system maintains its viability.

Nowadays, the "blob" may have been substituted by performative architectures that relate material system and design possibilities. However, even if that may represent a breakthrough, by creating the opportunity for more sustainable structures that are interconnected to their environment, they fail to encompass the user within the design system. It seems that the only stakeholders acknowledged in academic projects that investigate advanced digital fabrication technologies are the companies that fund the projects with the aim to expand their markets, such as KUKA has done in the recent years with Robotic Architectures. The participation of companies in the process is not a problem by itself. The real problem is to involve companies in the design system and exclude the final user. An evidence of this problem is the surge of numerous pavilions that are seductive in form and morphological performance, but do not change the way people relate to space and with one another.

The concepts of parametric design and digital fabrication were related to the notions of mass customization, that implies a large production of custom items without significant additional costs. The difference between design configurators, metadesigns, meta-meta designs, and toolkits for user customization was discussed as a way to democratize design. It was possible to conclude that digital design interfaces for architecture increase the variety of solutions if they are based on principles that enable the intervention of those who inhabit the space, by giving them the means to act. This ability can be seen as a genuine democratization of the design process. However, to design those systems, a different approach is needed that understand all stakeholders, design interfaces, and fabrication processes as systems and subsystems that together conform a dynamic architectural system.

Although parametric design is not a new concept, its contemporary integration with digital fabrication is creating a new flux of digital information from design to use. It was observed that the notion of a linear and continuous digital process gives a false idea of control that eliminates contingencies. In a different path, this thesis argues for the acceptance of the circular nature of design as it may lead to novel approaches where the contingent aspect of architecture is not seen as a problem, but as an opportunity for novelty to arise. In that context, parametric design associated with digital fabrication can be used as a strategy to generate circular information flows that potentialize the different conversational cycles involved in designing and building, instead of trying to obscure them.

5 | CYBERNETICS AND THE SYSTEMIC NATURE OF ARCHITECTURE

Drawing on Gordon Pask (1969, n.d.), this thesis argues that architects design systems that involves structure and man in dynamic interactions. Buildings are only meaningful as a human environment and only make sense when understood as part of a larger system that includes human systems, material systems, and structures. Following this reasoning, the concept of architectural system is used in this thesis to refer to a system that encompasses not only the built object, but also the process of designing, building, and using. The present chapter discusses some fundamental concepts of cybernetics with a special emphasis on the notions of systems, control, variety, and conversation. It discusses the notion of architecture as an exceedingly complex system and introduces the reader to conceptual tools that are useful for designers to come to terms with this complexity.

5.1. Systems

The notion of systems has its roots in biology, where the reductionist and analytical processes of mechanistic thinking failed in the attempt to explain social and biological phenomena. The struggle to understand complexities by reducing it in its constituent parts and then build an understanding of the whole by the knowledge of the parts proved unsuccessful (Skyttner, 2001). One can imagine that it is not possible to understand how we think and act by dissecting our brain. Systems thinking offers a more holistic perspective where the primary properties of a phenomena derives from the interactions of their constituent parts. The main argument for systems thinking is that it offers a framework for dealing with complexity.

The definition of “system” is according to Ludwig von Bertalanffy (1968, p.38) a “sets of elements standing in interaction”. In his words, “a system is a set of interacting units or elements that form an integrated whole intended to perform some function”. Bertalanffy

(1968) makes a distinction between closed and open systems. Closed systems are considered to be isolated from their context and environment. They are abstract models where the initial conditions - input - determines the final state - output. If the initial state changes the final will also change. In nature there are no such systems that are totally independent from their context - "every living organism is essentially an open system" (Bertalanffy, 1968, p.39). Open systems, are systems that are not closed, they interact with their context in a dynamic nature where one affects the other in a continuous flow. As Bertalanffy (1968, p.39) observes, "it maintains itself in a continuous inflow and outflow, a building up and breaking down of components, never being, so long as it is alive, in a state of chemical and thermodynamic equilibrium but maintained in a so-called steady state which is distinct from the latter". In open systems, the behaviour of an element outside the system may affects its function and the final state can be reached from different initial conditions and in different ways - a phenomenon called *equifinality.* Skyttner (2001, p. 36) complements Bertalanffy's definition of systems by adding that the elements "form an integrated whole intended to perform some function". In living systems, this function is to self-produce.

Maturana and Varela coined the term autopoiesis to define a particular organization in physical systems where the product of the operations as systems is necessarily always the system itself. When the network of processes that constitutes the autopoietic system is disrupted, the system disintegrates (Varela et al., 1974). For Von Foerster (2003), autopoiesis is an "organization which computes its own organization" and requires organizational closure. Organizational closure should not be confounded with closed systems. An autopoietic system, for example, is considered as organisationally closed, but structurally open. Organization signifies the relation between components that must be present for something to be recognized as part of a particular class of system. Structure is the particular physical form which those components take (Ramage, et al. 2009). A chair, for example, is recognized as such, not because of the material by which it is made, nor because of the intrinsic properties of the elements by which it is build. A chair is recognized as such because of the relation between the parts necessary for the observer to classify something as a chair - the possibility to sit down. Structure, in this case, is the form the legs, seat, and back take.

Alexander Backlund (2010) argues that although the definition of systems in the most common textbooks are very similar they, to some extent, "lack precision and are somewhat misleading". He asserts that some definitions end up including things that are not systems whereas some other exclude anything that is a system. Contrary to Backlund, Christopher Alexander (2011) sees the lack of precision in the meaning of the term systems as positive. Its vagueness enables new ideas to flourish, to be explored, and extended. Between the many meanings associated with the word Alexander (2011, p.59) highlights two: "the idea of *systems as a whole*, and the idea of a *generating system*." In the first case, the term system refers to a particular holistic way of looking at an object. "It focuses on some holistic phenomenon which can only be understood as a product of interaction among parts." For Alexander (2011), "in order to speak of something as a system, we must be able to state clearly: 1) the holistic behaviour which we are focusing on; 2) the parts within the thing, and the interactions among these parts, which cause the holistic behaviour we have defined 3) the way in which this interaction, among these parts, causes the holistic behaviour defined." Holistic behavior is a product of the interaction among the parts that define the stable behavior of the whole. In other words, a system can be characterized by the interactions that defines its stability.

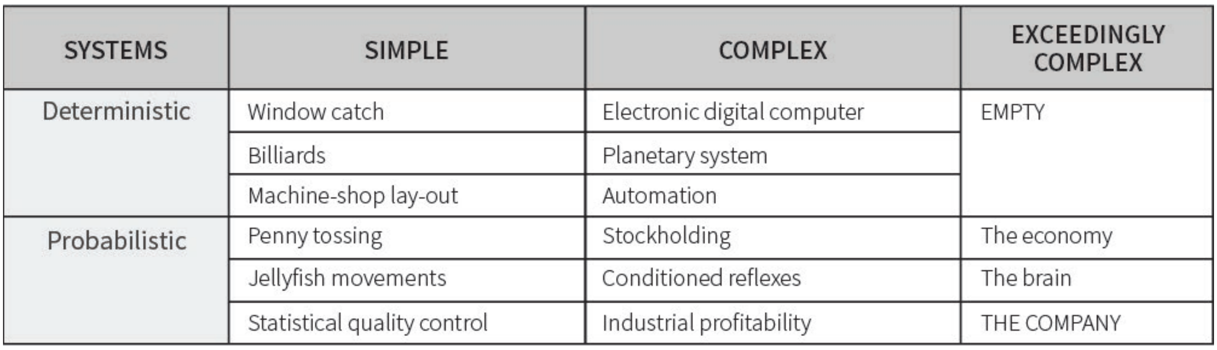
In the second case, the idea of *generating systems* refers to a "kit of parts" (or elements) with rules about the way those parts may be combined. Formal systems of mathematics, language systems, and genetic systems are a few examples of *generative systems*. They all provide rules to the combination of a given kit of parts to form a system (Alexander, 2011). Alexander (2011) argues that a building system can also be seen as a *generating system,* as columns, panels, windows and doors must be put together according to certain rules.

The two ideas regarding the meaning of system are directly related, as "almost every *system as a whole* is created by a *generating system*" (Alexander, 2011:66). A holistic behavior can only be perceived when there is a set of rules and constraints that characterize the interaction among the parts. Those explanatory rules and constraints enable the creation of abstract models - systems - that facilitates the understanding of a given phenomena. Alexander (2011:66) observes that "if an object has some holistic property caused by interaction among parts - then it is clear that these particular parts and these particular interactions will only come into being if the parts have very constrained relationships to one another." In design, the relation between *generating system* and *system as a whole* can be specifically relevant when the goal of the design process is to generate *systems a whole*, such as buildings and cities. It urges designers to shift their perspective from designing objects to designing systems. Alexander (2011, p.66) states that "to make objects with complex holistic properties, it is necessary to invent *generating systems* which will generate objects with the required holistic properties. The designer becomes a designer of *generating systems* - each capable of generating many objects - rather than a designer of individual objects."

The concept of a *generating system* is a compelling one, especially when it is associated with the use of computers in design. Within the framework proposed by Christopher Alexander, it is useful to see parametric design as a *generating systems* that lead to many outcomes. However, as discussed in Chapter IV, parametric design should not be confused with parametric models. In a parametric model it is possible to create rules and constraints among parts such as in a building system. Nonetheless, this does not guarantees that the product will be a s*ystem as a whole.* Properly functioning buildings, as Alexander (2011) observes, are systems where the building and people form a social human whole. Alexander (2011, p.67) makes a claim for a "more subtle kind of building systems, which doesn't merely generate buildings, but generates buildings guaranteed to function as holistic systems in the social, human sense." To enable the creation of this kind of holistic systems, parametric design should not only encompass a modeling system to conform the *generating system*, but also the material, and especially social systems. The idea put forward of a *generating system* seems to exclude the user from the generating process. Therefore, this thesis will use the concept of *designing systems* to refer to *generating systems* where there is an active participation of both user and designer - acknowledging that the roles of designer and user are interchangeable.

5.1.1. Exceedingly complex systems

In *Cybernetics and Management* (1959), Stafford Beer created a distinction between three classes of systems in the world: (1) *simple*; (2) *complex*; and (3) *exceedingly complex*. The first two systems are approachable from methods of modern science because they are, in principle, knowable and predictable. Exceedingly complex systems are systems that change in time and are so complex that they cannot be fully grasped through modern scientific methods. Table 02 is based on Stafford Beer's example for the classification of systems where different systems were subdivided in two categories, *deterministic* and *probabilistic*. According to Beer (1959, p.12), "a deterministic system is one in which the parts interact in a perfectly predictable way" so that is possible to determine future states of the system from the knowledge of its last states. In a probabilistic system this does not occur, and a detailed prediction is not possible.



SYSTEMS	SIMPLE	COMPLEX	EXCEEDINGLY COMPLEX
Deterministic	Window catch	Electronic digital computer	EMPTY
	Billiards	Planetary system	
	Machine-shop lay-out	Automation	
Probabilistic	Penny tossing	Stockholding	The economy
	Jellyfish movements	Conditioned reflexes	The brain
	Statistical quality control	Industrial profitability	THE COMPANY

Table 02 | Stafford Beer's classification of systems. Based on the original figure in S. Beer, Cybernetics and Management (London: English Universities Press, 1959), 18.

The idea of deterministic and *probabilistic* systems are connected to the concepts of *trivial* and *nontrivial* machines put forward by Von Foerster and Poerksen (2003). Given a system with a cause or input, a rule of transformation (t), and an effect or output (Figure, 61), a trivial machine is one where the relation between input and output is predictable, unconditional, and unchangeable - therefore determinable. Nontrivial machines, in turn, are always changing their internal structures and rules of transformation in relation to its previous states. As a result they cannot be analytically determined - they are probabilistic.

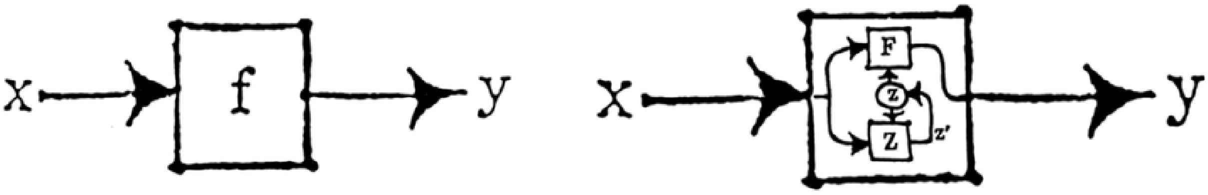


Figure 61 | Trivial and nontrivial machine (Von Foerster, 2003).

Architecture has both deterministic and probabilistic qualities. The layout of a school building, for example, can be seen as deterministic when studying where the students will enter the school, the size and position of the classrooms, laboratories, and other facilities. It becomes more complex when the system is adapted to define the construction of the school. Many contingencies have to be taken into account which will include many imponderables into the system. It evolves into a complex probabilistic system - specially when acknowledging the participation of several stakeholders including the construction workers and contractors. Nevertheless, it becomes even more complex when the system describes the actual use of the school involving students, teachers, parents, teaching methods, relation with the community, etc. It is relatively easy to describe the load-bearing structures, the acoustics, heating, and cooling systems. However, it is not possible to predetermine its use with all possible contingencies. A system that describes the physical elements will not be sufficient to understand the holistic behaviour of the system, which results from the different levels of interactions between humans - social system - and structural systems. In that sense, architecture can be seen as an exceedingly complex system - a nontrivial machine - when acknowledged that it encompasses material systems, building systems, communication systems and, most importantly, human and social systems. Nevertheless, many designers do not acknowledge this and trivialize the architectural systems to design trivial architecture machines.

Within the complex network of systems and subsystems, the design endeavor is a complex one, because it deals with problems that are ill-defined and resist resolution - they are *wicked problems* (Rittel and Webber, 1973). A systemic approach to design can be used to cope with this complexity without decomposing the problem into simple components, offering a more holistic perspective. However, this does not mean to apply any systemic design method or process to achieve a design solution. A designing system is a generative system that deals with control and communication within a continuous process. In that sense, the systemic approach to design is deeply intertwined to cybernetics - most importantly Second-Order Cybernetics.

5.2. Cybernetics and Design

Winston Churchill gave a speech in the House of Lords chamber on October 28, 1943 where he stated: "we shape our buildings, and afterwards our buildings shape us" (Churchill & Churchill, 2003). According to Michael Lissack (2015), that sentence embodies important cybernetic principles such as "the role of context, the role of affordances, the importance of action, ideas shaping action, actions shaping ideas, circularity, and the role of the observer". This leads Lissack to conclude that Winston Churchill was the first practicing cybernetician[100], a teaching he attributes to Ranulph Glanville (Lissack, 2015). Following the understanding that to be a cybernetician we have to apprehend and live in circularity, it may be actually hard to determine who was the first cybernetician. In fact, by accepting the idea of circularity, it is possible to say that we all live in cybernetics, and those that understand and acknowledge this circularity are cyberneticians. Paul Pangaro (2010) contributes to this argument by stating that:

> "once you see the world in a cybernetic way, through the cybernetic lens, all things are cybernetic. Because all systems become part of this set of languages of action and sensing and comparing and understanding and taking a meta-view. All intelligent systems have this property. Of trying, acting, seeing the difference, changing, acting seeing, sensing. This loop of acting, sensing, comparing is fundamental."[101]

Being all things cybernetic, so can design be seen as a cybernetic practice. However, this oversimplification may be misleading in the search for a deeper understanding of the relation between cybernetics and design. The special double issue of Kybernetes, Cybernetics and Design (Glanville, 2007a) made an important effort to show the

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[100] Michael Lissack notes that this is seen under modern usage of the term cybernetics ignoring Ampere's 1834 definition.

[101] (see http://www.youtube.com/watch?v=Cvorr7587dE)

connections between the two disciplines and create a deeper understanding of both.

Through his work, Ranulph Glanville (1994, 1998, 1999, 2000b, 2007) has explored the connections between cybernetics and design. He has shown that cybernetics can not only contribute to design, but that design can also inform cybernetics, understanding cybernetics and design not as separate entities but as a circular interwoven process of acting and reflecting, theory and practice. According to Glanville (2007, p. 1178), "cybernetics is the theory of design and design is the action of cybernetics". The idea of cybernetics as a theory of design was already put forward by Gordon Pask (1969, n.d.) who stressed the need for an unifying theory of design and pointed out that "cybernetics is a discipline which fills the bill insofar as the abstract concepts of cybernetics can be interpreted in architectural terms (and, where appropriate, identified with real architectural systems), to form a *theory* (architectural cybernetics, the cybernetic theory of architecture)."

Besides the seminal works from Pask and Glanville, several others have explored the relation between cybernetics and design (for references refer to Sweeting, 2016b). In those interchanges, important cybernetics concepts were explored in design to offer new insights and to contribute to the overall development of a design epistemology. Together with an introduction on First and Second-Order Cybernetics, this chapter will address some of those key cybernetic concepts with a particular focus on control systems, feedback, and variety. Those are key concepts for the development of the thesis argument and serve as a cybernetic toolkit for a more profound discussion of the experiments put forward in chapter II.

5.2.1. Cybernetics

Cybernetics, was first characterised as "the study of circular causal, and feedback mechanisms in biological and social science" (Macy Conferences, 1946 - 1956). What this characterization already suggests is that circularity is the fundamental principle of cybernetics. Cybernetics is not particularly interested in describing the elements within a system but is more focused in understanding the interaction between them, the dance, that involves a flow of information going back and forth between the elements, where one affects the other. In that sense, whereas physics provides a general theory for the material domain by explaining matter and energy relations, cybernetics provides a "theory of the informational domain explaining control and communication activities" (Umpeby, 2014).

Cybernetics as a field grew out of what became known as the *Macy Conferences on Cybernetics*[102] between 1944 and 1953. The interdisciplinary nature of those meetings contributed for cybernetics to evolve to a nontidisciplinary field that emcompasses machines, animals, social systems, the mind, management, artificial intelligence, and many others. The cross of many disciplines is highlighted in Mead´s[103] (1968) understanding of cybernetics as "a way of looking at things" and "a language for expressing what one sees". For Mead (1968), cybernetic represents a cross-disciplinary thought that enabled members from many disciplines to communicate with each other.

Cybernetics evolved in parallel with the school of *General Systems Theory* (GST) with which cybernetic thinkers developed many shared concepts. Ashby (1956), for instance, argued that cybernetic offer "a method for the scientific treatment of the systems in which complexity is outstanding or too complex to ignore." Both fields were interested in a more holistic perspective on systems that resisted a reductionist fragmentation of the whole in parts, and where the change of one factor at the time did not give the expected results. However, as pointed out by Heylighen and Joslyn (2002), "GST studies systems at all levels of generality, whereas Cybernetics focuses more specifically on goal-directed, functional systems which have some form of control relation." The two fields grew apart

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[102] Von Foerster suggested that the title of Wiener's book should be taken as the title for the conferences. Later "cybernetics" was accepted as the name of the discipline. (von Foerster & Poerksen, 2003, p. 136).

[103] Margaret Mead (1968) has a wonderful perspective of cybernetics as a shared language. She states that: "as an anthropologist, I have been interested in the effects that the theories of cybernetics have within our society. I am not referring to computers or to the electronic evolution as a whole, or to the end of dependence on script for knowledge, or to the way that dress has succeeded the mimeographing machine as a form of communication among the dissenting young. I specifically want to consider the significance of the set of cross-disciplinary ideas which we first called 'feed-back' and then called 'teleological mechanisms' and then called 'cybernetics' -- a form of cross-disciplinary thought which made it possible for members of many disciplines to communicate with each other easily in a language which all could understand".

and developed into other subfields such as *Control Systems Engineering*, *System Design*, and *Control Theory*. What distinguishes cybernetics from other systems sciences is the emphasis on circularity, control and communication in artificial systems, natural systems, nonlinear dynamic systems, living systems, social systems, and others[104].

5.2.2. Second-Order Cybernetics

> 'Am I apart from the universe?' Meaning whenever I look, I'm looking as if through a peephole upon an unfolding universe; or 'Am I part of the universe?' Meaning whenever I act, I'm changing myself and the universe as well." (Foerster 2003, p. 293).

The term "Second-Order Cybernetics" was introduced by Von Foerster (1995) as the "cybernetics of observing systems", in a clear distinction of "First-Order Cybernetics" that is defined as "the cybernetics of observed systems". This distinction points towards two epistemic modes of research, one from within where the researcher acknowledges his active role, as opposed to one from without, such as in traditional scientific method (Umpleby, 2016). In the traditional scientific method, the subjectivity of the observer is artificially removed from the system to achieve an objective description of the system being analysed. However, how would it be possible to make a description if the observer were not to have properties that allows for a description to be made? (Von Foerster, 2003). Can something be known without a knower? Or rather, can we know something without us knowing it? This nature of questions naturally emerge when the observer is acknowledged as part of the system. This inclusion does not only change how research is undertaken, but also how one act and reflect when engaging with its environment.

The will to highlight this paradigmatic change in how knowledge is created, and distinguish themselves from the more traditional scientific methods and mechanistic approach of system designers and engineers, is what led a group of cyberneticians to create a distinction between First and Second-Order Cybernetics (Heylighen and Joslyn, 2002). The Second-Order Cybernetics movement emphasized that our knowledge of a

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[104] The relation between Systems Theory, Systems Science, and Cybernetics is not a clear one. Some think of Systems Theory as a branch of cybernetics and others the opposite. There are also those that see them as to be the same (Glanville 2000b).

system is mediated by the model we create of that system. Because the model is fruit of our creating, its properties cannot be confused with the properties of the system. In the mechanistic approach, the model is treated as correspondent to the system and can be objectively studied and manipulated by an external detached observer. In Second-Order Cybernetics, the observer is recognized as being part of the system and the results of the observation depends on the interaction between observer and observed.

The notion of observing system put forward by Second-Order Cybernetics changes how the systems boundaries are addressed, as it is the observer who subjectively makes a distinction of what is inside or what is outside. That means that a system is not a thing, or collection of things, that exists objectively in space or time, limited by a physical barrier. As observed by Brün (2004, p.82):

> "A system is the result of a look at a collection of stipulated elements. Stipulated in that I say which elements I will look at. Collection because I stipulate that these elements I have decided to look at are not yet ordered, and my look will decide on what I put the emphasis and what I regard as not to be regarded entities". (Brün, 2004, p.82).

What follows is that it is the observer who establishes the elements and the interactions between them. As Fischer and Richards (2014, p.37) summarize, "in the Second-Order cybernetic view, systems and their boundaries are observer-dependent and, in principle, independent from physical configuration."

The transition from First-Order Cybernetics to Second-Order Cybernetics epistemology was not restricted to cybernetics or system science, but represented a scientific revolution for the general methodology of science (Umpleby, 2016). Umpleby (2016) exemplified this with a successful case of social research undertaken by the Institute of Cultural Affairs (ICA), where research was undertaken from "within", and started with current knowledge and learn by doing. Their methodology involved different cycles of evaluation were methods would change when needed and successful experiences would be repeated. This methodology where the observer is inside the inquiring system proved to be successful. However, the traditional scientists, that worked from "without", failed to validate this process. Umpleby (2016) observes that in Western traditional science:

> "the fear has been that allowing the properties of observers to be included in their description would open the door to subjectivism, biases, and irrationality. Wild pluralisms would be the mildest symptoms in science if researchers and their properties were admitted without further constraints. Nevertheless, human observers are biological organisms. Not to incorporate an understanding of the biology of cognition in our practice of science requires discarding relevant experience and knowledge".

Although Second-Order Cybernetics has been praised by many cyberneticians (Glanville, 2000b, Von Foerster, 2003, Umpleby, 2016, Sweeting, 2016b), Heylighen and Joslyn (2002) alert that "the second-order fascination with self-reference and observer observing observers observing themselves has fostered a potentially dangerous detachment from concrete phenomena." They further note that the emphasis of the second-order movement on observing systems and the subjectivity of modelling "has led many to abandon formal approaches and mathematical modelling altogether, limiting themselves to philosophical or literary discourses". This distantiation is seen by them as one of the possible reasons for the failure of cybernetics to be establish as a field.

In the same direction, Pickering (2011, p.26) argues that "to see cybernetics as being primarily about epistemology is to invite endless agonizing about the observer's personal responsibility for his or her knowledge claims". He correlates the change of focus from the more tangible modes of experimentation of First-Order Cybernetics towards the epistemological inquiry of Second-Order Cybernetics with the linguistic turn in the humanities and social sciences were we only have access to our words and representation of the world. Pickering (2011, p.26) advocates for a "shift from a representational to a performative idiom for thinking about science, and from epistemology alone to ontology as well".

Sweeting (2016b) counters Pickering's argument by stating that "Second-Order Cybernetics is a reflection on the performative involvement of observers within their observations, in contrast to the separation of observer and observed in conventional science". In that sense, there is no hiatus between the more tangible and performative experimentations of First-Order Cybernetics and Second-Order Cybernetics. The work of Gordon Pask (1971) with the "colloquy of mobiles" at the Cybernetic Serendipity (1968) is a clear example of that, as it fuses performative thinking with conversation, a Second-Order Cybernetic concept (refer to section 5.6.3).

5.2.3 Cybernetics Today

Many other definitions of cybernetics may be given[105], and that only demonstrate its dynamic character. Even today, it is very common for cyberneticians to hold conversations about their personal notions and definitions of cybernetics. In one of those conversations, at the 2014 American Society for Cybernetics conference “Living in Cybernetics”, Jude Lombardi (2014) proposed that instead of asking “what is cybernetics” we should ask “when is cybernetics”. This is an important shift as the definition and understanding of cybernetics has changed in time, place, and according to the different observers. According to Laurence Richards (2014), the “when question” invites multiple answers and everyone of these answers is a potential answer at a particular time, depending on what the person wants at that time. In that sense, the answer tells much about the person giving the definition. As expressed by Von Foerster (2003): “that is the fascinating thing about cybernetics. You ask a couple of people to give you a definition and although you don’t get to know much about cybernetics from them, you find out a lot about the person supplying the definition, including their area of expertise, their relation to the world, their desire to play with metaphors, their enthusiasm for management, and their interest in communications or message theory.” Along this lines, the “when” question invites more specific and contextualized thinking that acknowledges the observer as active participant.

The shift from “what” to “when” is in accordance with the title of the conference: Living in Cybernetics (2014), proposed by Ranulph Glanville to emphasise cybernetics not only as a field of study, but also a way of thinking and acting. The theme of the conference invites to see cybernetics as “a subject we can live in, not only as observers, but in how

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[105] To name a few, Gregory Bateson defines cybernetics as “a branch of mathematics dealing with problems of control, recursiveness and information”. For Stafford Beer “cybernetics is the science of effective organization”. On his turn Gordon Pask argues that “cybernetics is the science of defensible metaphors” and for Krippendorf (2008): cybernetics is “an inter-disciplinary discourse that brings forth radically reflexive realities”.

we act and the understanding we create of our world, and our place in it"[106]. As observed by Sweeting (2016b), this can be seen as an attempt to answer Margaret Mead (1968) challenge to apply cybernetics to cybernetics.

The steersman´s dance (dynamic system) involves the boat (controlled system), the flow of forces that act in and upon the boat (disturbance) such as the wind, waves, currents, torque of the motor, and the tools that are needed to understand the current status of the boat (measuring tools such as the compass) in relation to its target. To enable this dance to happen, that is, to understand how much the controls must be adjusted requires an understanding of control, feedback and variety. Those concepts are central to a cybernetic understanding and will de discussed in the following sections.

5.2.4. Control Systems

Wiener (1948) defined cybernetics as the "scientific study of control and communication in the animal and the machine", and therefore it is no surprize that "control" is a key concept in cybernetics. However, because the word is frequently associated with power and domination, there is some struggle with its use and discussions about control can be somehow problematic (Glanville, 2009). Control, in that perspective, is analogous to the more common use of the word, meaning to exercise restrain[107]. In social systems, restrictive control is authoritarian and related to a conservative perspective of society and dictatorial regimes where control is imposed on the other. This represents one of the most malefic forms of restrictive control, where the goal set by the controller is to

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[106] The full description of the conference theme goes as follow: Cybernetics, as the ASC practices it, has been called "a way of thinking". It is both a field of study and a way of acting. It takes as a central point circularity—in its many forms that include circular causality, feedback, recursion, self-reference, designing and so on. It takes the observer in the system (such as the switch in a thermostat) to be part of that system rather than outside it, and considers this sort of observer involvement to be the norm. As a way of thinking it can change how we understand the world and our part in it. It is a subject we can live in, not only as observers, but in how we act and the understanding we create of our world, and our place in it. Living in Cybernetics: 50th Anniversary Conference of the American Society for Cybernetics - Conference website: http://asc-cybernetics.org/2014/?page_id=161. Accessed 04/02/2017.

[107] Definition of CONTROL [WWW Document], n.d. URL https://www.merriam-webster.com/dictionary/control (accessed 2.22.17).

maintain control. However, in cybernetics the meaning of the word control has a different intended use, that is enabling control - or effective management (as put forward by Stafford Beer). As Glanville (2007) observes, "the purpose of enabling control is not to restrict, but to guide towards better performance".

In the same direction, Pickering (2011) argues that if there is any association of control as domination in science it should be with modern ones, and not cybernetics, which he characterises as a non modern science. As he puts it, "the aspire to grasp the inner workings of the world through knowledge and thus to dominate it and put it entirely at our disposal" is related to the royal sciences. Cybernetics, on the contrary, can be thought of as "anticontrol". Pickering (2011, p.31-32) observes that "the entire task of cybernetics was to figure out how to get along in a world that was not enframable, that could not be subjugated to human designs—how to build machines and construct systems that could adapt performatively to whatever happened to come their way."

The metaphor of the steersman trying to reach a port is an illustrative example of enabling control. Setting a course from point A to point B and pointing the rudder to that direction will not guarantee that the boat reaches the goal. If the steersman does not make the right adjustments to the rudder, the currents and the winds will take control over the boat. To illustrate this, figure 62 represents a model of a control system where three basic steps can be distinguished. (1) The controlling systems sets a goal for the controlled system that is external to itself. Glanville (1995) defines "goal" as "a desired state of condition for the system which determinates that it be treated as goal-oriented and which motivates its performance and response to the situation it is in, while satisfying the controller's intentions." (2) The controlling system compares the actual state of the system with the desired state and computes the difference. In this process, the controlling system chooses which variables are to be measured and compared. (3) The controlling system makes the necessary corrections, and the circle starts again.

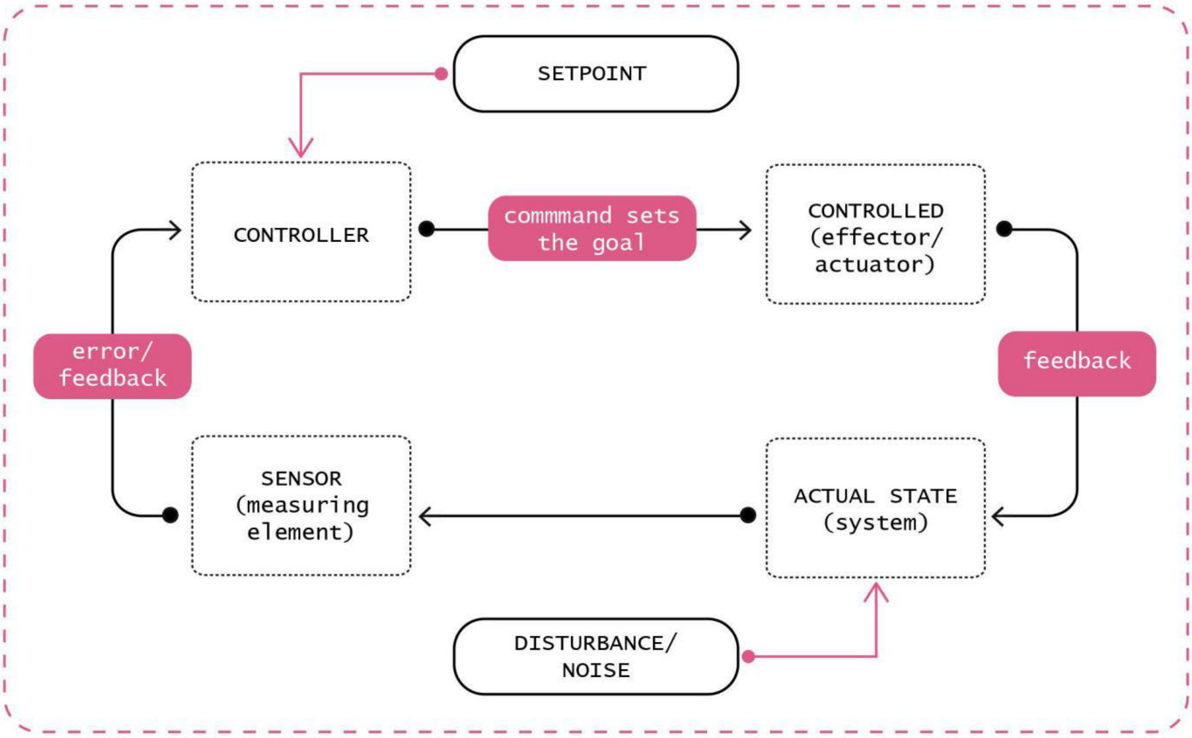


Figure 62 | Model of Cybernetic Goal-Oriented System (author, 2017).

The inability of the controlling system to predict the contingencies (noise and disturbance) of the path toward its goals - in other words, error - is what renders control necessary. Error, according to Glanville (1995, 2009), is "the ability of some systems or objects, to behave in a manner transcending the predicted (the regular) and deviating from (its progress towards) the aim." Contrary to common sense, error in cybernetics does not represent a problem and is not an indication of failure because it is a necessary integral part of any subject. As stated by Glanville (1995, 2009), "error, the failure of the world to be as we like to insist it is, the inaccuracy (and resulting discomfort) of prediction, our inability to act correctly is central to our experience and is central to cybernetics as it attempts to help us create and maintain some sort of stability in our interactions".

A recurring example of a control system is a thermostat that maintains the temperature stable in a room. In a thermostat, a sensor measures the actual temperature of the room (system). The controller compares the sensors reading with the goal temperature, and if the room is cooler than it should be the controller sends a command to activate the controlled - in this case, the heater - which warms up the room. When the value of the sensors reading of the room reaches the goal temperature, the controller sends a command to the heater to switch off.

What is interesting to notice in this system is that after the process has been triggered, it is no longer possible to define controller and controlled. The sensor controls the heater by switching it on and off, but the heater, in its turn, also controls the sensors readings. What can be learned from this is that controller and controlled are roles ascribed by the observer, and because they are relative positions, these roles can be switched. This is a classical example of a Second-Order Cybernetics approach of the systems, because it involves not only the observed system but also the observing system.

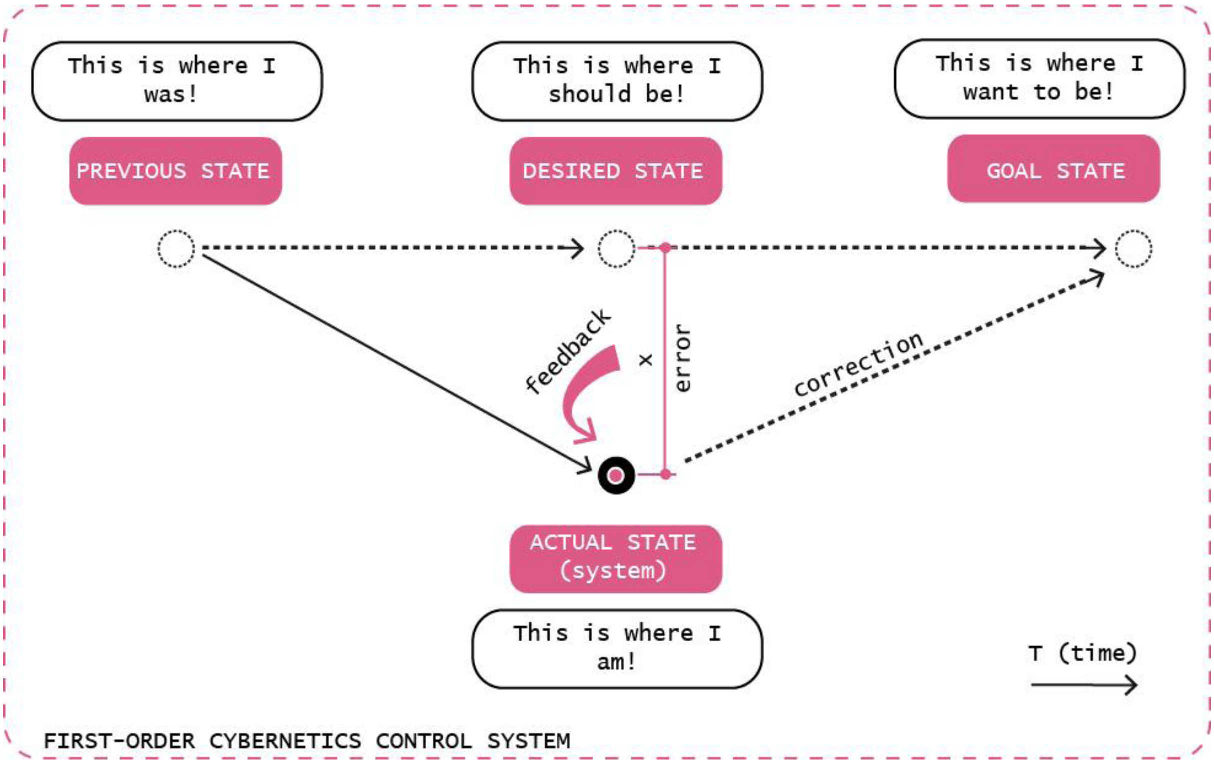


Figure 63 | Representation of a First-Order Cybernetics Control System. (author, 2017).

In a First-Order Cybernetic control system, the controller compares the actual state of the system with the desired state, and computes the difference (error) between the two states. Generally, the objective of the controller is to reduce error in order to achieve the goal state. Figure 63 is another representation of a First-Order Cybernetic control system. At a time "t" the system is at state x. State "x" is transmitted to the controller that compares state "x" to the desired state "y". The controller makes the necessary adjustments to reduce error and approximate the system to the desired state in order to achieve the goal state.

Different from most system models that are constructed by the observer to understand elementary features of the world, in design, models are frequently created to be used as a reference for the desired state of the system. For example, the blueprints of a house - a model build with a highly specialized set of codes (orthogonal projections, plans, cuts, etc.) - are used as a reference for the desired state (y) of the building during the construction process. Different stakeholders refer to the blueprints to understand and work towards the desired goals. However, because codes do not convey meaning, different interpretations of the blueprints may occur, frequently leading to deviations. In a First-Order Cybernetic process, every deviation of the desired state is regarded as an error that has to be corrected - sometimes with a high cost (financial and personal).

Second-Order Cybernetics gives a different perspective, as error is a value given by the observer. It is he who decides that a deviation of the system towards its goals is something to be corrected. Glanville (1995, 2009, p.76) observes that "our decision that we have error, giving rise to the quest of cause, leads us wishing to indicate the agent of error, to give it form, pattern, purpose, cause." However, because it is a decision made by the observer, it can be changed, and the quest for cause and agent of error can be shifted towards the search for opportunity. The benefits of transforming error in opportunity is similar to making a wrong turn in a car trip and getting to a wonderful unexpected place. Figure 64 depicts a Second-Order Cybernetic control system where error can be turned in an opportunity leading to creativity. That is not to say that every error is an opportunity. Making an error in the calculus of a building may lead to catastrophe. The calculus can be regarded from a First-order Cybernetics deterministic perspective where A causes B, thus A must be followed by B. An error in A causes an error in B.

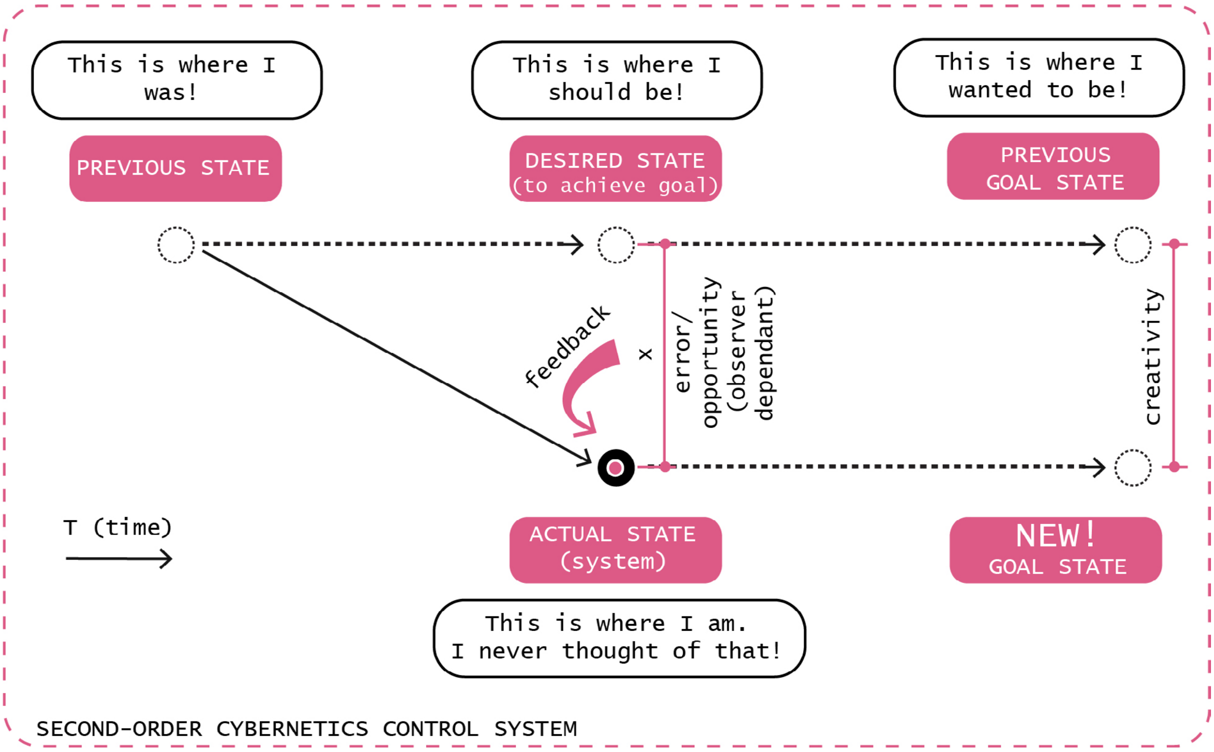


Figure 64 | Representation of a Second-Order Cybernetics Control System. (author, 2017)

From a Second-Order Cybernetic perspective, the involvement of the observers changes the way in which "cause" operates in the control systems. A controller causes the behavior of the controlled when it sets a goal. From that perspective, control and cause can be used interchangeably (Glanville, 1995, 2009). Cause evokes blame, to hold someone responsible, and in that sense, the controller is to blame for the actions of the controlled. However, if the controller and controlled are interchangeable roles, the controller is to blame for the actions of the controlled in the same order that the controlled is to blame for the actions of the controller. In the example of the thermostat this circular relation is easy to depict, but in social systems that can be more troublesome, especially in situations where there is no clear channel between the controller and controlled. This channel is what enables the essential exchange of information between controller and controlled called feedback. It is feedback that enables the circularity between controller and controlled, and without it, the system fails to reach stability.

5.2.5. Feedback

In the example of the thermostat, the circularity of action between the parts - the controller and the controlled - can be defined as “feedback”. According to Ashby (1956), feedback exists between two parts when each affects the other. In his mathematical examples, y’s value affects how x will change in the same way that x’s value affects y, as shown below:

$$x' = 2xy$$

$$y' = x - y_2$$

Feedback can give important insights about a dynamic system, because it is where the information flow is more explicit. However when a system becomes too complex, with many interconnections between different parts that affects each other, the flow of information becomes more blurry. As stated by Ashby (1956, p.54):

> “the fact is that the concept of “feedback”, so simple and natural in certain elementary cases, becomes artificial and of little use when the interconnexions between the parts become more complex. 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 every one 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.”

The concept of feedback is closely related to control, because it is through feedback that the controller can get information about the current state of a system, measure error, communicate the desired action to correct deviation, and identify the achievement of a goal. It is also feedback that enables control system where controller controls controlled that controls controller in a circular way. When feedback provides circularity, control is no longer in controller or controlled, but control is shared. As observed by Glanville (2004, p.1381), “neither is controlled, neither is controller: control is in either (or both) but shared between”. From that perspective it is possible to state that when feedback channels enable the flow of information between controller and controlled, regulator and regulated, it is possible to establish a mutual relation between the two. The notion of control gives place to mutuality, a notion that can be of particular interest for designers when designing dynamic architectural systems. However, a feedback channel alone is not enough to guarantee mutuality when the variety of one system differs from the other.

5.2.6. Variety

The concept of variety, as developed by Ross Ashby (1956), is central to understand cybernetic control systems. Ashby used the concept in two distinct forms. The first, was based on the physics of thermodynamics, where variety is related with *entropy* (such as in Information Theory - section 5.4). It refers to the number of possible states a system actually uses, in comparison with the number of states it could potentially use (Glanville, 1998). In the second, variety can be thought of as the number of states a system might take (Ashby, 1956). The state of a system is, according to Ashby (1956, p.25), "any well-defined condition or property that can be recognised if it occurs again." This definition of "state of a system" is easy to depict in binary systems such as a light bulb that has two defined states, on and off. It is also the case in digital computing where the bit can be either 0 or 1. When there are two light bulbs, the number of states jumps to four, with three light bulbs to eight, with four light bulbs to sixteen, and so on. However, in a situation such as where those light bulbs have different colours and serve as a traffic light system, not all combinations are used. In this system,red typically stands for "stop", amber for "caution", and green for "go". When amber is flickering, it means that the system is down for all road directions and caution is necessary. In that sense, there are four states the system actually takes (stop, caution, go, and system is down) instead of the eight states the system could potentially use. This illustrates the difference between the first and the second form in which Ashby used the concept of variety. In the first he would compute the total number of states the system could potentially use (eight), and in the second, only those states a system might use (four). In this system, a constraint is present that reduces the number of possible combination to those in use.

A constraint is defined by Ashby (1956, p. 117) as "a relation between two sets, and occurs when the variety that exists under one condition is less than the variety that exists under another." In architecture, this principle is particularly helpful when discussing the number of states of a built environment, especially when it contains dynamic elements with multiple states or analog qualities. A simple door, for example, is not either open or closed (two states), it can vary its position according to the opening angle (n states). However, little variations do not cause distinguishable changes in space and can, therefore, be constrained. That is not to say that subtle variations do not matter. Opening the door enough to look inside an environment can offer a sense of security for who is looking. However, it may not provide meaningful information when analyzing the difference in the variety of two spaces. Therefore, the number of states of the system to be analyzed is observer dependent. In other words, variety might depend more on the interest of the observer, and the criteria he uses than on the amount of available data. That means that there is no general variety, it arises according to established criteria. As observed by Ashby (1956, p 125), "a set's variety is not an intrinsic property of the set: the observer and his powers of discrimination may have to be specified if the variety is to be well defined."

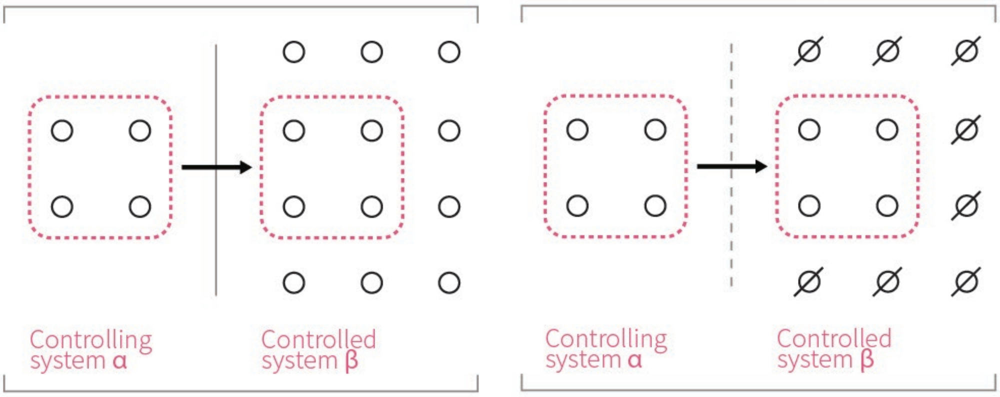
An important distinction that has to be observed concerning constraints is if a system is constrained from the outside or the from the inside. Outside and inside are subjective positions that are redrawn continuously by the observer (Glanville and Varela, 1981). They are given by the observer in relation to where he sees himself as being in reference to the system - within, affecting it or from the outside, forming it (Glanville, 1997). This relation is connected to the First-order Cybernetics independent observer and the Second-order Cybernetics participant observer. According to Heinz von Foerster (2003, p.298) the observer, looking from the outside can tell others how to think and act: "Thou shalt…, Thou shalt not...". This detached perspective gives origin to moral codes. However, when the observer is inside the system, he can only tell herself how to act. "'I shall . . . ' 'I shall not . . . ' This is the origin of ethics." (Von Foerster, 2003, p. 298). Ethics, as something intrinsic, is more an attitude than something to be theorized. In this sense, constraints that originate from within imply ethics and those from the outside moral codes.

5.2.7. Variety and Control

According to Ashby's Law of Requisite Variety (1956), if one system is to control another it has to have at least as much variety as the controlled system. Otherwise there is no effective control. In figure 65a, the dots represent the states each system may attain. Because the controlling systems α has fewer states than the controlled system β effective control is not possible. As stated by Glanville (1998):

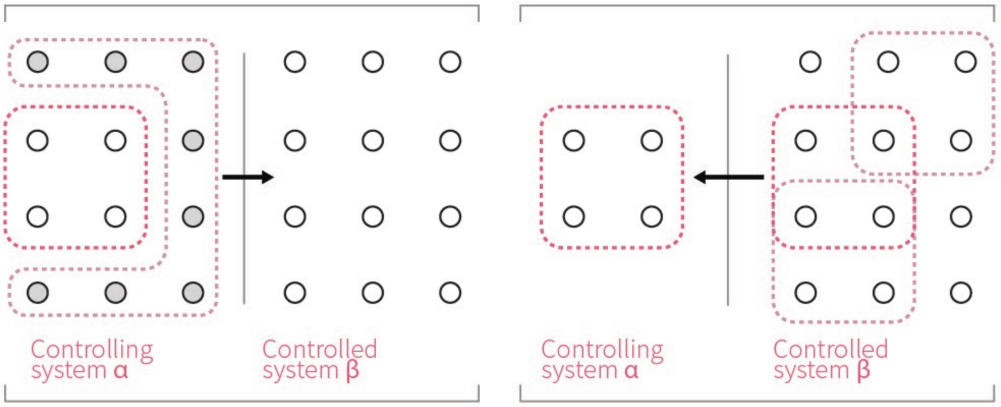
> "if the controlling system cannot 'map' all the states the controlled system may attain, it cannot control its behaviour because some of the behaviours of the controlled system are outside the range of the controlling system. All the controlling system can do in the case that some behaviours is presented by the controlled system which it cannot map, is to ignore this behaviour: and that is not controlling."

The idea of "mapping" the states of the controlled systems is connected to a second law called Law of Regulatory Models (Conant and Ashby, 1970) which states that "every good regulator of a system must be a model of that system." When this fails to happen, and the controlling system has less variety than the controlled system, there are three possibles ways to enable effective control. The first is to restrict (attenuate) the number of states in the controlled system to the number of states of the controlling system (regulator). This is represented in figure 65b (top right) where the number of states in β is restricted to match α. The restriction of variety can be voluntary - as done by musicians playing instruments, or through power relations such as dictatorial systems that permanently reduces the variety of people in an "uncybernetic" type of control (Glanville, 1998). The second way to reach effective control is to amplify variety in the controller (regulator) to match the variety of the controlled system - figure 65c. The third is to combine both ways, attenuating the number of states in the controlled system and amplifying the controlling system to reach a stable condition - figure 65d.



α can only “map” the same number of β as it processes.
No effective control.

α restricts the number of states of β.
Control by restriction.



α increases its number of states in order to control β.
$\alpha'' = \alpha + \alpha'$

β has effective control over α. Because there is redundancy the controller can change the control configuration.
Dynamic control system.

Figure 65 | Representation of four control situations. (author, 2017).

The notion of attenuating or amplifying variety to achieve stability in the controlled system (regulated system) is put forward by Beer (1993) in the context of the dynamic systems that conform our human environment, such as homes, schools, offices, cities, firms, states, countries, etc. Beer suggests that those systems are unstable because they have too many possible states (variety overload). To overcome this, there are three essential tools to achieve regulatory variety amplification: the computer, teleprocessing, and cybernetics. However, those tools are frequently used in a wrong way by generating more variety within the social system instead of being used to amplify regulative variety (Beer, 1993). In the case of the computer, that means that it is not being used to create means to cope with the complexity of the human institutions, but as tools to generate more complexity within the same institutions, what could lead the system to overload.

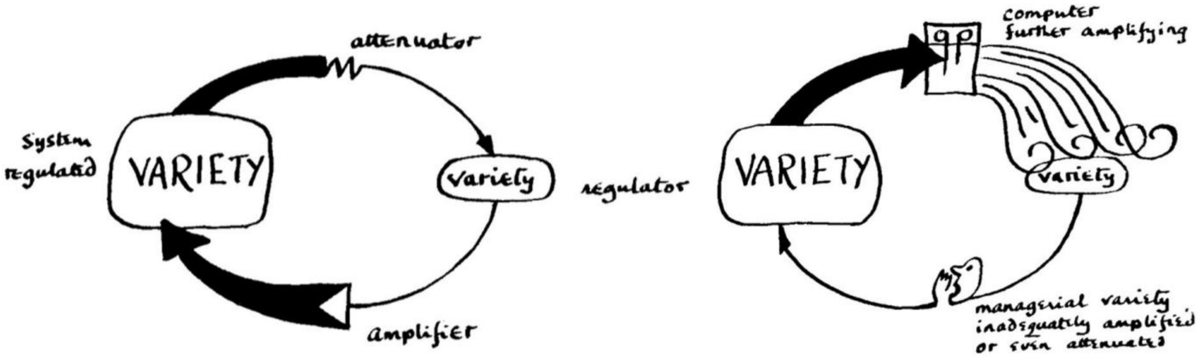


Figure 66 | Variety amplifier and attenuator on left and the computer further amplifying variety on the right. Beer (1993).

It is useful to explain Ashby's Law of Requisite Variety and discuss the notion of regulative variety amplifier using the metaphor of a GPS navigation used in a car. Let's consider a driver going from point A to point B in a large city he does not know. In this case, the variety of the road system exceeds the variety of the driver regarding his knowledge of the city's roads. By using a GPS application where the roads are computerized, the driver amplifies his variety to match the variety of the road system to reach effective control and arrive at point B. It is possible to state that the variety of the system driver is the function of the variety of driver and the GPS. What is interesting to notice is that in the system driver the variety of the driver is smaller than the variety of the GPS application concerning his knowledge of roads. Whereas many will assume that the driver is in control because he steers the car, from a different perspective, it can be said that within system driver, the GPS is the controller and driver the controlled when in interaction with the road system. From this example, it is possible to conclude that the tool used for variety amplification (GPS) of the regulating system (system driver) may end by controlling the regulator (driver). From this perspective, not knowing how control operates can lead to catastrophic situations[108][109].

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[108] In Brazil there are several examples of people who were led by the GPS to dangerous neighbourhoods with terrible consequences. Rio, D.G., 2015. Mulher morre após casal entrar por engano em comunidade em Niterói [WWW Document]. Rio de Janeiro. URL http://g1.globo.com/rio-de-janeiro/noticia/2015/10/mulher-morre-apos-entrar-por-engano-em-comunidade-em-niteroi-rj.html (accessed 10.12.17).

[109] Sorrel, G., 2008. GPS Causes 300,000 Brits to Crash [WWW Document]. WIRED. URL https://www.wired.com/2008/07/gps-causes-3000/ (accessed 11.1.17).

The example of the GPS is also useful to explain another way of variety amplification. The road system of a city can be characterized as a simple deterministic system and does not represent a significant challenge to be mapped using modern technological devices. The traffic system, however, is an exceedingly complex dynamic system that involves roads, moving cars, buses, traffic lights, one and two ways traffic, and other indeterminate events. To cope with the variety of this system, new GPS navigation applications such as Waze[110] use the information that a community of users shares in real-time. By sharing and processing real-time information of many users, Waze amplifies the variety of the system driver using a network of drivers. This made such navigation systems very useful for getting to unknown places and also for people who already know the city to outsmart traffic. This is an example of variety amplification through what Glanville (1994) called "cooperative sharing".

Beer's (1993) perspective of variety amplification and variety attenuation in social systems follows Ashby's (1956) application of variety to the amplification of intelligence. In Ashby's understanding, intelligence could be amplified for effective problem solving by removing distractions and restricting attention to the problem area (variety attenuation with constraints). Glanville (1994), from a different perspective, argues that creativity might be amplified through cooperative sharing. He draws from Mike Robinson's[111] (1979) application of variety in a classroom situation and proposes that "it is by sharing that we have the possibility of transcending the limitations of our (individual) brains, of increasing our power, by "borrowing" the power of others" (Glanville, 1994, p.96). The understanding that the variety of a group of people can be shared for creative purposes is important in this thesis. It points towards the notion that a radical involvement of the user in the design process may amplify the creative potential of the designing system, offering a possible way of coming to terms with the complexity of architectural systems and increase the possibility for novelty.

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[110] Free Community-based Mapping, Traffic & Navigation App [WWW Document], n.d. URL https://www.waze.com/en-GB/ (accessed 10.12.17).

[111] In class with 20 students, it can be said, for an illustrative purpose, that the potential brainpower available in this system will be n20. Even if the teacher has a larger brainpower than one individual student, he will never reach the same variety of the class. In a traditional scenario, for effective control to happen the teacher restricts the number of states of the class by making students wear a uniform, speak only when told, etc. Robinson (1979) indicates that strategies that lead students to cooperate, study and teach themselves can bring them to benefit from the variety of the whole system.

In the example of the GPS, the variety of system driver is amplified, but this does not necessarily mean that intelligence/creativity is enhanced. This is because in this case, the GPS is used as a tool and not as a medium. As discussed in the first example of the GPS, the use of digital processes as tools to amplify the variety of a system may lead to catastrophe - the controller may end being controlled by the tool. However, its use as a medium may lead to new situations where the controller can explore new routes, share relevant information, and learn.

5.2.8. Out-of-Control

In the article, The Value of Being Unmannageable, Glanville (2000b) discusses that systems can become so complex that their variety is no longer computable - they are "transcomputable systems". According to Glanville (2000b, p.3), "in transcomputable systems, it is inconceivable that enough variety can (realistically) exist in the control system in order for the conditions of the Law of Requisite Variety to be satisfied." He advocates that those systems must be considered unmanageable. For a system to be considered unmanageable "the variety of the controlling system cannot conceivably be increased to match that of the controlled system" (Glanville, 2000b,p.5). Glanville describes three ways to face unmanageability. The first is to reduce complexity by restricting the variety of the controlled system as discussed in section 5.2.6. The second is to change the organizational structure by changing how control operates - shifting towards mutual and self-control. The third is to accept unmanageability and embrace the advantages of an "out-of-control" condition. Unmanageability, according to Glanville (2000b, p.6), "exists at the same site where control exists, between the (nominally) controlling system and the (nominally) controlled system: unmanageability lies in interaction." Unmanageability is not a bad thing as out-of-control conditions can give rise to novelty (Glanville, 2000b).

5.3. Conversation in design

In The Architectural Relevance of Cybernetics, Pask (1969) explores the vital connections between cybernetics and architecture and proposes that cybernetics can function as a unifying theory for design. The underlying arguments for this proposition are that "architects are first and foremost system designers" and that cybernetics can provide metalanguages for critical discussions and explanatory power for simulations where the systemic nature of architecture is taken into account (Pask, 1969, p.494). In his article, he introduces the concept of conversation in design by discussing the idea of dialogue between man and "learning environments." Later at the Architectural Association (AA), Pask's further explores the notion of conversation in architecture by showing how it could be useful in a client-architect relationship, bringing better results than the more common initial briefing of instructions (Glanville, 2009). Those are two of the many examples of the influx to a more precise understanding of the association between conversation and design. According to Glanville (2009, 2014), the relationship between design and conversation is a reason to assume a critical connection between cybernetics, architecture, and design. These connections will be explored in the following discussion about conversation, design, and cybernetics. Due to the context in which this thesis was written, there will be particular emphasis on architectural design, but the central questions addressed can be generalized to all design fields.

5.4. Conversation and Communication in Design

Conversation is together with communication the two main forms of human interaction. Both concepts are close related, and because of their affinity, it is important to distinct them. Conversation requires communication - transmission and transformation of signals - to happen, but the quality of the conversation does not depend on the quality of communication. "Bad" communication can lead to "good" conversations and "good" communication can lead to "bad" conversations. Communication is often represented as a transfer of information between two entities, a sender and a receiver connected by a channel that enables the flow of information. In his seminal paper *A Mathematical*

Theory of Communication, Shannon (1948) developed a mathematical model that described the transmission of information from the sender to the receiver with minimal interference and error. Shannon and Weaver[112] (1949) further developed this model extending it to a more general system of communication that can be applied to many fields of knowledge. The fundamental problem of communication addressed by Shannon (1948) "is that of reproducing at one point either exactly or approximately a message selected at another point". He deliberately ignored that messages have meaning which he considered "irrelevant to the engineering problem" (Shannon, 1948). What Shannon (1948) considered significant was that "the actual message is one *selected from a set*[113] of possible messages" and the system has to be designed to operate for each possible selection (Shannon and Weaver, 1949).

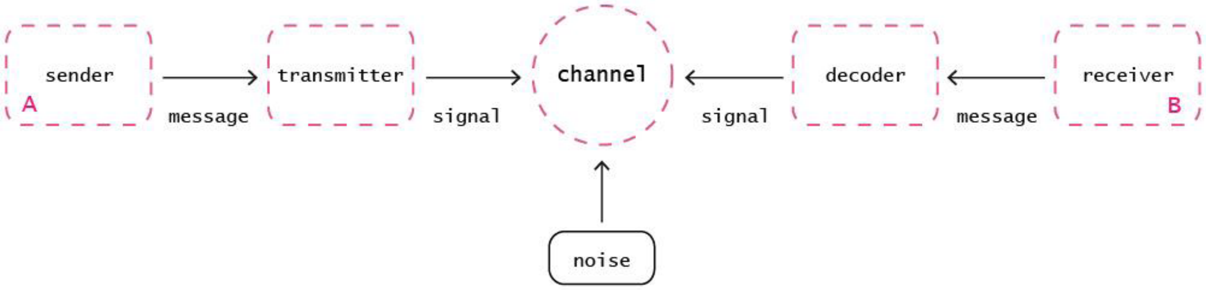

Figure 67 | Shannon and Weaver's (1949) general communication systems (author, 2017)

The overall scheme of his communication system[114] is represented in figure 67. In this scheme, messages chosen by an **information source** - the sender - are **encoded** and converted by a **transmitter**. The **signals** are sent through a channel to a **decoder** that will convert the signals back to its initial form by reconstructing the message to the **receiver**.

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[112] According to Krippendorff (2009) the publication of "The Mathematical Theory of Communication" as a book was an initiative by Wilbur Schramm's where Warren Weaver contributed with a brief commentary. Although Weaver did not contribute more directly with the theoretical aspect of the paper he did an important work to make the ideas and concepts more accessible to a general public.

[113] Original Griffing

[114] Communication systems can be divided in three categories: discrete, continuous and mixed. In discrete systems message and signals are a sequence of discrete symbols. That is the opposite in continuous systems where message and signals are continuous. The third category is a combination of both, where continuous message and discrete signal function together (Shannon, Weaver, 1949). The three systems are exemplified as following: (1) Morse Code: Message - letters / Signal - dots; (2) Radio Show: Message - sound / Signal - radio waves; (3) Youtube Vídeo: Message - sound / Signal - binary code.

The channel may contain **noise** that affects the transmission by adding unwanted distortion or error in the signals. Static in radio, crossed lines in telephones, and pixel distortion in a skype video call are some examples of **noise** in communication.

Although Shannon's model concerned the transmission of information as codes, it is often confused with the transmission of meaning. Von Foerster (2003) challenges the notion of communication where information (meaning) is seen as an object that can be transmitted through a pipe connecting sender and receiver, as for him information cannot be transmitted, but is created by the observer. In his view, effective communication only happens when the signals are transformed into information by the receiver. Von Foerster (2003) observes that "it is the listener and not the speaker who determines the meaning of a statement." This view is following a constructivist notion that knowledge cannot be transmitted. Ernst Von Glasersfeld (1984, p.5) defines constructivism as "theory of knowledge in which knowledge does not reflect an 'objective' ontological reality, but exclusively an ordering and organization of a world constituted by our experience." He affirms that "language frequently creates the illusion that ideas, concepts, and even whole chunks of knowledge are transported from a speaker to a listener [...] rather each must abstract meanings, concepts and knowledge from his or own experience" (Von Glasersfeld (2002).

The linear model of communication where the sender has an active role that selects the message and the receiver is a passive receptacle of information fails to address these subtleties of the learning process and human knowledge. In human communication, the sender adjusts the way of communicating with the characteristics of the receivers in an interactive and circular process. Krippendorff (2009) questions this critique by arguing that Shannon's objective was not to extend his theory to circular communication structures, but to provide a "versatile calculus." It is true that Shannon's mathematical model is effective for understanding and modeling the transmission of signals and codes, but another model is needed for more complex and circular processes of communication that generates novelty.

Before signals can be transformed and coded into information, there has to be an agreement on what those signals are and to construct this agreement another kind of interaction is needed, namely a conversational interaction. As stated by Glanville (2001), "the qualities required in a conversational model are prior necessities for the setting up of an encodement model. Put another way, the encodement model is a highly specialized, limited restriction of the conversational model (as Newton's mechanisms are of Einstein's model)". Hence, conversation is a form of interaction where new messages are generated by each participant and communication is a restrictive form of conversation aimed at the transmission of signals. However, how can we reach shared understandings while not being able to transfer meaning? Pask's (1976) Conversation Theory helps us to understand how those processes occur in a conversation as discussed below.

5.5. Conversation Theory

We are observing beings, and we learn by interacting with what we observe: other observers, objects, and spaces. Construing these interactions as "conversations", as noticed by Pangaro (1996), "is highly useful in both metaphorical and formal ways." In a design process, different forms of conversations are involved. The most explicit are those that relate to a more traditional design practice: (1) conversation between designer and user; (2) conversation between designer and designer (internal); and (3) conversation between designers (design groups). Others that may not be very explicit are (4) conversation between a user and designed object; (5) conversation between designer and designed object; and the last (6) conversation between designed objects. To understand this different forms of conversation and their implication, we have to clarify the processes involved in conversations. The process of conversation was formalized by Gordon Pask (1975) in his Conversation Theory, which offers a framework to understand conversational processes in different contexts and systems.

In Conversation Theory Pask (1980) defines conversation as "a process of conjoint concept execution, by participants A and B, as a result of which the agreed part of the concept is distributed or shared and cannot be functionally assigned to A or to B." This idea is based on the constructivist notion that it is not possible to transcend the limits of individual experiences, and therefore knowledge is created by individual experiences and cannot be transmitted. In that sense, participants A and B cannot share knowledge in a direct manner, but can only create knowledge together by agreeing (including agreeing to disagree) on their particular view of a target subject. Figure 68 illustrates this process in a verbal conversation between two participants. In this diagram, a circular iterative feedback loop is represented. Each participant hears what the other has to say and responds in their own way how they understood what was said. They compare their understandings to correct possible errors.

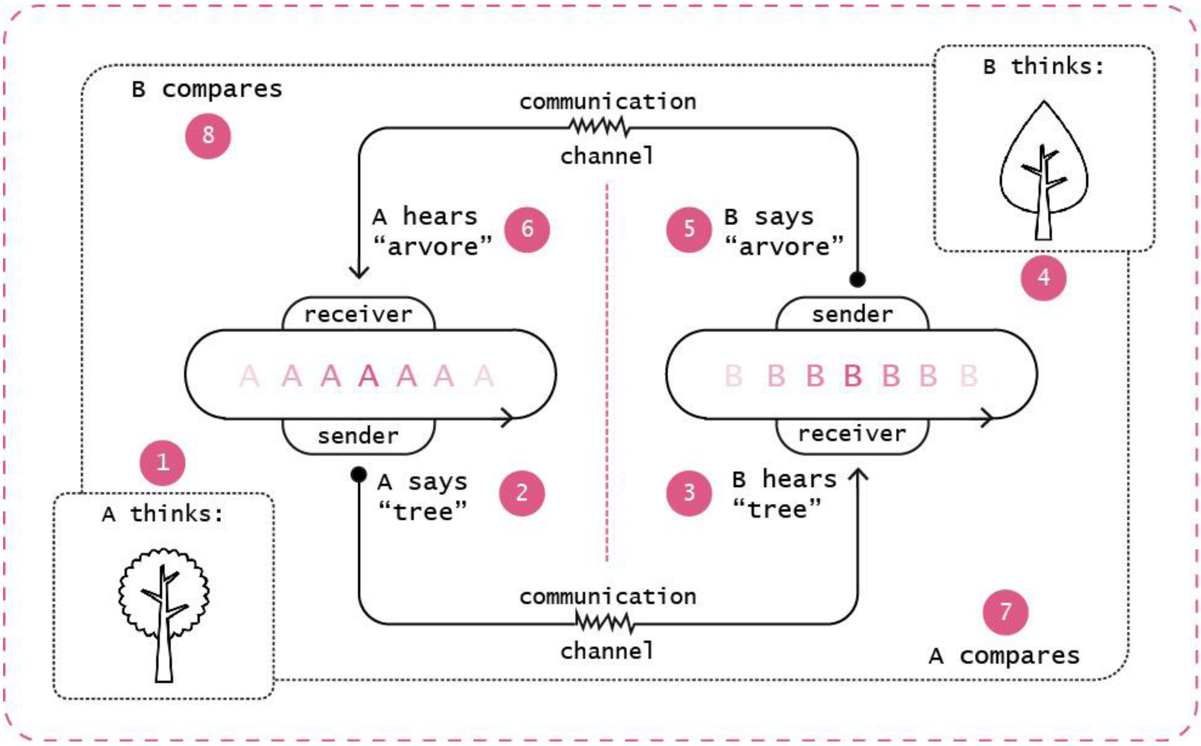

Figure 68 | Diagrammatic presentation of the stages in a normal Paskian verbal conversation based upon Glanville´s (2009). (author, 2017)

For Pask (1993) the identification of conversational participants as people was not entirely satisfactory. Groups converse with other groups, just as much as people converse with people. In that sense, participants A and B can be identified not only with people but can be generalized to a broader scope such as: (1) A and B are coherent points of view; (2) A and B are distinct groups of people; (3) A and B are self-replicating schools of thought; (4) A and B are conglomerations of people and the machinery that exteriorize many of their mental operations by computing on their behalf; and (5) A and B as collections of interacting but a-priori-independent processors, a computing medium made of biological or other-than-biological fabric (Pask, 1980). It is interesting to notice that for Pask (1996) the purpose of the conversation is not about its target (T), but about the participants A and B. By sharing their perspectives about a given target, they get to know each other. This discussion leads to what is according to Von Glasersfeld (2001) one of the fundamental insights of Conversation Theory: "every conversation involves not two but four individuals" - "the two speakers that an observer might distinguish and, more importantly, the construct that each speaker builds up of the other." When we interact with others, we cannot access what they are, but only what we interpret of what we hear them say, see them do and the context they are immersed.

To properly identify those different possibilities for participants A and B, Pask (1975) created the concept of psychological individuals (P-individuals) - self producing conceptual systems with organizational closure - housed by mechanical individuals (M-individuals). P-individuals are the participants in a conversation, and the conversation in itself can be a P-individual when it results in stable concepts. As Boyd (2004) observes, P-individuals represents the deconstruction of the conventionally understood psychology of the individual - a supposedly continuously present stable autonomous integrated individual - into a collection of psychological individuals whose presence is variable and heterarchical[115]. According to Pask (1975), "typical P individuals are people regarded as personalities – characters (in plays) executed by any actors, the performance of stable roles in society, the organization of coherent groups, factions, governments, cultures, and persistent ideas".

In turn, M-individuals are strictly "any dynamic fabric able to accommodate a P-individual" (Pask, 1993) - it is what embodies P-individuals. They may be "any interpretative medium, human, animal, organizational, possibly mechanical, possibly even cosmological" (Pask, 1996). Each M-individual will bear the index of the P-individuals it incarnates (Pask, 1996). Multiple M-individuals can house one P-individual, as for example, a group of designers (M-individuals) working together creating a group intelligence (P-individual). There can be also multiple P-individuals in one M-individuals which is illustrated by a designer

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[115] People often have internal conversations to solve difficult problems or to take decisions. That can be an example of multiple P-individuals housed in a M-individual - the brain.

that creates, through internal conversation where multiple P-individuals are housed in one M-individual, the body. This more general understanding of the participants of a conversation works as the foundation for the structure of a conversation. It enables Conversation Theory to be used in distinct fields and to model conversations not only between people or groups of people, but also other biological and nonbiological entities. This can be of great value if we are to understand how we converse with architectural space.

For many, it is a great challenge to fully understand Pask's Conversation Theory. His texts and books are not always clear for a wider public and demand a great effort from an average reader to properly grasp his concepts and ideas[116]. Both Glanville (1993, 2001) and Pangaro (2001) sought to clarify and build upon Pask's *Conversation Theory*. Glanville (2001) contributed with Pask's general framework with a series of requirements needed for conversation to be successful. As explained by Glanville (2001), those requirements seeks to determine what is needed to make a conversation work properly, rather than giving specifications of the architecture and mechanisms of conversation. They are divided in two groups, operational and inspirational requirements. Operational requirements are related to the mechanisms of conversation and the inspirational requirements refer to the attitude of the participants.

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[116] Glanville (1996) pointed that Conversation Theory is "in many parts very hard to understand, because of a tendency to present it all, all the time, in its full complexity" and Scott (1980, p. 328) portrayed some of Pask's writings as "esoteric, pedantic, obscurantist."

The operational requirements are:

1. At least two participants **willing** to take part in the conversation;
2. Having a **topic** (even if it is about having a topic);
3. Existence of **different understandings** in all participants - we all understand things differently;
4. **(re)presenting** the different understandings to others so that they may construct their own understanding of what is being presented;
5. ability to **compare** understandings: do I understand your understanding of my understanding;
6. the accessibility to three co-located and contemporaneous levels: (1) conversation; (2) meta-conversation (a conversation about the conversation for evaluation); and (3) substratum (negotiable and, usually, shifting topic);
7. the ability to **monitor** and **correct** errors by shifting between the three levels; and
8. a way of initiating and terminating the conversation.

Glanville (2001) notes that the comparison for mutual understanding is not necessary in every conversational loop. Participants may access shortcuts where they think there is already a shared understanding. But he alerts that those shortcuts may lead to inadvertent communication pathologies[117].

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[117] Bernard Scott (1997) discusses these pathologies and the forms they take in social organisations in his article "Inadvertent pathologies of communication in human systems".

The inspirational requirements are:

1. **Recognizing differences** between participants - each participant has different understandings and ways to represent those understandings;
2. **Respect for others** and their differences;
3. **Openness**: willingness to listen;
4. **Self-respect**: willingness to construct my own understanding rather than trying to absorb the understanding of others;
5. Willingness **not to impose** our own view;
6. **Open-mind**: willingness to make room for other ideas and understandings;
7. **Welcome novelty** - opportunism to look for novel situations and surprises;
8. **Willingness to learn**;
9. The results of conversations are of **shared property** between the participants; and
10. Recognition of the **active role of the conversation** - in Glanville's (2001) own words "conversations have lives of their own. This is the nature of interaction. Each participant contributes, but the conversation, nevertheless, has a life of its own: it is also an individual and a participant. This is how we find novelty in and through conversation". The conversation itself is a P-individual.

Glanville's (2001) inspirational requirements are constructed by two groups of qualities: (1) generosity (respect, honesty and drama); and (2) openness (imagination, opportunism and wit)[118]. In this relation between the operational and the inspirational requirements Glanville offers a more humanistic perspective on conversation, and connects those qualities to Pask. In a different approach, Dubberly and Pangaro (2009) constructed a

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[118] Glanville (2001) indicates that those qualities represent a portrait of Gordon Pask

more pragmatical framework for conversations to be effective, focusing on the design of conversational computer interfaces and marketing strategies. Their framework has several similarities with Glanville's requirements, but also some important differences. For Dubberly and Pangaro (2009), participants have to perform the following tasks for an effective conversation to happen:

1. **Open a channel** and establishing common ground;
2. **Commit to engage**: participants have to pay attention to the messages and have symmetrical commitment to engage in the conversation. Either side have to see value in continuing the conversation, otherwise it can be broken;
3. **Construct meaning**: participants can construct, re-construct and create meanings. One participant constructs a message with shared topics and distinctions (ex: common language and social norms) and presents this message using a message channel to the other participant, that in his turn tries to re-constructs the meaning;
4. **Evolve**: when conversation takes place the interaction changes the participants. When the changes brought about by a conversation has lasting values for the participants the interaction is called by Dubberly and Pangaro (2009) "effective conversations";
5. **Converge on agreement**: participants try to reach an "agreement over an understandings" by comparing the understanding of the first participant understanding of the understanding of the second participant understanding of the first participant. An agreement happens when they judge that the concepts match sufficiently.; and
6. **Act or transact**: when conversation leads to action beyond the conversation.

A key difference between Glanville's (2001) framework and Dubberly and Panagaro's (2009) relates to how people commit to engage and maintain a conversation. According to Glanville's framework openness, self-respect, open-mind, and willingness to learn are some of the main attributes for engagement in a conversation. Dubberly and Pangaro (2009) have other direction and focus on giving value and making trade-offs as to whether or not it is worth starting and maintaining a conversation. They use the concept of "bio-cost" (Dubberly, Maupin, Pangaro, 2009) as a way to quantify this value.

5.5.1. Bio-cost x Pleasure-Gain

> "It is human experience and not abstract theories that should decide what we do." (Jones, 1991, p5)

Bio-cost refers to the energy, attention, and stress expended by the participant over time to perform certain actions and achieve their goals. Energy is of a physical nature and is related to how much calories will be spent to perform a certain work. Attention is associated to the mental effort to think about or perform a certain task. Stress is how we emotionally connect to certain tasks or goals, as fear, worry, uncertainty, and anxiety may generate a higher cost for the participants involvement. (Dubberly, Maupin, Pangaro, 2009). All those components are involved when we take action to achieve a goal. Bio-cost, as Dubberly, Maupin and Pagaro (2009) affirms, "limits what we can achieve because we may not have the resources to get what we want, or we might spend too much for what we get in return". Strategies such as cooperation (figure 69) and collaboration (figure 70) can be used to reduce bio-cost. In cooperation one participant agrees to perform actions for another to achieve his goals and in collaboration participants create common goals and agree on how to achieve those goals.

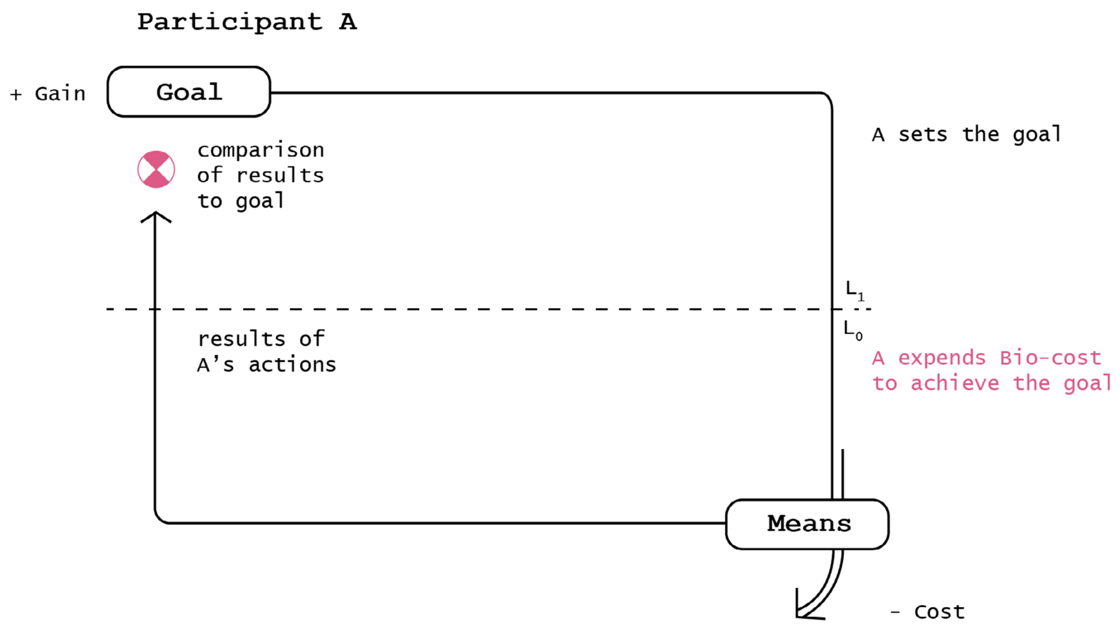

Figure 69 | Bio-cost for single participant. The figure is based on Dubberly, Moupin and Pangaro's (2009) reinterpretation of Pask's (1975) model of goal/action system. Participant A sets the goal in the goal level L1 and expends bio-cost to achieve the goal in the cost level L0. The results of A's actions are compared to the goal for evaluation of the gain. (author, 2017).

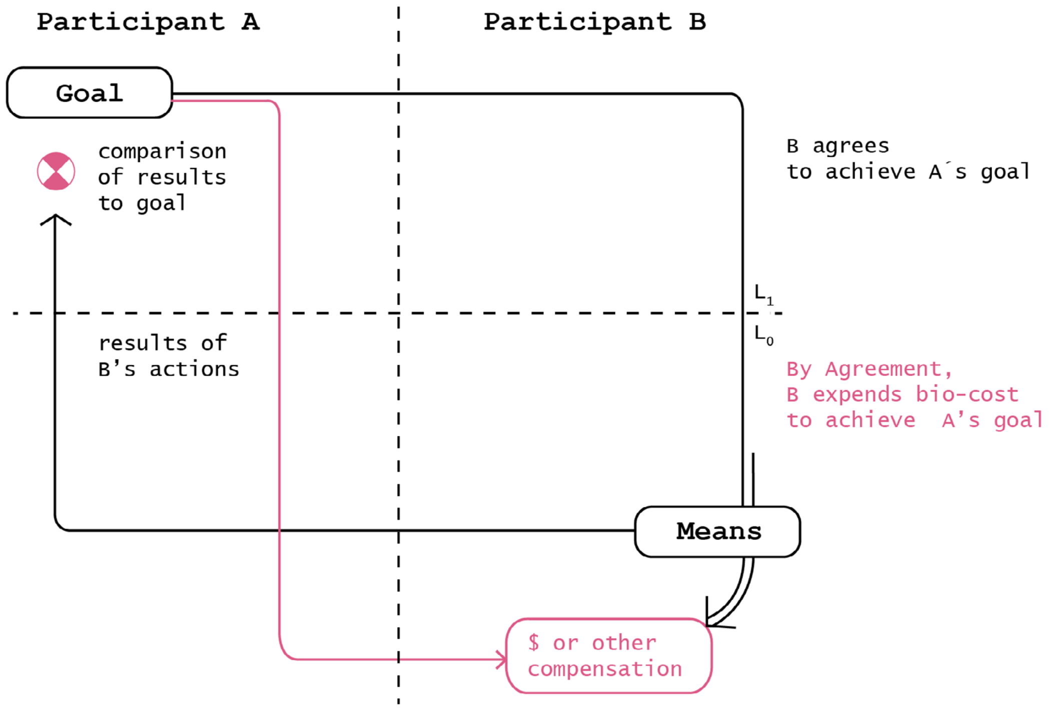

Figure 70 | Bio-cost for cooperative participants: Participant A sets the goal and Participant B agrees to achieve A's goal. The vertical line separates goal-setting and action-taking. The results of B's actions are compared by participant A to the goal for evaluation of the gain. (author, 2017).

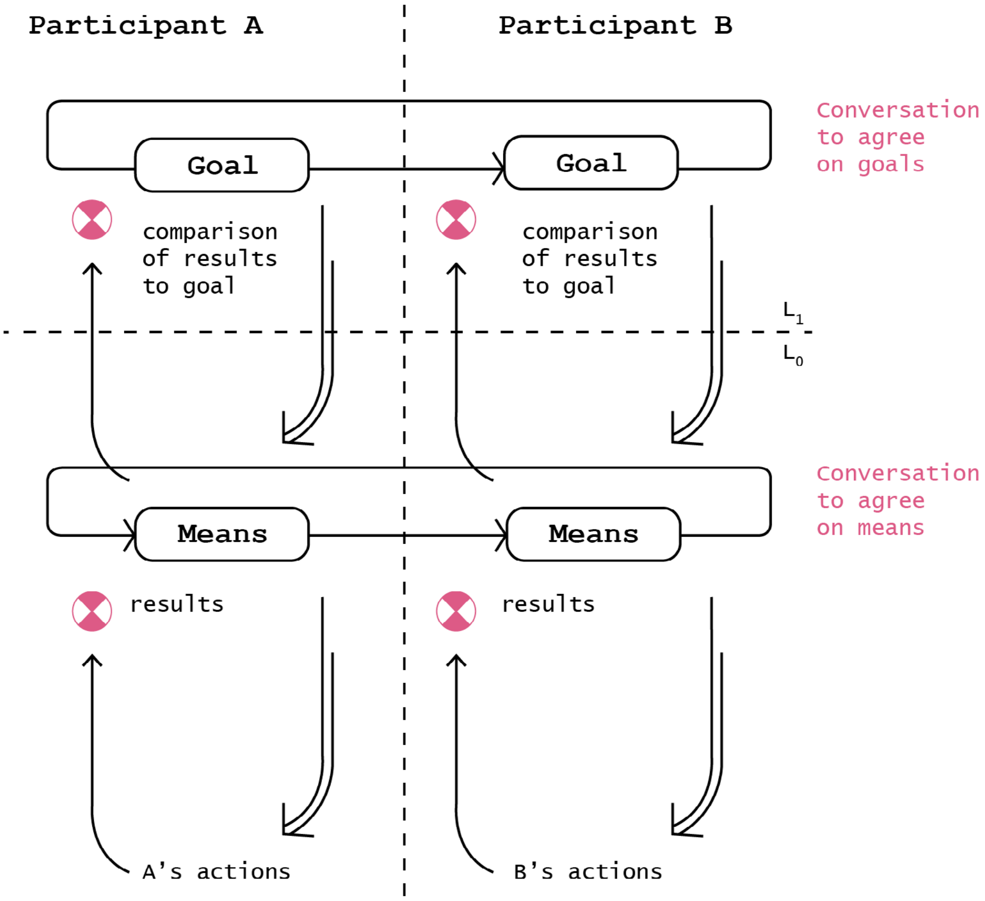

Figure 71 | Bio-cost for collaborative participants: Participants A and B converse on the distribution of roles and actions to create shared goals and means. (author, 2017).

Dubberly, Maupin, and Pangaro (2009) relate the bio-cost trade-offs to commercial transactions where we consider cost versus gain. In that model, money can be spent to lower one or more dimensions of his bio-cost. In their view, reducing bio-cost can be an ethical motivation in the design process and "lead to a more human world" (Dubberly, Moupin and Pangaro, 2009). This model can be useful to attain financial goals or to calculate spendings in companies internal processes. As they put it, "the success of modern corporation is a measure of the huge scale on which they reduce collective bio-cost expenditures" (Dubberly, Moupin and Pangaro, 2009). However, it runs the risk to flatten our experience and delight to converse into a monetary transaction. The struggle to compare cost (bio-cost) versus gains of a conversation can mislead us to an attempt to predict the possible outcomes of the conversational process; otherwise, there would be no matter to be waged and compared. By doing so, we might end up missing the chance of being delighted and surprised in a conversation.

In Dubberly and Pangaro's (2009) framework, uncertainty (about goals, roles, responsibilities, and stability) is a source of stress and can have a high bio-cost. But if uncertainty is understood as a state where we do not know the outcome, something that is unknown, it may be welcome and lead to novel situations. Indeterminacy is within the nature of conversation as the product of a conversation cannot be determined in advance as it results from the interaction between the participants. Although both frameworks can help us to analyze the different forms of conversations that are central to design, Glanville's (2001) framework seems to gently embrace the potential of uncertainty and indeterminacy to generate novelty - to design.

Pask (1971, p76) states that "man is prone to seek novelty in his environment and, having found a novel situation, to learn how to control it." Novelty concerns something unconventional, unfamiliar, and unexpected to a given individual. Control refers to how the individual relates to this unexpected event by trying to understand, explain, and conceptualize it to compare it with previous experiences and learn. According to Pask (1971, p76), "when learning to control or solve problems man necessarily conceptualizes and abstracts. Because of this, the human environment is interpreted in various levels in an hierarchy of abstraction". The will to learn is what strives "curiosity and assimilation of knowledge" that invites man to explore and engage in conversational interaction with its inanimate and social environments (Pask, 1971). In summarizing this issue, Pask (1971, p.76) states that: "man is always trying to achieve some goal and he is always looking for new goals. Commonly, he deals with goals at several levels of an hierarchical structure in which some members are freshly formulated, and some are in the process of formulation." For Pask (1971, p.76) this activity is inherently pleasurable and essentially human, and humans find pleasure in activities that deal with novelty and leads to knowledge gain. From this perspective, an alternative to the measurement of bio-cost spent to perform certain actions and achieve goals is to think about the Pleasure-gain of such activity and pursuit of goals.

Because there is pleasure in learning, and learning is related to novelty, Pleasure-gain is a concept that invites people to reflect on how to generate novelty and engage in novel experiences. The goal of the proposed concept is not to serve as a way of measuring pleasure, which would not be desirable or even possible. Neither it is to define a method. It is proposed as a way of looking at things differently than from a Bio-cost perspective. An example of such difference is the analysis of a dynamic space that incorporates a sliding panel to change the states of the spatial system. From the perspective of Bio-cost, one should measure: (1) how much calories will be spent to open or close the panel or (2) how much money will be spent to pay someone to open or close the panel or (3) how much money will be spent to automate the panel to open or close, and finally (4) what will I gain when opening and closing the panel. From the perspective of Pleasure-gain, one should ask, what is the variety of states generated by manipulating the panel? Will it lead to novel and pleasurable interactions? These are all questions related to how we converse and relate to each other - human experience - and as put forward by John Chris Jones in the opening quote, it is based on that, that we should decide what we do.

5.6. Design conversations

In design, it is common to attribute great importance to drawings. Many designers, for example, envision that their work is to create detailed drawings that ideally describes every formal aspect of the building. Bryan Lawson (2002) observes that this primacy of drawings and the enduring emphasis on the visual aspects in the design field can mislead us to see that, in reality, much of the design is done through different levels of conversations. Because conversation is not recorded in the creative process and drawings are, we tend not to notice its importance. In fact, if we analyze conversation in design we will see that its importance goes far beyond the creative process, where drawing and sketching are seen as conversational processes. The following pages are devoted to discussing the main forms of conversation in design in more depth by relating them primarily to Pask's Conversation Theory and Glanville's and Pangaro's contributions.

5.6.1. Conversations: designer & designer

In design, drawings (physical or digital) are not only used to represent the results of a design to a client, builder, or legislator, but they are part of the design process itself. In fact, the conversational process of sketching and doodling is central to the design activity (Pask, 1969, Shön, 1984, Gedenryd, 1998, Glanville, 2009). The process of sketching combines two activities: (1) proposition - action - and (2) evaluation - reflection. Both operations are executed by a different persona (P-individuals), the maker and the viewer. This different persona engages in a circular iterative process that can be characterized as a conversation (Glanville, 2009).

For designers, the concept of sketching and drawing as a conversation with oneself is rather simple to depict. They do not only feel this circularity in their day to day work, but in general, they also recognize the creative potential of this form of conversation and explore it in different ways in their practice. Schön (1930-1997) analyzed the design practice in his book - The Reflective Practitioner (1984)- in which he explores the knowledge professionals use in their practice. Shön understood design as a reflective activity with its related notions of reflection-in-action, reflective practice, and knowing-in-action. He advocated that "doing and thinking are complementary. Doing extends thinking in the tests, moves, and probes of experimental action, and reflection feeds on doing and its results. Each feeds the other, and each sets boundaries for the other" (Shön, 1984, p. 280). Extending this rationale to design, he argues that "the process spirals through stages of appreciation, action, and re-appreciation. The unique and uncertain situation comes to be understood through the attempt to change it." Moreover, "the practitioner's moves also produce unintended changes which give the situation new meanings. The situation talks back, the practitioner listens, and as he appreciates what he hears, he reframes the situation once again" (Schön, 1984, p. 131-132). Schön's understanding of the reflective practice is circular and conversational, thus cybernetical, even if he did not mention it[119].

Gedenryd (1998) also explored the design activity as a circular act by investigating how designers work out their ideas in interaction with the medium. He proposed that cognition is not an activity going on inside the mind (intramental), but an interactive process between mind and the world he calls "interactive cognition" (Gedenryd, 1998, p. 101). Interactive cognition reconciles cognition and the world where artifacts and their properties participate in the cognitive process. It shows that cognition and the world are connected through our performative being. It follows that designers think in conversation with the medium.

From the perspective of Pask's Conversation Theory, the internal process of design involves at least two P-individuals housed in one M-individual (the designer's body). Each P-individual construct the world differently and have their distinct understanding of the target subject. When drawing, the M-individual bears the index of the P-individual drawer and when observing, he incorporates the P-individual viewer. In this interchange, P-individual-drawer and P-individual-viewer engage in a circular interactive process of conversation, and as noted by Glanville (2009), this process leads inevitably to change. "The designer, sketching/doodling, starts somewhere but ends somewhere else, often unable to explain the move from the one place to the other" (Glanville 2009). In a conversation between multiple designers what happens is that more P-individuals will conversate generating what is called group intelligence. The different P-individuals come together and interact creating M-individual-designers.

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[119] Although Shön's design theory is a reference for many authors, in Glanville's (2009) perspective, the idea to use conversation to explain the central act of design was "borrowed" by Shön and did not represent a new insight. Glanville (2009) states that he, Pask and others before them, already used the metaphor of internal conversations with oneself through drawings and sketches. Without belaboring the question of who was first (probably there were many as recognized by Glanville), the framework used by Pask and Glanville - Conversation Theory - seems to be more far-reaching because it offers the possibility to understand the cognitive activities of conversation in design at different levels. Pask's concepts of P-individuals and M-individuals are central to comprehend how those activities occur.

5.6.2. Conversations: designer & user

According to Glanville (2009), three years before Pask officially published on conversation theory, he discussed how conversational exchanges could be helpful to clients and architects to develop a proposal that became better than it would have been if simply briefed by initial instructions. It is common in traditional design workflow to start the process with a briefing from the client (or other stakeholders). The client presents a list of quantitative and qualitative demands and the expects the designer to understand the explicit and implicit meanings that he is trying to convey. From the other way around, architects frequently think that they "know better" and, because of their training and expertise, they will deliver something that is better than what the client originally demanded. In a commonly quoted passage, Lasdun (1965, p.185) says that "our job is to give the client, on time and on cost, not what he wants but what he never dreamed he wanted and, when he gets it, he recognizes it as something he wanted all the time." However, because meaning cannot be transmitted, the final result will be inevitably something new both for the client and for the designer. Although this may sound desirable, several clients and architects neglect this opportunity for novelty and regard any deviation from their goal as an error. Many treat the conversation as coded communication and expect that information will be transmitted without noise.

The conversation between designer and user is perhaps the most visible form of conversation in design. Within this context, users can be individual clients, contractors, and other stakeholders that are involved directly and indirectly in the design process. One of the major concern designers should acknowledge, is to properly understand the desires and needs of the people who are going to make use of the designs implemented. Von Foerster (1989) addressed this question in an article about "the need of perception for the perception of needs and desires." In the article, he discusses the importance of understanding perception so that it is possible to perceive people's needs. He argues that "we may not see that we do not see the needs and desires of the people we wish to serve, and happily address ourselves to what we think are their needs and desires" (Foerster, 1989, p.224). This is what designers often do when they think they possess, a priori, the right answers.

Perception, from a constructivist point of view, is created within the nervous system, and is not a result of the existence of an objective reality. Therefore, it is much closer to an act of creation - conception - then as in reception (Von Foerster, 1989). The idea of an objective reality independent of the observer evades responsibility, whereas the idea that we create our own reality reinforces it. This leads to the central argument presented by Von Foerster that architects should embrace aesthetics so much as ethics. Kenniff and Sweeting (2014) discuss this further and argue that in design the relation between the ethical and the aesthetic must be understood as a "dialogue in and of itself, as well as part of the dialogue between all participants in the design process."

A crucial understanding to potentialize this process is given by the inspirational and operational requirements for conversation developed by Glanville (2001). The use of Glanville's framework in the design process may not only create more meaningful experiences for the different stakeholders involved in the design process, but also for the designer, which may find himself delighted by the unexpected results of the process. Because the results of conversations are of shared property between the participants, the outcome will be a new situation for all participants. Nevertheless, in architecture, it is frequently not possible to predict who is going to interact or be impacted by a design outcome. Therefore, when the future users is unknown, it is difficult to establish meaningful conversations between designers and users in a traditional design process. The question arises as to how address the issue of not knowing, or being able to interact, with future users in the design process.

5.6.3. Conversations: user & designed object

> Man is prone to seek novelty in his environment and, having found a novel situation, to learn how to control it" (Pask, 1971, p.76)

Radical Constructivism suggests that "we have no one but ourselves to thank for the world in which we appear to be living" (Von Glasersfeld, 1984, p.1). From that perspective, the way a building communicates with people, and the meaning it creates through interaction is highly individual. As observed by Pask (n.d. p.7), architecture can be seen as a language - it is “probably, the most universal and most widely comprehended of all languages.” It involves the observer in different levels of conversation: “architecture speak to us”, “people speak to one another through architecture”, and “we converse with ourselves, playing different roles, through architecture”. Sweeting (2011, p.1163) observes that, “thinking of the interpretation of a building in terms of a conversation, what is striking is that the conversation is between the observer and the building itself rather than with the designer”.

In architecture, this means that all that is communicated through design and all that is understood are a matter of interpretative construction on the part of the observer in conversational interaction with the architectural space. Designers often ignore this and frequently treat architecture as a coded model of communication, in an attempt to make a statement or to transmit a message to the observers. However, the understanding that the observer will construct from codes embedded into a design cannot be subjected to the control of the designer. Sweeting (2011, p.1163) advocates that “meaning is not directly given and it is therefore extremely difficult to communicate precisely through architecture. But part of architecture’s communicative power is its very lack of representational accuracy and its resulting openness to a variety of interpretations”.

The way we explore and understand our environment is especially notable when a one-year-old child enters into contact with a new environment. It is perceivable that very young children engage space mainly by way of performative interactions. They do not yet possess a toolbox of abstract concepts to explore through a representative filter. They smell, taste, touch, see, and heer and create a synesthetic experience to relate to objects and space (to control it)[120]. Adults, on the contrary, do not necessarily need, for example, to smell, taste and touch a chair to understand that it is primarily used to sit on because they may have learned that through conversation between different observers. In the same way, when people call something an architectural unity, some agreement between different participants is needed so that it is perceived in that way and a shared consensual domain can be established (Pask, n.d.). In order to be perceived, the system has to be

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[120] When I was writing this section my son was starting to crawl and explore his world. Therefore, this observation is not only fundamented by a constructivist understanding, but also from my own observations of how he interacted with the environment.

stable enough for that they can be discerned and specified. Therefore, as put forward by Pask (n.d.), an architectural unit is a dynamic, productive, entity that determines their own boundaries. In other words, from a cybernetic perspective, they are systems with organizational closure (see section 5.1),

In an analyses of the chair (in this example a wooden chair) from the perspective of Conversation Theory, it is possible to state that there is a M-individual-wood-structure that bears the index of a P-individual-to-sit-on. When the observer engage in aesthetic activities, the performative filter can once more gain prominence, and the M-individual can come to house another P-individual, or multiple P-individuals, even if temporarily. Chairs may be for example used to make sculptures, such as in the works of Tadashi Kawamata[121] and Ryan Philbin Jesse. This may foster a productive and pleasurable dialogue that invites people to reconceptualize objects and spaces through conversation. What is important to notice is that concepts - P-individuals - associated with space are created and changed through conversation. Designers can, and should, operate within this domain by designing objects and spaces that invite the user into a circular process that enable both representational and performative activities within a conversation. The *Chaise Longue* designed by Charlotte Perriand and Le Corbusier is an example of a design that point towards this interactive reconceptualization through performance. The angles of the Chaise can be changed so that the P-individual-to-sit-on is reconceptualized in a P-individual-to-lay-on. It can be said that the design of the Chaise has an open parameter (angle) that, when acted upon within the given constraints, enables the reconceptualization of the object. Pask (1971) calls such structures, that are designed to foster productive and pleasurable dialogue, "aesthetically potent environments."

The concept of *aesthetically potent environments* defines environments designed to stimulate pleasurable interactions, where men are impelled to explore and discover - to engage in conversation with the environment. According to Pask (1971, p.1), aesthetically potent environments should:

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[121] Chairs for Abu Dhabi - Tadashi Kawamata - Artists - galerie kamel mennour, 75006 Paris [WWW Document], n.d. URL http://www.kamelmennour.com/media/6072/tadashi-kawamata-chairs-for-abu-dhabi.html (accessed 5.29.17).

> (a) “offer sufficient variety to provide the potentially controllable novelty required by a man (however, it must not swamp him with variety-if it did, the environment would merely be unintelligible;
>
> (b) contain forms that a man can interpret or learn to interpret at various levels of abstraction;
>
> (c) provide cues or tacitly stated instructions to guide the learning and abstractive process.
>
> (d) It may, in addition, respond to a man, engage him in conversation and adapt its characteristics to the prevailing mode of discourse.”

Pask (1971) observes that any competent work of art can be seen as an aesthetically potent environment. Painting, for example, can foment dynamic exchanges between the observer and artwork, by provoking internal conversations between our active perception of the work (representation), and our immediate awareness (performance). Pask (1971, p.77) stresses that “the external aesthetically potent environment gives rise, bit by bit, to an internal representation and the reciprocal interaction of “d” is internalized as a discourse between the internal representation and our immediate selves.” This process also happens when conversing with a building. Buildings can be designed as aesthetically potent environments that invite productive and pleasurable interactions. These interactions can occur through internal conversations - as in the example of the painting - and also through external conversations when the conversation is explicit and observable.

It is within this notion that Pask (1969) asserts that Antoni Gaudi’s Parc Güell (1914) is at a symbolic level one of the most cybernetic structures in existence. “As you explore the piece, statements are made in terms of releasers, your exploration is guided by specially contrived feedback, and variety (surprise value) is introduced at appropriate points to make you explore” (Pask, 1969). For Pask (1969), Gaudi created (intentionally or not) the possibility for conversation between the environment and the observer without the use of movable structures, where the dynamic relation is achieved by the movement of people.

Pask's investigation into aesthetically potent environments departed mainly through the development and observation of his "maverick machines". The first was called Musicolour, a transducer that used the sound of a musical performance as an input to control a coloured light show (vocabulary of visual symbols), with the aim to create a synesthetic combination of lights and sounds by means of a playful interaction between machine and performer (Pask, 1971). The machine was built by Pask and Robin McKinnon starting in 1950s, and the whole project took several years in which several versions were developed.

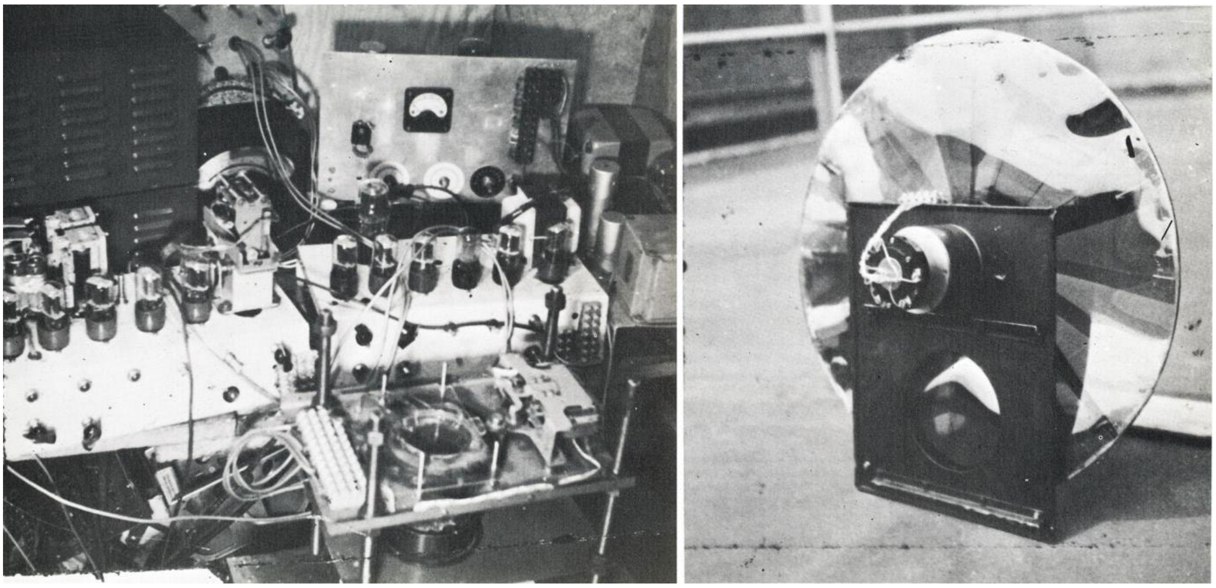

Figure 72 | Musicolour, 1953-57, projection wheel controlled by a servomechanism (Pask, 1971, p.81).

Musicolor was a device that not only synced music to light, but invited the performer to a mutual learning experience. It worked by means of an array of different property filters, varying from frequency band pass filters to complex rhythm detectors. The parameters of each filter could be independently adjusted and the output was mapped by an adaptive threshold device that automatically modifies its sensitivity to its inputs. The output of the threshold device determines when a selection is to be made from the available visual vocabulary. What visual pattern is to be chosen is determined by the output of the property filters. As Bird and Di Paolo (2008, p.192) explain:

> "the visual pattern is selected by controlling a servo-positioned pattern or color wheel. The particular parameter values are selected on the basis of how different the output of the filter´s associated adaptive threshold device is, compared to the other filter´s thresholded outputs, and how long it is since a particular value has been selected. The selection strategy aims to increase the novelty of the filter outputs and to ensure that all the parameter values are sampled".

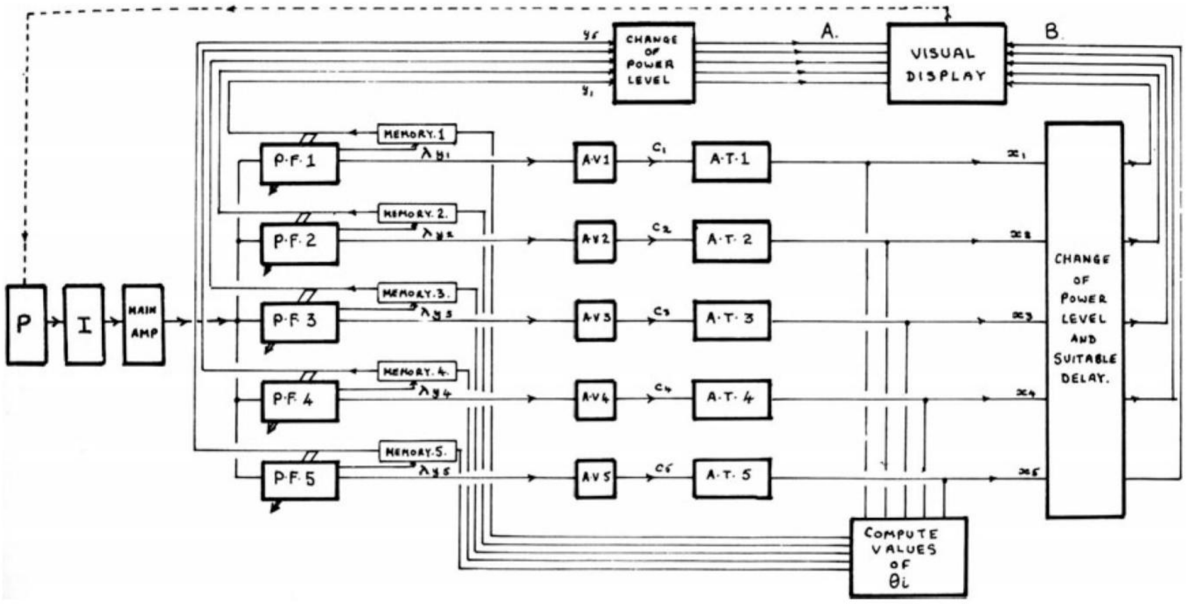

Figure 73 | Outline of a typical Musicolour system, 1953-57, (Pask, 1971, p.81).

One of the main features of Musicolor is that when the input became repetitive, the system would "get bored" (Pask, 1971). If there was no new input, the adaptive qualities of the threshold device would lead the system to become increasingly sensitive (a gain control circuit constrained the input amplifier gain within a certain level) changing the parameters values to generate different light patterns. Although the visual performance of Musicolour was its main commercial feature, it was not the main focus of the research. As Pask (1971) observes:

> "the interesting thing about Musicolour was not synaesthesia but the learning capability of the machine. Given a suitable design and a happy choice of visual vocabulary, the performer (being influenced by the visual display) could become involved in a close participant interaction with the system. He trained the machine and it played a game with him. In this sense, the system acted as an extension of the performer with which he could co-operate to achieve effects that he could not achieve on his own."

Musicolour points to a system where there is no hierarchy between man and machine. Pickering (2011, p.319) observes that:

> “a Musicolour performance staged the encounter of two exceedingly complex systems — the human performer and the machine (...) — each having its own endogenous dynamics but nevertheless capable of consequential performative interaction with the other in a dance of agency. The human performance certainly affected the output of the machine, but not in a linear and predictable fashion, so the output of the machine fed back to influence the continuing human performance, and so on around the loop and through the duration of the performance.”

In this system - as long as the performer and the machine are willing to conversate - it is no longer possible to determine controller and controlled. P-individual-performer engages in conversation with P-individual-machine to form a P-individual-performance. “The point to note is that in performance the performer learned (performatively rather than cognitively) about the machine (and vice versa), and Pask therefore regarded Musicolour as a machine in which one could learn—scientifically, in a conventional sense—about learning” (Pickering, 2011, p.318).

Socrates Yiannoudes (2016) explores the importance of asymmetry in the relationship between the human and machinic actor in his book Architecture and Adaptation. One of his conclusions is that most productive interactive relations have an asymmetrical nature. He draws upon the work of Joseph Weizenbaum [122](1966) with the computer program called ELIZA[123], developed at the MIT Artificial Intelligence Laboratory between 1964 and 1966. ELIZA[124] simulated a conversation between a psychotherapist and a human by analyzing and using the person’s responses to shape the computer’s replies. Weizenbaum’s (1976) simplified description of how ELIZA works goes as follow: “the

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[122] Joseph Weizenbaum (1923–2008) was an important pioneer in computer technologies. He became later well known for his critique of technological progress epitomized in his book “Computer Power and Human Reason.”

[123] A demo of how ELIZA works can be found at: http://www.masswerk.at/elizabot/eliza.html

[124] Weizenbaum’s (1996) simplified description of how ELIZA works goes as follow: “the text is read and inspected for the presence of a keyword. If such a word is found, the sentence is transformed according to a rule associated with the keyword, if not a content-free remark or, under certain conditions, an earlier transformation is retrieved. The text so computed or retrieved is then printed out”.

text is read and inspected for the presence of a keyword. If such a word is found, the sentence is transformed according to a rule associated with the keyword, if not a content-free remark or, under certain conditions, an earlier transformation is retrieved. The text so computed or retrieved is then printed out". ELIZA was regarded by many as one of the first computer programs capable of passing the Turing Test. Although Weizenbaum repeatedly adverted that it was just a computer program, with an algorithm that simulated dialogue, many people believed that it did demonstrate intelligent behavior and that it could be used as substitute to a human therapist in the future (Weizenbaum, 1976). The point to notice is that ELIZA, a relatively simple computer program, generated extremely complex behavior when it engaged in a conversation with a human. In that sense, there was no need for ELIZA to "appreciate the observer's joke" to generate conversations. The only thing necessary was a circular feedback relation between ELIZA and the observer designed to enhance the observer's complexity.

Historically, the interchanges of cybernetic concepts and theories and design is specially related to initiatives that involves the notion of AI and "responsive environments". In the book *Soft Architecture Machines*, discussed in chapter 3 (section 3.3), Negroponte (1975) advocates for the development of intelligent environments that makes decisions and executes some functions. Negroponte made a provocative suggestion that a house is a home only once it can appreciate the dweller's jokes. This points out that responsive environments were, in Negroponte's perspective at that time, spaces capable of responding to the desire of their occupants by creating a symmetric relation between space and observer. Pask's Musicolour Machine and ELIZA shows a different perspective in pointing out that our efforts to make environments adaptive does not depend on our ability to force upon them our own characteristics. In conversation, there is no need for symmetry between P-individuals for it to be successful. This understanding is very useful for designers to rely on simpler strategies to trigger meaningful conversations.

5.7. The cybernetic toolkit

The main objective of this chapter was the introduce the reader to several conceptual tools put forward by cybernetics. Many of those tools have been used by researchers and designers in the past without an explicit reference to cybernetic thinking. The main concepts addressed were the notion of designing systems, exceedingly complex systems, trivial and nontrivial machines, control systems, feedback, variety, and conversation. Together they compose the general conceptual framework used to explore and understand the systemic nature of architecture.

6 | CONVERSATIONAL CUSTOMIZATION

The objective of this chapter is to promote a reflection upon various issues brought forth by the research-sketches described in chapter 2, together with literature review and theoretical discussions developed in chapters 3, 4, and 5. It departs from the notion that, in face of the exceedingly complexity of architectural systems, it is no longer possible to rely on the amplification of the designers limited capacity to solve problems. The tools for variety amplification - design amplifiers - are not only insufficient to amplify the regulating system, the *designing systems*, or attenuate the regulated system, the *architectural systems*, but they also have become self-referential systems that amplify themselves (for example Autocad - Autodesk). In this process, when used as tools, CAD systems may take prominence in the design process and can end up controlling the *designing system*.

The thesis puts forward the notion that a possible way to reach a paradigm shift in the process of production of architectural space is to use conversation as a design approach. It proposes a shifting of focus from the object to process, amplifying variety and the potential for novelty to arise. The objective is to offer designers a new way of thinking about design that focuses on conversation and intersubjective processes. The notion of *conversational customization* is put forward to offer a conceptual base for architects to explore conversation in design. It defines a design approach where people are involved in the design of their own space through conversational interaction between several agents, man, and machine alike.

1.1 The world is full of variety.
1.1.1 Variety is noise.
1.1.2 The world is full of noise.
1.2. The traditional work of the designer was to constrain noise.
1.2.1 This is no longer possible.
1.3. Noise is everywhere.
1.3.1 Noise is unmanageable.
1.3.2 The world is unmanageable.
1.4. Designers choose not to see this.
1.4.1 Designers design interfaces to manage the world.
1.4.2 Interfaces do not manage the world as a whole.
1.4.3. Interfaces manage designers.
1.4.4. Interfaces do not constrain the world as a whole.
1.4.5. Interfaces constraints the view of designers.
1.5. The world as a whole is unmanageable.
1.5.1 The world is full of variety.
1.5.2 Variety is a creative source.
1.6 Designers have to connect, to share, to design.
1.6.1. Designers have to design the connections.
1.7 We are all designers.
1.7.1 Our world is our design.
1.8 We are unmanageable.

Figure 74 | Conversational Customization - a way of thinking. (author, 2017).

6.1. Variety in the human environment

Historically, architects have always been involved in different practices related to the regulation and accommodation of human beings. In other words, they were continuously engaged in designing control systems (Pask, 1969). If architecture can be seen as a control system, then a building is, on a symbolic level, the result of a control programme put forward by the designer. Thus, as discussed by Pask (1969, p 494), "the designer is controlling the construction of control systems and consequently design is control of control, i.e., the designer does much the same job as his system, but he operates at a higher level in the organizational hierarchy." In the past, architects dealt with control systems through constraint-oriented processes based on predetermined codes - styles and manuals - which are today no longer capable of dealing with the amount of variety proliferation in social systems. The design systems used by architects, much based on problem-solving processes and representation methods, are no longer adequate to deal with the constant change in how people see, perceive, and interact with the environment and with each other.

To deal with the constant proliferation of variety in human environments, different tools for variety attenuation were developed (Beer, 1993). The creation of domestic architecture, for example, can be seen as a response to the growing complexity of the social and natural context. Architecture functions as a tool for variety attenuation by establishing symbolic and physical constraints, which restricts the variety of the environment, and creates a viable space that regulates our spatial and social relations. This notion is related to how people perceive and conceive their world. Following a constructivist perspective, our construction of the world is continuously impeded by obstacles that function as constraints that orient, but not determine, our actions (Glasersfeld, 1984). In the same way, architecture creates constraints that regulate but does not define people's actions and behaviors. Those constraints are not only a result of the physical matter of bricks and mortar, but more importantly, they emerge through our interactions with the architectural space. However, traditional constraints no longer respond in an effective way to the constant proliferation of variety that overwhelms our contemporary society. As put forward by Vilém Flusser (1999, p.83), our domestic space has been perforated by material and immaterial cables to the point that a home can be compared to a "Swiss Cheese." Flusser (1999, p.83) argues that "home-as-one's castle has become a ruin with the wind of communication blowing through the cracks in the walls." For Beer (1993) the very tools that would enable people to come to terms with the variety of the human environment are wrongfully used and have become, in fact, a source of variety proliferation.

The human environment is overwhelmed by a flux of information where everything becomes computerized, digitized, real-time, responsive, and interlinked in a machine-to-machine communication that penetrates our "attention worlds" (Kwinter,1993). Nowadays, the flux of information brought forth by computational systems conforms, together with the natural systems, the human environment, and designers should no longer ignore this. Following Ashby's Law of Requisite Variety (1956) and Conant and Ashby's Law of Regulatory Models (1970), for architecture to be able to regulate the variety of this exceedingly complex system it has to be modeled as an exceedingly complex control system, as only variety can absorb variety - or in Ashby's terms only "variety can destroy variety" (Ashby, 1956, p.207). Following this reasoning, the acknowledgment of architecture as an exceedingly complex control system brings up the question of how to relate to this system, where the number of states is exponentially higher than the designer can anticipate. In this context, it is necessary to create conceptual models to understand, analyze, and effectively intervene in dynamic performative environments that integrate technical, architectural, biological, and social structures.

Symbolically, "bricks and mortar" are now enhanced by material computation (Menges, 2014), programmable matter (Oxman, 2012), shape-memory alloys (Puckett, 2017), and self-assembly processes (Tibbits, 2016), that actively shape our dynamic environment. They are inserted in a context where the "dynamics of information has gained ascendancy and control over the dynamics of energy." (Kwinter, 1993, p213). As observed by Kwinter (1993,p213), "we are passing from an age dominated by a competence - one realized through techniques of mimesis, representation, and reproducibility - to one characterized by a performance, that is, of pragmatics or modeling." Nevertheless, despite the many advances on the technological and conceptual ground, architecture has been unable to address fundamental problems such as housing shortage, environmental issues, and many others, in a more appropriate and effective way. As discussed in previous chapters, many designers and researchers have explored different approaches to deal with this complexity asymmetry between designers, the systems they design, and the human environment. The following sections will reach to the cybernetic conceptual toolkit described in chapter V to examine previous discussions, problematize, and propose a possible alternative to come to terms with the complexity of our human environment.

6.2. Variety in Design

The concept of variety is approached in this thesis from three complementary perspectives associated with the context, design process, and use. The first is related to the variety of dynamic systems that give form to the human environment, as described by Beer (1993). From this perspective it is useful, for illustrative purposes, to differentiate variety as noise when it is undesirable. Information Theory refers to noise as undesired information in a communication channel which is not part of the intended message. Noise is an evaluative term that is only observed by the receiver (Umpleby, 1995). Therefore, it is the observer who defines to what point the variety is desirable and when it is regarded as noise. This understanding is helpful to discuss variety in the design process, where vast variety can be both regarded as an advantage or a disadvantage - a classical case of observer dependence.

The second perspective is connected to creativity and draws from Glanville's (1994, 2000b, 2007) understanding of variety in design, and from the concept of constraint-oriented design put forward by Fischer and Richards (2014). Glanville (2000, 2013) advocates that the variety of the human environment should be appreciated as a rich creative resource. Because the variety of the world can be understood as much richer in variety than one's brain, instead of controlling this variety in a restrictive manner, people should benefit from the variety imbalance by using the excedent as a way that may lead to novelty. In this condition, the system is "out-of-control" (Glanville, 2000). Another way of amplifying creativity put forward by Glanville (1994) is by the cooperative sharing of brainpower. By sharing their brainpower, designers can amplify their capacity to generate novelty (chapter 5, section 5.3).

Fischer and Richards (2014) offer a different view and point out that vast variety seems to offer unfavorable conditions for the creative process. The authors argue that, in the design process, establishing constraints to the number of states a systems may take can be helpful to enable the creative process. They draw on the notion of a "design space" put forward by Rittel, that defines the variety available to the design activity where constraints exclude design options that should no longer be considered. Fischer and Richards (2014) advocates that a *constraint-oriented approach* - in contrast to a *goal-oriented approach* - can offer "open corridors" and "fields of possibilities" within a solution space, which "lends itself naturally to a true participative / democratic process". Nevertheless, the authors indicate that the constraints, especially when imposed from outside the design system, should be seen as negotiable or even as reversible. This move, which they refer to as "constraint reversal", compels designers to challenge the context of a given design specification and to venture outside the constraints of the design space (Fischer and Richards, 2014).

In design, the distinction between constraints established from the inside or from the outside of the system is a critical one. As described in chapter 5 (section 5.2.6), the position is given by the observer in relation to where he sees him being in reference to the system. Departing from Von Foerster's (2003) perspective on ethics, constraints that originate from within imply ethics, and those from the outside moral codes. In this context, it is useful to recall Von Foerster's ethical imperative that says "act always as to increase the number of choices"[125], which means that people should not try to limit the activities of other people and, instead, they should behave in a way that increases the choices of others (von Foerster and Poerksen, 2012, p. 37). When people have freedom to act they are accountable for the choices they make, but when restricted they can avoid responsibility. This means that constraining the variety of a system evoques responsibility.

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[125] Where one must read: "Heinz, act always as to increase the number of choice", which imply that this can be only enacted by the observer. (Von Foerster and Poerksen, 2012, p. 37).

The third perspective from which the concept of variety is approached corresponds to the idea of the contrived variety in the built environment, such as discussed by Pask (1969) (Chapter 1). It follows that the exceedingly complexity of the human environment lead designers to find ways of amplifying their creative potential to be capable of designing dynamic architectural systems that can accommodate the variety of the users. As discussed in previous chapters, Pask (1969) brought forth the comprehension of architecture as a dynamic system. This view contrasts with the perception of a building as a set of static material objects. As discussed in chapter 5, the interaction with architectural space can be seen as a form of conversation, and designers can design space to foster productive and pleasurable dialogue (aesthetically potent environments).

What this different perspective on variety show is that the human environment is overwhelmed with variety to the point that it is uncomputable. This can be seen as a disadvantage - noise - or as an advantage for creativity. When viewed as an advantage, designers can operate by exploring this condition as it is - full of variety - so that it may lead to novelty, or they can try to amplify their variety with different means of cooperative sharing. When seen as noise, they can constrain the number of states of the system so that it becomes manageable. In fact, this seems to be the way most designers deal with large-scale architectural solutions, as will be discussed next.

6.2.1. Tools for variety amplification

Perhaps the most common way designers relate to the complexity of architectural systems is by attempting to amplify their variety through different technological and non-technological means, tools, and methods. In the last decades, different tools and processes have been developed to help designers to deal with the awareness of the growing complexity of architectural systems. Alexander and Chermayeff (1963) wrote: ”the problems have outgrown a single individual´s capacity to handle them. Society must invent ways and means that, in effect, magnify the designer´s limited capacity and make it possible for him to apply himself more completely to those problems that he is equipped to solve”. The Design Methods Movement presented in chapter 3 (section

3.4), most notably in its initial phase of prescription of an ideal process and description of the intrinsic nature of design problems (Cross, 1984), can be framed as an attempt to amplify the variety of the designer to manage the complexity posed by a systemic view of architecture. The many efforts to computerize (Terzidis, 2006) the design process, including the creation of CAD, BIM, and parametric software and processes, can also be framed within this perspective.

Architecture, when seen as a material practice, is predominantly related to an approach that prioritizes the elaboration of form to the detriment of its subsequent materialization and phenomenological qualities. Especially after the Renaissance period, there was a growing division between creation and materialization, theory, and practice, with the idea that it was possible to create a correspondence between representation and represented. In the so-called perspectival paradigm, the copy was the building, and the drawing the original (Carpo, 2011). This has led to the development of a particular dependence on the tools for architecture representation, such as scientific perspective and orthographic drawings, that did not change significantly with the development of the first CAD processes (when used as an extension of the drawing board).

Nowadays, some may argue that the many contemporary tools, processes, and methods put forward to develop technological and non-technological mechanisms for variety amplification are, to some point, effective in improving the variety of the designer to manage architectural systems. Evidence would be that small architectural firms are now able to deal with large and complex design assignments[126] which were in the past delegated to large offices with many draughtsman. Despite the fact that this form of variety amplification may seem desirable to some, the lack of awareness of the control relations involved is potentially catastrophic. The tools used for variety amplification - technological and non-technological design mechanisms - can end up controlling the designer and become the center of attention (chapter 5, section 5.2.6). Instead of amplifying the variety of the designer - the regulatory system - they may end up amplifying the variety of the system they are trying to manage.

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[126] The advantage of size, 2012. . ArchitectureAU 101.

Jones's (1991) observation that the design methods turned into itself and became the study of methods seems to corroborate in this direction. That is not different with CAD software when they are used as tools for control purposes (Glanville, 1992). From a symbolic level, the automated draughtsman - "computer as illustrating" (Glanville, 1992) - not only automated part of the design process, it also automated the designer. To understand this, it is helpful to put it in terms of variety and control. If follows that the attempt of using digital tools for amplifying the variety of the designer to regulate the exceeding complexity of architectural systems will likely result in the tool taking prominence in relation to the designer. Under the Law of Requisite Variety, considering the variety of architectural systems to be transcomputable, the number of states of the controlling system - design system - would need to be equally transcomputable for effective management. Therefore, the variety of the tools for variety amplification would similarly need to be transcomputable - thus becoming unmanageable for the designer, who may end up being controlled. That is not to say that the variety of CAD tools is transcomputable - which it is not. CAD tools are part of tool systems - a system that produces and sells tools - and those systems are becoming more and more complex. Tool systems are developing into a self-referential system that amplifies themselves. They are companies where the primary objective is to self-perpetuate, and therefore it is of their interest that designers become dependent upon their products. An illustrative example of this condition is an article published by Bryan Gardiner in Wired Magazine in 2007 about 25 years of CAD in design. The first aspect to be noticed is that the article is published in the business section of the magazine, and not in the design section. The second aspect that stands out is a saying attributed to former CEO of Autodesk, Carol Bartz, which says: "Look around you: if God did not create it, Autocad did." (Gardiner, 2007).

Today, one of the main arguments used to sell CAD systems is still that they produce more and faster. What follows is that designers are demanded to produce more and faster (what is today common knowledge). Furthermore, because of the prevalence of the tool, designers may lose touch with what they are designing. From this perspective, it seems that the argument put forward by Beer (1993) in his 1973 radio broadcast, which states that transferring existing processes to the computer may make existing instability more unstable, is still very precise. When agreed upon this perspective, it is not a surprise to see that many first-year architecture students are eager to learn CAD tools - it is how they identify the profession. When the tool takes over, the result is that the variety of the product - the design intent - will likely correspond to the variety of the tool. That happens when the designer only relies on the tool to generate a given outcome - he is constrained by the tool. This same critique can be applied to parametricism, especially as put forward by Schumacher (2008, 2009). Therefore many authors advocate that designers who are willing to break from traditions and generate novelty are challenged to transcend the limited possibilities of the tools (Glanville, 1992, Sheil, 2012a, Cabral Filho, 2012, Baltazar, 2009).

6.2.2. Mass Production and Standardization

As described in the previous chapter, a possible way to face unmanageability is to reduce complexity by restricting the variety of the controlled system - such as in dictatorial systems. In fact, this is currently one of the main approaches towards larger scale projects where standardization restricts the variety of the space and user when mass producing objects. Because the architect cannot address the variety of each user, he restricts the variety of the whole by creating a standard ideal user - a passive user (chapter 3, section 3.1.6). As observed by Friedman (1971, p. 98), since the architect "designs to a common standard of perfection, none of the individual imperfect users is satisfied". Le Corbusier's (1997) concept of the house as a Machine for Living epitomizes this approach in its vindication of modern technological and industrial processes in architecture. Le Corbusier used the metaphor of the house as a machine from the technological perspective and suggested that architecture should adopt the industrial process of mass production. Mass production is the essence of the industrial age, where the machine represents an extension of the human body. The automation of the gesture enables more speed and repetition to make more in a faster and controlled way. One of the key aspects of mass production is standardization. In general, the goal of standardization is to maximize control by restricting the variety of the production process - from design to fabrication. This is the case in the production line, where designers/companies use the variety of their system to create a design, a product, that they in turn impose to whom is going to fabricate (workers wearing uniforms and doing repetitive tasks) and to whom is going to use the object or process. In that sense, it is possible to state that what standardization and mass production do is to impose the variety of the controller to the controlled. In that case, the variety of the system is restricted to the variety of the designer, lowering the variety of the whole system and the potential for novelty[127].

The use of restrictive control processes in design can also be exemplified with Le Corbusier´s patent invention called Modulor, an anthropometric scale of proportions idealized on the measurements of a standard man. The objective of Modulor was to find a universal solution to what some saw as the problems of the human proportion and resolve communication obstacles between the imperial and metric system. The lack of dimensional standards was identified by the industrialized world as a serious impediment to efficiency in the building industry. Le Corbusier sought to create an ideal base for standardization by reconciling the needs of the human body with the Golden Section (Ostwald, 2001). Le Corbusier's Modulor constrained the physical variety of humans to what he saw as an ideal proportion of man (he rejected the female body as a source of proportional harmony). By doing so, the Modulor would function as a tool for variety attenuation that restricts the heterogeneity of the human body flattening the rich singularity of bodies, race and gender. The Modulor is just one example of variety attenuation tools developed by architects and designers to create standard measures to orientate their works.

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[127] The limits of standardization of variety in design is made clear in Le Corbusier ´s *Plan Voisin* for Paris in 1925, where he proposed to level down (*tabula rasa*) a part of Paris to build standard high-rise housing units. Le Corbusier used different design strategies to amplify his variety to create, what he believed, to be a proper design proposal for future users and city dwellers. The problem with this top-down approach is that even if a designer is able to amplify his variety - by collaboration with other designers or other design methods and tools - he will only be able to accommodate a small part of the variety of the system.

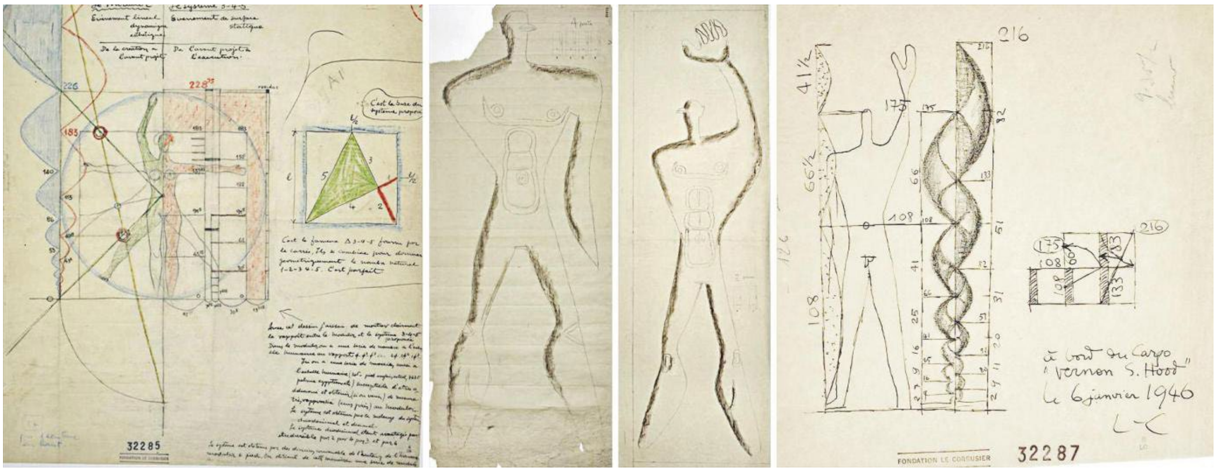

Figure 75 | Different sketches by Le Corbusier in his quest to reconcile body and architecture through Euclidean geometry. (Fondation Le Corbusier, n.d)

The restriction of variety of both user and space is still one of the main processes of production of space. Nevertheless, looking at a group of standard constructions over a given timespan will reveal that, even in the most standard and restrictive environments, people will manage to make small adaptations and customizations. Stewart Brand (1995) has shown that over time every building change to adapt to the needs of different occupants. Identical houses will transform in singular spaces through the interaction with the occupants that change furniture, painting, windows, doors, and sometimes even the structure by rearranging existing space or adding new rooms. People make their homes and places of work personal by choice of items they place in them, how they arrange them, and how they are used. Personalization is more a process of evolution than of deliberate planning (Norman, 2005). From that perspective, it is possible to argue that the variety of an architectural system depends more on the variety of the occupant than the variety of space. Nevertheless, if the human relation with architectural space can be seen as a conversation, in a variety rich environment this conversation can be more pleasurable and engaging. Furthermore, because the dweller constitutes his identity through dwelling, "by making and unmaking himself", in interaction with the architecture space, the more the space offers itself as a conversational environment, the richer the possibilities for the inhabitant to defines himself. (Cabral Filho, 2009, p.174).

The process of standardization of both space and user has proven to be effective to achieve the goal of building large numbers of houses with a relative low budget, but it fails to create an appropriate urban and social environment that can effectively accommodate the variety of the users and acknowledge their creative potential. As discussed in chapter 3, this model of production of space, based on mass-housing solutions with variety restriction, is what motivated many architects and researchers (Negroponte, 1970, Friedman, 1971, Landau 1971, Habraken, 1972) to propose alternatives using different processes, concepts, and methods. Despite the effort of many people, variety restriction by standardization is still the main strategy of production of the built environment in several countries, such as in the United States, Brazil, China, India, and many others. In Brazil, for instance, the federal housing plan *Minha Casa Minha Vida* is building thousands of mass production houses creating entire new neighborhoods of standard dwellings. There is an estimate that the housing shortage will be of about 20 million homes in 2024 (Rockmann, 2015), and it is highly questionable that this enormous deficit can be adequately addressed by building standard cities. It is challenging for architects to reflect on how they can participate in the process without restricting the variety and creative potential of the future inhabitants - that is, dealing with indeterminacy - while managing the massive demand for social housing.

Figure 76 | Contemporary and historical examples of mass housing. Upper left: Aerial view of Levittown, New York. (Mathosian, 2017).Upper right: Physical model of Le Corbusier’s Plan Voisin (1925). Lower left: Minha Casa Minha Vida Curitiba, Brasil (2015). Lower right: Hong Kong Mass residential housing in Tseung Kwan (EPA, 2016).

6.2.3. Mass customization

The contemporary convergence of industrialization and architecture can be inserted into a broader scope of the renewed interest in the approximation between science and design triggered by the promise of computational processes to democratize the means of production. The confluence of parametric design with digital fabrication is expanding beyond the design studio and is being explored by different companies to offer the possibility for people to customize their products. Mass customization, as discussed in chapter 4, is seen by many as a process that democratizes the design by offering tools to the user to create and customize objects. Several companies explore parametrically driven design processes that enables the user to digitally simulate changes in their environment using digital interfaces, Augmented Reality (AR) and Virtual Reality (VR) applications, product configurators, and many more. It is possible to see value in these forms of visual simulation and design interfaces, since they indicate the possibility of handling control of the design process to the user. People can dismiss the need of a designer to mediate the design process to choose new colors for their home, test possible layouts of a room, design custom furniture, or designing a whole house. Most interfaces offer the user visual feedback to enable instant test and evaluation of different design configurations giving an apparent freedom of choice.

This apparent freedom, called by many design democratization, is not only envisioned in the scale of objects, but also to the scale of the city. Kent Larson (2013), for example, advocates that mass customization thinking should be applied to the urban scale in order for cities to be rethought. The idea is that mass customization can, “like a great theatrical script”, provide “a strong top-down framework to enable bottom-up creative interpretation, improvisation, and execution” (Larson, 2013: XIX). Larson (2013) exemplifies this with the concept for a new urban plan for Paris, substituting Le Corbusier’s Plan Voisin for his own ideal of modernity, where the attributes of each neighborhood could be adjusted parametrically to different values and criteria (climate, culture, demographics, and the desired street and commercial activities). The proposal for this utopic city is build upon fancy adjectives, such as compact, service-rich neighborhoods, parametric density/vibrancy, mobility-on-demand, personal space-on-demand, and urban farming.

Although the idea of democratizing design and space through mass customization seems very seductive, it hides a new form of an old control system. Behind these tools there is an economic and cultural control system that restrict the possible choices. Most online design interfaces are deterministic and do not allow a creative exploration. Instead of amplifying the variety of the user they tend to constrain the options to their variety for effective control. In this case, the constraints are established from the outside of the design system restricting the potential for novelty. What most systems offers is not much different from going to a pizza restaurant which enables the consumer to choose different toppings for a pizza within a restricted set of options. If these pizzas are made by robots, the consumer may receive the pizza faster, but this does in principle not alter what he receives. And if he makes a bad choice of flavors, cope with the consequences!

6.3. Research-sketches and design conversations

To further inform the discussion about variety in design it is useful to refer back to the different research-sketches and the way they addressed the question of variety and constraints. In the MILU (chapter 2.1), it was found that for a creative participation of the user in the design process it is necessary to go beyond the design of interfaces, towards the creation of design systems that enables external inputs and creative exploration. Contrary to what was imagined at the beginning of the experiment, the process showed that the use of dynamic parameters and user-centered design interfaces is not enough to create dynamic design systems that incorporates the variety of the user. In the way it was proposed, MILU functioned as a prototype for a mass customization product configurator. The research-sketch has shown that the number of possible outcomes of a parametric design process may not generate as much variety as expected. The exploration of variety may be considered extensive, while the overall parametric schema will not change.

The research-sketch was essential to indicate that the perceived variety of the interface is not given by all possible states the designer stipulates, but by the number of states the user can differentiate. What follows is that, from a Second-Order Cybernetic perspective, the design space is not what the designer defines but what the user perceives. The use of parametric design interfaces represents an improvement when compared to more restrictive design processes where the designer creates a standard object to be replicated in a production line. Nevertheless, the designer (company or other stakeholders) is still in control of the design outcome and does not benefit from the variety of the user. Generally, they do not allow conversation; they only enable reactive interaction - menu picking - that does not invite novelty and creative exploration - design.

This system can be improved by creating feedback channels for conversation that amplify and improve the design space. The number of states the user can recognize can be expanded by feedback cycles between the user and design interfaces (interactivity) or between the user and designer (the designer can help the user to see new differences - conversation). Through feedback, the designer can also improve his variety (the user helps the designer to see further differences - conversation) and enhance the variety of the design system (usability or user experience - conversation). In this case, available communication channels can invite people to converse. If conversation is established, the design system is no longer constrained by the interface but involves the designer, the interface, and the user in one higher level designing system.

Notwithstanding, when the interface was used beyond its initial intention (chapter 2, figure 10) different possibilities emerged. The young designers invited to play with the interface were asked to go beyond the established possibilities by combining different designs in a playful manner. In that sense, they performed according to what Fischer and Richards (2014) call a constraint reversal, where the designer venture outside the established constraints. Nevertheless, it is important to notice that the designers were requested to do so - to play with the interface in a non-programmed way. In fact, professional designers do that often, and this does not represent a challenge for most of them. However, for a user, this may not be so.

This discussion raises some important issues concerning the notion put forward by Fischer and Richards (2014) that a constraint-oriented approach can contribute to participative processes. In fact, the idea of creating a design space where the stakeholders can navigate between a field of possibilities is seductive and is what initially motivate the investigation with parametric design and digital fabrication. MILU, for example, was designed to explore the possibility of providing users with the ability to change the open-parameters within established constraints to create an open - and ethical - design process. From the designer's perspective the constraints were designed from within the system, so he may benefit from the choice of expanding and contracting the design space. However, from the point of view of the user, who will navigate the "open corridors," the "walls" are already given. In this sense, the metaphor of corridors, even when considered open, still infers a linear path from A to B. In other words it infers the existence of a goal in the end of the corridor. This means that the user is restricted to the variety of the design system. Should he want to explore outside of the "walls," he may not have the conceptual tools and means to "break it." It would be possible to approach this issue by teaching the user to reverse the constraints. However, this would probably lead to the creation of more constraints (teaching design methods for example) which would only remove them away from the initial question. From an ethical perspective, a way to approach this issue is for the user to become part of the designing system so that he can participate in the definition of the constraints. Therefore, the shift from goal oriented to constraint-oriented design as a strategy for user participation is only effective when the user is part of the designing system.

In WOKA, the constraints were also defined from outside of the system. The open parameters were very restrictive, leaving only a narrow field to be navigated. The idea was to guarantee control over the technical specifications of the module leaving the outer layer and infill to be decided by the user. In this sense, the central idea resembles the infrastructural approaches that create a general structure and leaves the infill to be designed by the user. Nevertheless, this resemblance is only superficial as behind the WIKIHOUSE construction method there is a social network of people that freely collaborate and share their designs in social media. Therefore, the structure is socially created whereas the infill is individually designed. In this sense, the system approximates to the original ideas developed by Habraken (1972) of the support and infill, that suggests a shared control of the design and building process. In this context, what the WOKA system did was to constrain the variety of the WIKIHOUSE system so that it becomes easily deployed. In this sense, if agreed that the design of constraints evokes responsibility, the proposed system can be seen as an irresponsible design act, as it creates the constraints from the outside without claiming responsibility. Again, if the user makes a lousy choice - for example, a sealing system that is not suitable to work with the wood structure - he has to cope with the infiltrations and leaks.

In the 13MAY research-sketch, design constraints were applied even further. The use of the parametric model was not intended to generate a variety of outcomes. It was created as a constraint to the number of possible states of the system to match those that would fit the Box system (one sole state regarding the fittings). In other words, it was used to control the possible transformations of new elements so that they can function properly within the overall set. The Box system, in this discussion, is seen as a designing system that encompasses the design system (parametric model), the material systems (material inputs), and the social system (students and community representatives). For an external observer, the purpose of the parametric model in the design system was to restrict the formal solutions to those that would fit specific configurations. It was created to maintain stable relations between each element through the joints. However, looking from inside-out, what the parametric system did was to amplify the system's capacity to adapt to different material inputs. In other words, to enable the system to adjust to different contexts. It is a system that can change the internal states within the essential variables to adapt to external pressures - it is a dynamic system.

It is noteworthy that, when observing from the outside, the parametric design system created by the students functioned as a tool for variety attenuation. However, from an inside perspective, it is seen as a tool for variety amplification. From this point of view, the simple parametric model works as a design system that increases the number of choices. Although this may seem somewhat trivial, the change of perspective offers new insights. It puts into consideration that the constraints were brought forth from within the system. Thus, from that perspective, the use of constraints, when designed from within the system, amplifies rather than attenuates the variety of the system (figure 77).

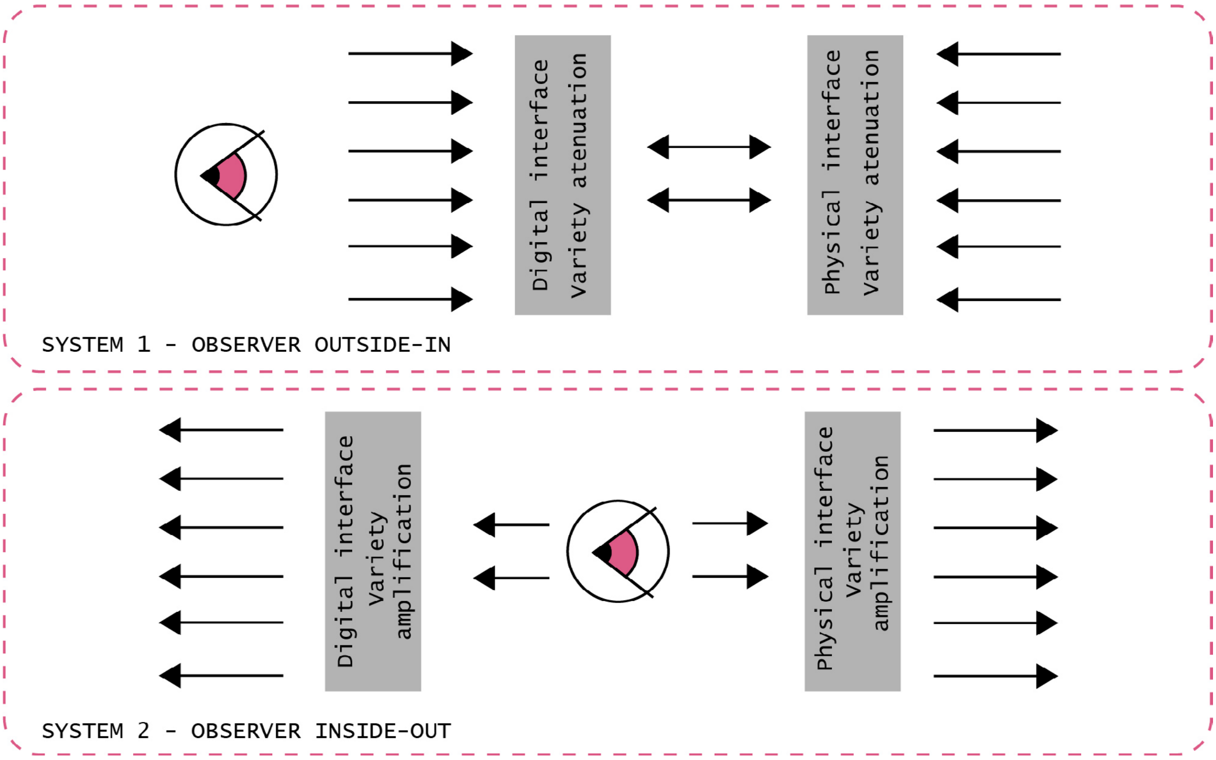

Figure 77 | Outside-in and inside-out perspective of the BOX system. (author, 2017).

Another important feature of this research-sketch was the adopted modular design principle. In this system, the logic of the components is not necessarily connected to the logic of their use. In this way, the system opens itself to endless possibilities and serves as a tool for variety amplification. Jones (1991) advocates for this type of design principle because it does not stabilizes functions. However, he warns that flexible systems with adjustable components will fail when the "effort-of-adjusting is greater than that of adapting, personally or socially, to the worse condition of leaving the thing unadjusted" (Jones, 1991, p.202). The "effort-of-adjusting" put forward by Jones can be related to the concept of Bio-cost (Dubberly, Maupin, Pangaro, 2009) discussed in chapter 5 (section 5.5.1), where people wage the energy expended to perform certain actions to achieve a goal. Nevertheless, this does not seem to be the case of the BOX system. Not because it offers a new solution to the "effort-of-adjusting" or "energy spending" equations, but because the need for change arose from within the system. In a different context, the possibility to explore the various configurations using the modules may indeed not be used, and the variety of the system can even be regarded as noise. However, in 13MAY the need to constantly change the spatial arrangement was intrinsic to the circumstance and the modular system is a custom response for that specific context. Therefore, its use is more a matter of Pleasure-gain than Bio-cost.

The BOX system reveals itself as a complex designing system that involves different stakeholders in a design process. Nevertheless, the complexity of the system does not arise because of the use of parametric design, nor by cause of the adopted modular design principle. Complexity emerges through the interaction with a very specific context. It is a system that suits a particular arrangement. It is a custom system to that particular arrangement. Both physical and digital interfaces are built from within and serve as tools for variety amplification of the regulating system.

Because the designing system is customized to the particular context, it is not something that should be replicated in different circumstances. Using the same configuration of parametric design and modular design principle in other condition would mean to constrain the variety from the outside of that particular situation. Therefore, from an ethical point of view, this system should not be applied to other context or reproduce as a product. Nevertheless, the creative process that led to the creation of that system can be replicated in other situations. The description and analysis of the research-sketch in chapter 2 (section 2.3) showed that the different cycles of conversation were fundamental to enable the development of the system. 13MAY showed how cybernetics can structure a research and teaching process where there are no fixed goals and the constraints are defined from within the system. The custom system developed within the different conversation cycles could not be foreseen in advance and was a shared creation of the various participants. From a general perspective, what characterized the 13MAY research-sketch was a conversational process that resulted in a customized designing system. This characterization will be called *conversational customization.*

6.4. Towards conversational customization in design

> "The design goal is nearly always underspecified and the "controler" is no longer the authoritarian apparatus which this purely technical name commonly brings to mind. In contrast the controler is an odd mixture of catalyst, crutch, memory and arbiter. These, I believe, are the dispositions a designer should bring to bear upon his work (when he professionally plays the part of a controller) and these are the qualities he should embed in the systems (control systems) which he designs". Pask (1969, p.496)

Traditionally, many architects use methods based on a prescriptive design representation based on an encodement model of communication. That allows little or no openness for user participation in the design process. When trying to control all design parameters and restrict noise the architect may end up diminish the potential for a more creative architectural appropriation and novelty. If accepted that architecture is a contingent discipline (Till, 2008), the number of states of an architectural system is exponentially higher than the number of states that the architect can anticipate and the system is transcomputable. As discussed by Glanville (1997), in transcomputable systems, it is inconceivable that enough variety can exist in the control system for satisfying the conditions of the Law of Requisite Variety. This makes this system unmanageable, but Glanville (1997) already showed that being unmanageable is not a bad thing. The value of being unmanageable is the possibility to enhance creativity.

This thesis puts forward the concept of conversational customization as a way of thinking that acknowledges architecture as an exceedingly complex system. It invites designers to abdicate restrictive control so that both designer and user can benefit from the variety of the human environment. The central idea of conversation customization is to empower the user to play an essential role in the creation of his environment. For expert designers, this approach means not only to use the computer as a medium but also as means to open the design process to the user. It proposes the creation of a designing systems that generate constraints from within and enable a circular and continuous design process were the goals are always underspecified. In this sense, the way to produce architecture, as well as the work of the designer are sensibly modified.

6.4.1 Conversational Age

For Pangaro (2011), we are currently living in a transition between the Information Age and a Conversational Age. In the Conversational Age, conversation is the new paradigm, and the machine represents the "amplification of the collective mind" (Pangaro, 2011). In a Conversation Age, all information will be synthesized through intersubjective conversations, infinitely reproducible, and will be designed to be changed by its receivers and forwarder as new information. This notion is based on the concept of telematic society, as put forward by Flusser (2011), where the hominis universales of the Renaissance, the genius designer, is no longer necessary and not even possible. People in conversation can be disproportionately more creative than any great author. As proposed by Glanville (1994), "it is by sharing that we have the possibility of transcending the limitations of our (individual) brains, of increasing our power, by 'borrowing the power of others.'"

In a Conversational Age, where people are interconnected through computational interfaces, there is no longer an original, everything is a copy, and there is thus no original author. As observed by Glanville (1994, p.99), "the very function of the computer is to remove ownership from the equation, thus allowing potentially positive and constructive sharing".One could rationalize that any copy is linked to an original and the original to the author. However, when it is no longer possible to distinguish original and copy the term "original" loses its meaning, together with the associated authorship. As observed by Flusser (2011, p.98), "the myth of the author (and the original) distorts the fact that the production of information is a dialogue." A photograph, for example, can be seen as the result of the conversation between different p-individuals through the m-individual apparatus. Because in a conversation, the result is of shared property and there is no sense in distinguishing the author.

The amount of variety proliferation in human systems has reached a point where it is no longer possible to process it using individual brains. As observed by Flusser (2011, p. 99), the inner dialogue has become inoperative in the face of the astronomical dimension of information available to people that can no longer be computed in human memory. However, because cognition happens in a circular relation between the mind and the world (Shön, 1984, Ghedenryd, 1998, Glanville, 1999), it is possible to connect mind and medium to deal with complexity. In this sense, Conversation Theory is useful to create effective alternatives that combine different P-individual to create a system to compute information. In this sense, the concept of a conversational customization is proposed as constraint-oriented design process that benefits from the "collective mind." It can lead to the creation of a system where variety from different observers can interact and amplify the potential for novelty to arise. The idea of an age where people share their creative potential through conversation might point to a true paradigm shift in design.

6.4.2. Variety Sharing

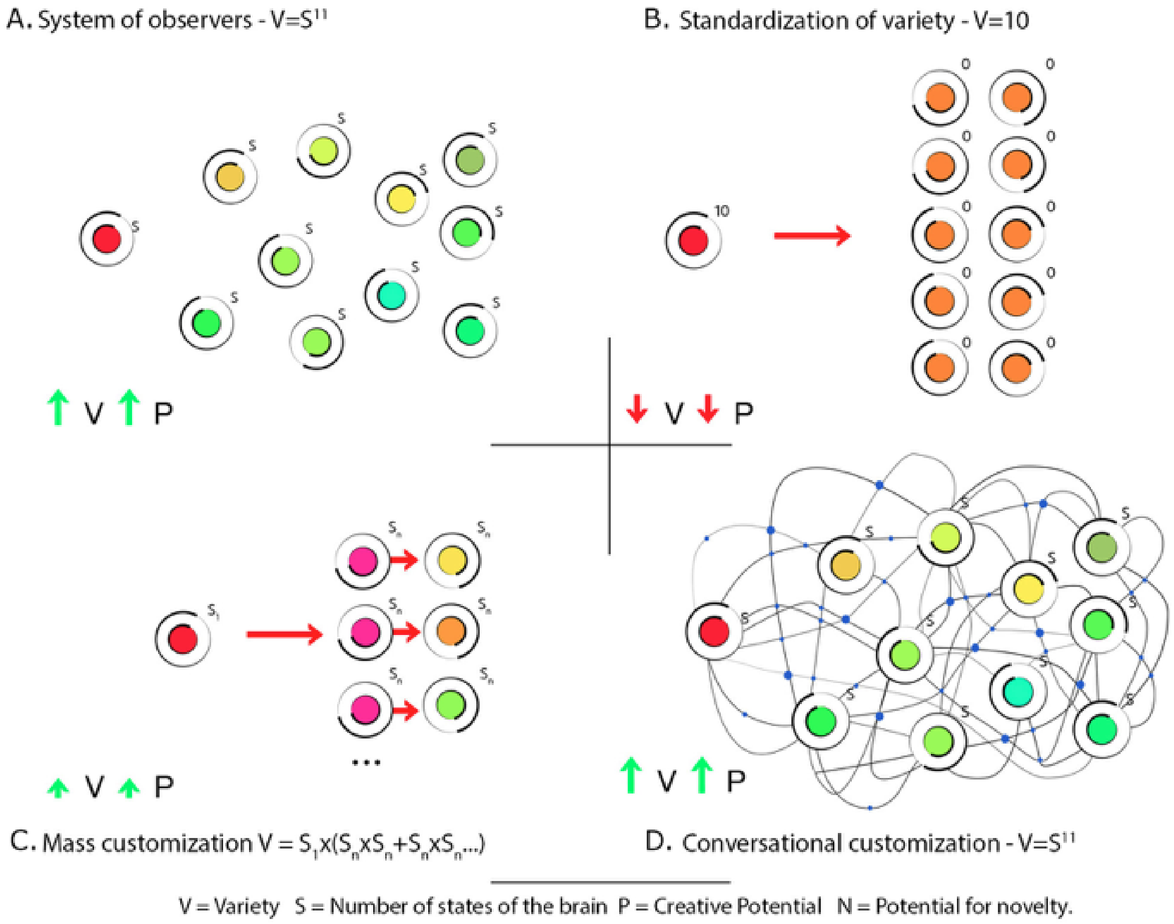

Figure 78 | Variety in design in different design strategies (Stralen, 2015).

The diagrams in figure 78 depict the relation between the potential variety in a system of observers in different design strategies: standardization, mass customization, and conversational customization. If people can share their brain power to amplify creativity, it can be assumed that the higher the number of brain states available in the system, the higher the creative potential of the system. And consequently, the higher the possibility for novelty to arise - to create something new - to design. Of course, the brainpower of a given group of people cannot be numerically measured, but this abstract representation helps to show orders of magnitude of potential interactions that can lead to novelty. The first diagram (figure 78A) represents a system composed of various subsystems with organizational closure - a community of people for example. The second, figure 78B, illustrates the process of standardization of both space and user in design for that same system. This represent a designer, or a group of designers or a company, that produces an object - a home for example - for the community of people from the first diagram. From the perspective of the designer, the variety of the user is restricted to the variety of the model of a standard user created by the designer. The variety of the system - in terms of its creative potential - is thus restricted by the controlling system. Figure 78C depicts a different design proposal where people can customize elements within a given structure. This can represent a product configurator for example. The overall variety of the system is not fully restricted, but it is still constrained by the variety of the controlling system. Figure 78D represents a design process where the designers, users, and their environment take part in a conversational process.

It is within this network that digital and physical design interfaces can be used to potentialize the design conversations. As put forward by Glanville (1994, 2007), computers are ideal tools for this process because it is within its nature to encourage cooperative sharing, and thus amplification of the creative potential of the designing system. With the use of computers, novelty can be generated by users for other users. When a user uses a material originated by other user, transforms and shares it, the user who originated the material can be surprised with the transformations when the changes go outside his expectations. As long as both users keep an open mind and share constructively and co-operatively, they can be surprised by the results. In that sense, both the original material and the user will undergo changes and have their creativity increased through shared work (Glanville, 1994).

In that sense, the concept of conversation customization is proposed as a process where people can share their creative potential through a network of relations. In an age where the machine represents the "amplification of the collective mind," the network of interactions between observers in a group already exists. People are already connected through social media where they act as both designers and users of content. What designers can do is to act as spatial agents, as proposed by Till (2009), to create a conversational process that can amplify and channel the creative potential of the system to the built environment.

Nowadays, architects dispose of the necessary mediums for conversational design. As discussed in chapter 3 and 4, there are interactive systems - with sensors and actuators - that can be built to respond to people's needs and amplify their relation to space and with one another. There is parametric design that enables the creation of digital interfaces for variety amplification. There is digital fabrication that invite users to share designs, modify them and fabricate them at home or at a Fablab nearby. More recently, there are also robots and drones that can be programmed to perform distinct tasks in specific contexts. As demonstrated in chapter 3, significant advances have been made in the direction of the creation of conversational design processes.

6.4.3. Physical interfaces for variety amplification

In chapter 2, both WOKA and 13MAY made use of customizable modular systems to enable different spatial configurations (WIKIHOUSE WREN and The BOX). Chapter 3 presented other possibilities for dynamic architectural systems that propose a participation of the user in the continuous design of the built environment: Rietveld-Schröder House, Open Building, Fun Palace, Generator, and Self-builder. What seems to be a common feature between those examples is that the logic of the components that render those systems dynamic is not necessarily connected to the logic of their use. As discussed in section 6.3, the separation between the logic of the components from the logic of function does not stabilize functions (Jones,1991).

Drawing on Maturana and Varela (1974), from a systemic perspective, the use of a given object is related to its organization and structure. As discussed in chapter 5 (section 5.1), organization signifies the relation between components that must be present for something to be recognized as part of a particular class of system. Structure is the physical form which the components take. What happens, when the logic of the component is not connected to the logic of use, is that the different arrangements of the structure change the systems organization. In fact, structure may not change. What changes is the way in which each element relates to the others, which in turn, changes how people perceive and interact with the system. The BOX system, for example, is seen as a bench in one given state it, and in the other, as a bookcase. The complexity of the system is related to the number of states the system can take. If the variety of the system is large enough, surprising arrangements may occur.

In the Rietveld-Schröder House (1925), for example, the relation between the different sliding panels generate various spatial configurations. This feature, combined with the ingenious way in which Rietveld arranged the other elements of the rooms, enables a rich spatial variation. As discussed in chapter 3, the different spaces defy classification according to determined function and can, therefore, be adapted to various forms of appropriation. In other words, the organization of systems changes as the relation between the different elements of the system changes. Another issue that deserves to be highlighted is that the constraints of the system were designed from inside the system. That differentiates the Rietveld-Schröder House from other similar approaches. The dynamic elements arose to respond to specific demands that were internal to the system. The participation of the observer in the designing system may explain why in the Rietveld-Schöder House the dynamic elements were used to its potential. (Rietveld, 1932, apud Friedman, 1988, p.80).

In Hertzberger´s (2016) concept of polyvalence, a different relation between organization and structure is established. When seen from a systemic perspective, a polyvalent system enables the change of organization without changing the structure. In this context, the organization is changed through interactive conversation with space. This form of conversation is similar to the one described by Pask (1969) in Gaudi's Park Güell (1914), where the variety of the architectural space may enhance the interaction between the environment and the observer. From the perspective of Conversation Theory, in a polyvalent system one M-individual - stairs for example - houses several P-individuals - to stairs, bleacher, auditorium, theater, etc. This form of interaction occurs through internal conversations, but can be expanded when a mutual control relation is established between the user and the environment. Such form of conversation was proposed in Cedric Price's Fun Palace (1963-67) and Generator (1976-79), where conversations would be explicit and observable.

Both the Fun Palace and the Generator projects are examples of control systems that invite the user to a conversational process that involves feedback, mutual learning, and the creation of novelty. From that perspective, the projects can be seen as cybernetic designs, where the generation of novelty is not the result of innovative technologies, advanced computer interface, or to the use of dynamic movable systems. Novelty is generated through a conversational process between all spacial actors - man and machines alike. From that perspective, those cybernetic projects can be differentiated from infrastructural approaches such as the megastructures and the concept of open-building that envisages a different relation between support and infill. Open building suggests a hierarchical control structure where the support determines the infill. In the cybernetic approach, support determines the infill that, in turn, determine the support. There is an idea of mutual control - architectural mutuality - where one determines the other. From that perspective, the constraints that define the architectural space are designed, and redesigned, through interaction from within. In this process, the roles of designer and user are in constant shift, as a circular relation between design and use can be established. Because the system knows its previous states, it can function as a non-trivial machine to generate unpredictable behavior and enrich people's conversations with the architectural space.

What this discussion shows is that systems were the organization changes according to changes in structure enable different uses. Therefore, they can be used as physical design interfaces for variety amplification that foster conversations and allow the user to continue the design process. Nevertheless, in conversational customization, there is no ideal design system for variety amplification. The choice for a specific strategy depends on the context, and therefore it should emerge through conversation between the various stakeholders within that particular context.

6.4.4. Digital interfaces for variety amplification

The capability of parametric models to generate a variety of outcomes is discussed by many as a way for designers to amplify their capacity by generating differentiations. However, architecture, when understood as an exceedingly complex system, is too complex for any model to manage all of its aspects. Models may become either simplistic or too deterministic - making interaction with the design object difficult and hindering more profound design explorations (Iordanova, 2007, p.688). As discussed in chapter 4, design for change is time-consuming and not as easy as it may seem (Davis, 2013, Scheurer, 2012, Hudson, 2010, Smith, 2007).

Nevertheless, the use of parametric design as a medium may bring new insights and enable different levels of conversation. In computational design processes, different skills and design strategies such as sketching, copying, modifying, and abstract thinking are combined when making parametric models (Woodbury, 2010). Within computational models there is no ambiguity of information within the model as it follows a coded form of communication. However, the results of each change and iteration made within the script and algorithm have different outcomes which are open to various interpretations by the observer. In this sense, the P-individual-coder makes the rules, associations, and set the constraints and P-individual-viewer analyses and gives meaning to the results. In this manner, if the computational models are treated as a creative medium, a wide array of possibilities emerge. The designer can doodle with codes, by copying, pasting, transforming, generating, and so forth. In a Conversational Age (world of digital workflows), the sharing, copying, pasting, and editing of code can be seen as an opportunity for design conversations. Within this perspective, when used as mediums, computational processes may be explored to enhance the internal and external conversational processes to amplify the variety of the designing system in dealing with complex systems.

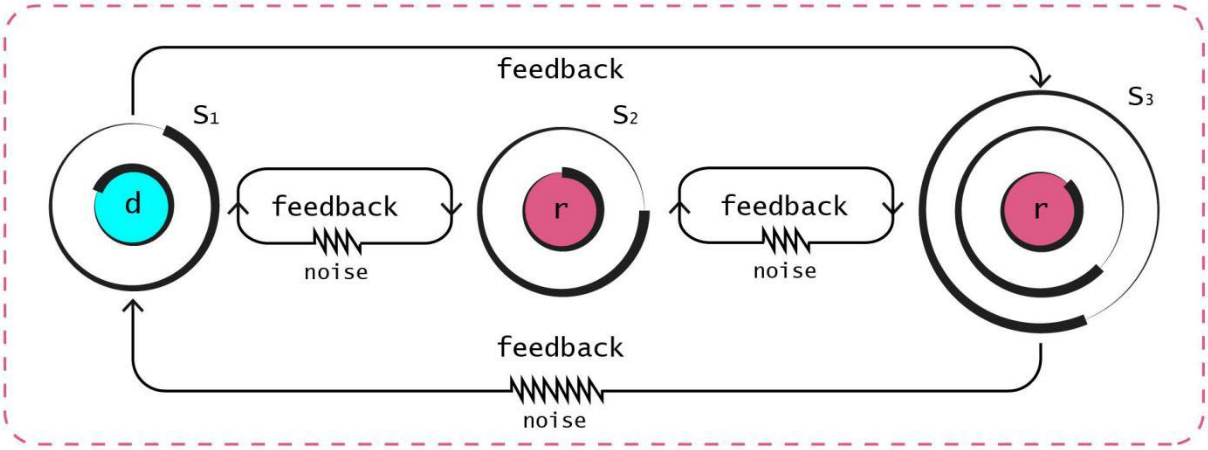

Figure 79 | Diagram depicting different interactions between designer and a digital construct. System S1 represents the designer, system S2 the design system (digital construct), and system S3 the an evaluative system. Long feedback cycles between system S1 and S3 may be an obstacle for re-evaluation of the design. (author, 2017).

Most computational design processes involve digital models that enable the representation and evaluation of formal and performative properties. As described in chapter 1, Oxman (2006) distinguishes three classes of interaction with digital environments (there is also interaction with paper-based representation). The first is interaction with digital constructs - typical in CAD-based design - related to visual feedback through digital sketches, drawings, and models. The use of models enables simple and complex simulations of performative properties. Those simulations include environmental and formal parameters that cover the amount of natural light in the room, winds, forces and loads acting within and upon the building, etc. Generally, this type of performance simulation concerns the analysis of the behavior of the model in a particular modeled context. From the analysis, the architect can make changes in the design and improve the defined performance towards a specific goal. However, because this process is commonly executed by different specialists using different software and database, the feedback loop is slow and costly. The separation of models for representation and models for evaluation creates long feedback loops that hinder iterative cycles.

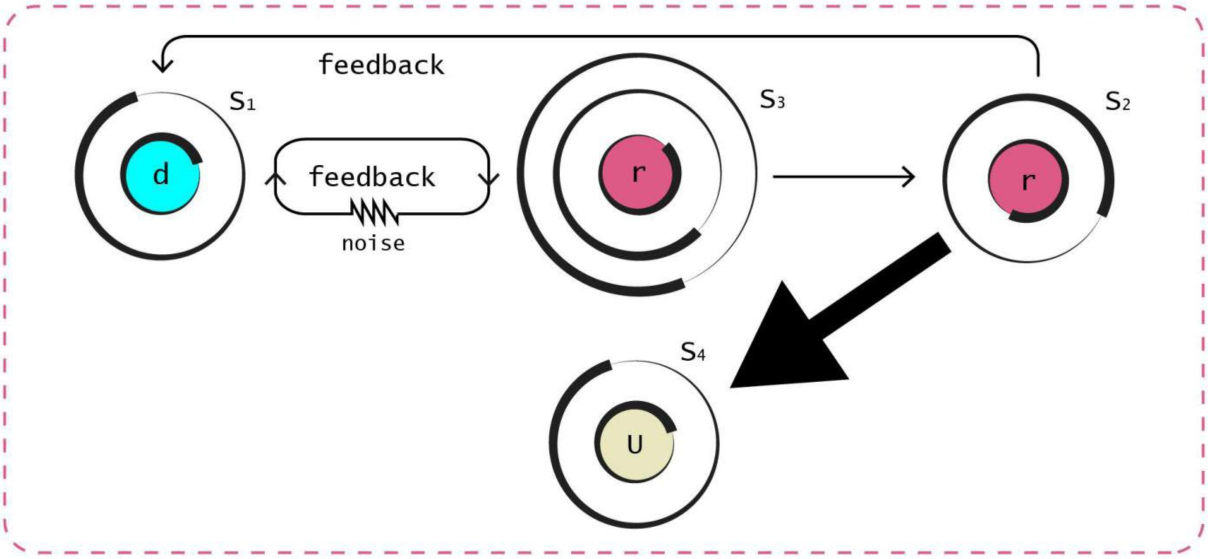

Figure 80 | Diagram depicting different interactions between designer and a digital construct. System S1 represents the designer, system S3 the design system that incorporates evaluation processes (digital construct), and system S2 a representation system. In this diagram system S2 is the output of the interaction between system S1 and S3. System S4, the user, does not participate in the process. (author, 2017).

The second form of interaction is with a digital representation generated by a mechanism. As observed by Oxman (2006, p.244), "in this case the designer interacts with a digital structure that was generated by a mechanism according to a set of predefined rules or relations." In this form of interaction, there is a possible inversion of the design process were performance appears as a parameter that generates form (figure 80). Within this context, performance is defined as a technique or process in which the variations are defined parametrically by the conditions specified by the designer (Oxman,2006). The third is the interaction with digital environments that generates a digital representation. It is related to the interaction with the operative part of a generative design mechanism. What this interaction implies is a possible shift from the designing of form to the designing of design systems. The capability to interact with the operative part of the design mechanism opens the possibility for designers to build specific tools for a particular context that responds to the demands of a distinct designing system to deal with complexity.

In computational design, where computation is inextricably part of the process, such as algorithmic and parametric design, in which the designer designs computational process to generate form, self-reflectivity, as proposed by Second-Order Cybernetics, is particularly relevant. The design of the design process that generates form gives the idea that form is not "given", but "found." The idea of giving shape - data forces shape onto passive matter - makes the connections between observer and process explicit, as most designers are eager to claim their involvement in the process. However, in form finding, where matter and data interact and give shape, this becomes more blurry, as questions can arise as to who is responsible for the design. This process leads to the idea that computers themselves are generating autonomous objects following objective criteria. However, from a Second-Order Cybernetic perspective, the designer is also responsible for the final design. Form is coded in the computer by the designer. It does not emerge by chance; it emerges with purpose. A purpose defined by the designer. The observer is included in a self-reflexive act of designing design.

That is also the case of digital fabrication where machines perform precisely coordinated movements that lead to high definition in material practices. Precision is not necessarily a prerogative of machines; they are precise because they are designed to be so. What is important to notice is that for Second-Order Cybernetics all that is designed is not given, but it is performatively created by the observer in conversation with the medium. Recognizing the conversational nature of this process leads to two important issues. The first is of admitting responsibility for the process. Parameters and codes transmit the idea of objectivity, but, as discussed in section 4.3, the design parameters and the relations established with the parameters are given by values that involve judgment and beliefs. The second is that treating this process as a form of conversation can be useful to explore ways to involve the user by externalizing the creative process. In this sense, in conversational customization, generative and performance optimization processes can be explored as tools for variety amplification were form emerges through conversation.

Following this reasoning, to illustrate this discussion, it is useful to think of the WIKIHOUSE system as an example of a conversational customization process. The WIKIHOUSE system combines a dynamic design strategy (WREN structure) together with parametric design systems that helps to generate the structure. And, more importantly, the systems offers different communication channels to allow people to engage in conversation, share experiences, codes, copy design solutions, etc. Thinking the WIKIHOUSE as a conversational customization process is helpful to understand that it should not be applied to a specific context - such as the housing problem in a given city or country for example. This would probably only generate noise by restricting the the variety of the users in that particular context. However, designers and users can contribute to the development of the WIKIHOUSE system from within, by accessing the available conversation channels. In this way, the system can eventually expand and evolve to the point that, in the end, it eventually helps to diminish the housing problem. A recent example is the open source optimization plugin developed by Landin et al. (2017) that helps to optimize the nesting of the wren sections using genetic algorithms. The plugin can be used as a design aid that improves the overall process. Nevertheless, most plugins developed to the point hinder the participation of unskilled users. Such plugins can be improved and incorporated in larger and more user friendly digital interfaces for variety amplification that deal with qualitative, and not only quantitative aspects. In this way, machinic systems can evolve together and in interaction with human systems.

In this context, it is useful to recur to the notion of "design amplifiers" put forward by Negroponte (1975, p.100). It refers to the idea of a personal interface that acts to elaborate upon and contribute technical expertise to the user's design. This notion is valuable to understand how computational processes can be used as variety amplifiers in conversational customization. As discussed in chapter 3 (section 3.7), the shift of focus from an architecture machine that plays the role of the architect towards design aides that gives support to the user's creative process, can point towards a condition where both may evolve. Nevertheless, there is no need for this interfaces to be complex and "intelligent", such as implied by Negroponte. Pask's Musicolour machine and Weizenbaum's ELIZA program (chapter 5, section 5.6) indicate that the complexity asymmetry between user and interface does not hinder successful conversations. This point towards the possibility to design designing systems that rely on the variety of the observer to create meaningful conversations.

6.5. Dynamic Architectural System

> "To invent something new, and to bring it into being, is to change not only one's surroundings but to change oneself and the way one perceives" (Jones, 1991, p. 127).

The discussion put forward points out to the notion that designers have the necessary tools and means to design both physical and digital design systems that are context dependent. They can benefit from a "collective mind" where previous experiences can be shared, copied, adapted, transformed to a new context, and shared again. In other words, previous experiences should not be neglected or replicated but propagated, so that they be copied and transformed in a specific context. Nevertheless, this will only constitute a system if conversation cycles are established between all participants. This points out that one of the main roles of the designer in a conversational customization process may be one of creating the right conditions for conversation to emerge. In this context, Conversation Theory offers a framework to enable designers not only to engage in conversation but also to design tools and means that foster conversations. Having a topic and different understandings. Be able to represent the different understanding to others so that they can compare understandings. Shift between different levels of conversations - conversations about the conversations for evaluation and error correction. Having ways of initiating and terminating the conversation. These are all part of Glanville's (2001) operational requirements for conversation and should be of the designer's concern. If successfully established, the conversational process can give rise to shared values that, in turn, determines the constraints and parameters that orientate the development of the physical and digital design systems. Those systems can be build within the perspective of pleasure-gain so that people can learn and profit from the spatial variations through active engagement.

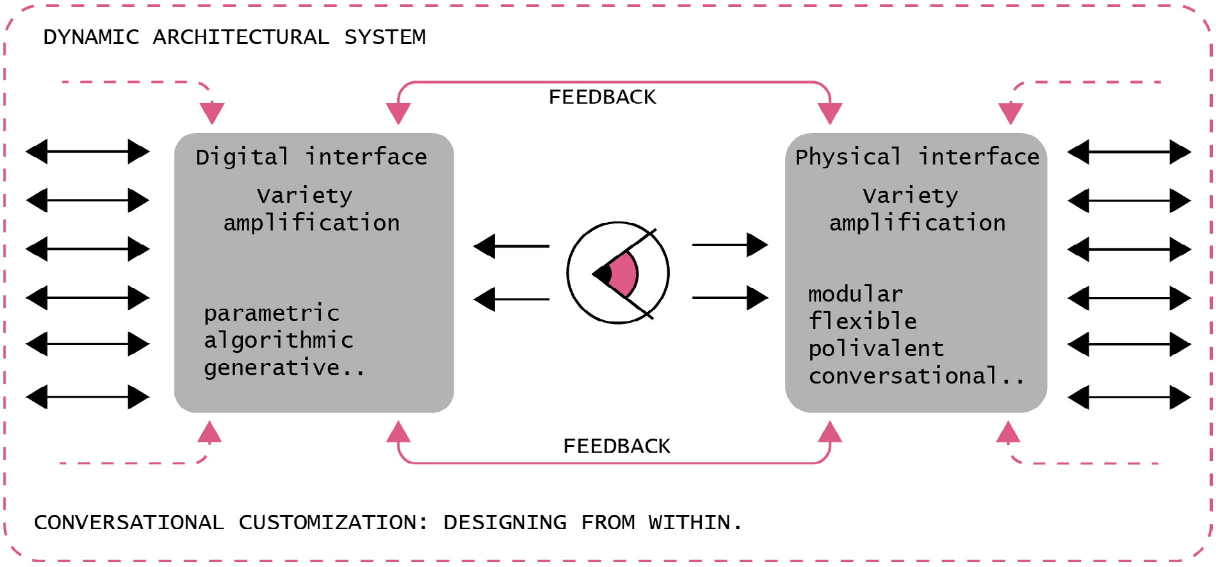

Figure 81 | Conversational Customization diagram. (author, 2017).

In this chapter, the concept of conversational customization was put forward as a way of thinking and acting that counters design strategies based on standardization and mass customization, by proposing a radical involvement of the user in the designing system. It explores the possibility of using conversation as a design approach from where dynamic architectural systems may emerge (figure 81). It departs from the notion that designing systems should not only involve the designer and his tools, but an interconnected set of elements, involving the designer, physical design systems, digital design systems, and more importantly, the user. From that perspective, it proposes a shift from a First-Order Cybernetic approach to design towards a Second-Order Cybernetic design process, where there are no fixed goals and the constraints can be altered from within, creating opportunities for novelty to arise.

7 | FINAL CONSIDERATIONS

The primary objective of this thesis was to explore possible ways of designing dynamic architectural systems that involve both users and their environments in a mutual, continuous, and circular design process. The thesis departed from the understanding that architecture is a system that involves people and structures in a dynamic nature, where one determines the other. There is a mutual reciprocity between structure and men (society) where one regulates the other (Pask, 1969). The acceptance of the inclusion of the user in a more systemic view of architecture does not only requires a change in the design process and design process research, but it also requires a different approach towards the design of the object itself, rendering it more dynamic and open to uncertainty. This systemic view of architecture expands the notion of design beyond the creation of objects towards the creation of systems that involve the idea of circularity, the role of context, communication, conversations, control, constraints, goals, and the role of the observer. It evokes architects to accept the challenge of expanding the understanding of architecture beyond its physical dimension towards a more holistic perspective that embraces design, building, and a radical involvement of the user.

Looking the research process in retrospect, it is possible to identify two main lines (tracks left by a wheel on sand) of investigations. The first is related to the MILU and WOKA research-sketches, which are connected to the development of tools and means to enable the participation of the user in the design process. This line of investigation can be framed within a field of inquiry identified in chapter 3 related to Experimenting with New Tools and Technologies. The second line of investigation is defined by the focus on conversation as a design strategy. This line, which gained force in the 13MAY research-sketch, is better framed within the field of inquiry that explores the Rethinking the Architectural Practice.

7.1. Dynamic parameters

The association of parametric design and digital fabrication was put forward as a design strategy to create dynamic architectural systems. The ability of parametric design to generate variations and bespoke outcomes, associated with the capability of digital fabrication to render this variety physical, was investigated as a design approach that fosters conversations. The initial understanding was that opening the design parameters to the user, both in the design process and use, would enable the designer to involve the user in a continuous design process. The idea of creating dynamic parameters (open-parameters) in a design interface was explored in the research-sketches in different ways.

The MILU and WOKA experiments demonstrated that in building open processes, the role of the designer shifts from the design of objects to the design of design systems which includes at least a generative principle, a design interface to manipulate dynamic parameters, and an associated fabrication or assembly method. Nevertheless, both practical work and theoretical discussions revealed that to enable the user to give creative inputs and creative explorations it is necessary to go beyond the idea of a design interface towards the creation of a designing system. As put forward in chapter 5, the concept of designing systems refers to a generating system where there is an active participation of the user in conjunction with the designer and the design systems. Furthermore, the research-sketches were essential to indicate that the perceived variety of the design interface is not given by all possible states the designer stipulates, but by the number of states the user can differentiate. In other words, from the perspective of the user, the design space is not necessarily what the designer defines but what the user perceives.

This discussion can contribute to the analysis, critique, and improvement of product configurators connected to the concept of mass customization. As discussed in chapter 4, mass customization is seen as a strategy for design democratization (Kolarevic, 2015). Most design configurators offer the user different choices and open-parameters used to customize a product. Nevertheless, from a Second-Order Cybernetic perspective, those design systems still operate in a way where the controlling system - designer, interface or company - restricts the controlled system - the user. Because feedback channels between designer and user are scarce, a mutual control relation cannot be established. Therefore, it is advocated that only by giving people the means to act from within the system it will be possible to lead to a genuine democratization of the design process. Otherwise, the design process will be restricted to what Negroponte (1975) called a “menu-picking activity.”

As discussed in chapter 6, product configurators such as MILU can be improved by the creation of feedback channels that enable different cycles of conversation between (1) user and design system, (2) user and designer, and (3) designer and design system. If a meaningful conversation is established, the design system may evolve into a higher level designing system that involves designer, user, and design system. Designing design systems require different frameworks where various stakeholders should be taken into account. Conversation Theory offers this framework because it not only includes conversations between different observers but also between observers and machines. As discussed in Chapter 4, parametric design may give form to a system that stretches beyond design, encompassing material systems and use. This parametric system may represent a design possibility that embraces aesthetics and ethics through conversation.

7.2. Systemic nature of Architecture

In chapter 5, the analysis of the architectural system has pointed out that, from a cybernetic perspective, when architecture is understood as a system that includes material systems, building systems, communication systems and, most importantly, human and social systems, it has to be addressed as an “exceedingly complex system” (Beer, 1959). Furthermore, an architectural system can be seen as a “nontrivial machine” (Von Foerster, 2003), where the input and output relation depends upon rules of transformation that are in constant change in relation to its previous states. The question of how designers can come to terms with the exceeding complexity of architectural systems, without restricting or ‘trivializing’ the architectural system, was discussed in the light of First and Second-Order Cybernetics. The concepts of system, observer, feedback, control systems, variety, constraints, and Conversation Theory were introduced to the thesis to compose the general conceptual framework used to explore, understand, and come to terms with the exceeding complexity of architecture systems.

Following Ashby's Law of Requisite Variety (1954) and Conant and Ashby's Law of Regulatory Models (1982), the relation between the transcomputable variety of the world and the exceeding complexity of architectural systems were discussed in chapter 6. The concept of variety was approached from three complementary perspectives associated with the context, design process, and use. The different perspective on variety are connected to the notion that the human environment is overwhelmed with variety to the point that it is transcomputable - beyond computability. When this is seen as an advantage for creativity (Glanville, 1994, 2000), designers can lose control of the design process or amplify their variety by cooperative sharing. When seen as noise, they can adopt a constraint-oriented design process where constraints are created to restricts a design space to be explored as "open corridors" and "field of possibilities" by the designer or user (Fischer and Richards, 2014).

The ethical implications of defining constraints from inside-out (ethics) and the outside-in (moral codes) were discussed and related to different design practices. The thesis argues that in design the users should participate in the definition of the constraints from inside-out. On the contrary, only the designer will benefit from the possibility to navigate and expand the design space. The user will be restricted to the "walls" leaving no option but to go from A to B. Thus, the adoption of a constraint-oriented design approach should be associated with the creation of a designing system that involves the user in the creation of the design space. In this way, both will benefit from the creation of constraints.

The discussion about control and variety in design was also essential to show that the computational tools used by designers to amplify their variety, in order to come to terms with the complexity of the architectural space, can turn upon themselves. Instead of amplifying the designer, they may end by amplifying the variety in the system architects are trying to control, or even worse, they can end controlling the designers. This already happened with the design methods movement, and all indicate that this is happening again with computational design processes.

7.3. Conversational design

In the second line of research, the 13MAY research-sketch, together with the theoretical discussion, suggests that conversation can be explored as a design approach to involve the user in the design process. The combination of parametric design and physical design interfaces in the project pointed out to a system that enables the continuity of the design process. The purpose of the design process should not be a product with a determined function, but rather the very continuity of the design process. The focus on the process acknowledges the circular relation between design and use, where all participants are recognized as designers. Therefore, in this thesis, it is advocated that an architectural system should be understood as a designing system. In this way, design is acknowledged as part of our spatial experience.

In chapter 2 it was suggested that the digital interface developed by the students in 13MAY was not used to generate complexity, but to manage the complexity of the system so that complexity could emerge in use. However, as discussed in chapter 6, an inside-out perspective shows that both interfaces - physical and digital - were used as tools for variety amplification. Both enable the user to deal with external pressures. This inversion demonstrated the importance of designing the constraints from within the system.

The concept of conversational customization was discussed as a way of thinking and acting that counters restrictive design strategies based on standardization and mass customization. It explores the possibility of using conversation as a design approach together with physical and digital design systems that fit a specific context. Parametric design, along with other computational processes, can be used to create models with a particular purpose. Designers can benefit from a Conversational Age, where people are interconnected through computational interfaces and can share their creative potential through a network of relations. Everything is a copy, and nothing is original. Therefore, there is no original author and designers are free to copy, past, use, and abuse of available information.

The objective of conversational customization is not to maintain control after the design process, but to enable users to adjust the spatial constraints to fit new needs. The best way to do this is when the constraints were established by users in the first place. If this is connected to physical and digital designing systems that enable the change of states within the essential variables, a dynamic architectural system may emerge.This notion is put forward to counter contemporary discourse on computational design where technological development is focused on increasing the control of the design process by the designer, as exemplified by Schumacher´s Parametricism (2008, 2009, 2016).

7.4. Challenges for the future

The concept of conversational customization is discussed as a way of thinking and acting that invites the user to a central position in the design of the architectural space. The attempt to bring the user to the center of the spatial stage is not only a design issue, but more importantly, it represents a political stance on the role of the designer in the contemporary society. The recognition of this political nature opens the research to a vast field yet to be explored. Further research could especially benefit from the notions of agency put forward by Jeremy Till (2013), political agency by Ana Baltazar and Silke Kapp (2009), and particularly the idea of the capitalist dominance of space discussed by Lefebvre (1991). Nevertheless, the present research and the discussion it puts forth of a conversational design process paves the path to ground further discussion on a Second-Order Cybernetic approach to design.

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