Modes of Interaction in Computational Architecture

by

Dragana Čebzan Antić

A dissertation

Submitted for the degree of

Doctor of Philosophy

(Centre for Cultural Studies)

Goldsmiths, University of London

March 2012

I hereby declare that this thesis is entirely my work

Dragana Čebzan Antić

March 2012

Abstract

This thesis is an enquiry into the importance and influence of interaction in architecture, the importance of which is observed through different modes of interaction occurring in various aspects of architectural discourse and practice. Interaction is primarily observed through the different use of software within architectural practice and in the construction of buildings, façades and systems. In turn, the kind of influences software has on architecture is one of the underlying questions of this thesis.

Four qualities: Concept, Materiality, Digitization and Interactivity, are proposed as a theoretical base for the analysis and assessment of different aspects of computational architecture. These four qualities permeate and connect the diverse areas of research discussed, including architecture, cybernetics, computer science, interaction design and new media studies, which in combination provide the theoretical background. The modalities of computational architecture analysed here are, digital interior spaces, digitized design processes and communicational exterior environments. The analysis is conducted through case studies: *The Fun Palace, Generator Project, Water Pavilion, Tower of Winds, Institute du Monde Arabe, The KPN building, Aegis Hyposurface, BIX Façade, Galleria Department Store, Dexia Tower*, and also E:cue, Microstation, Auto-Cad, Rhino, Top Solid and GenerativeComponents software.

These are important for discussion because they present different architectural concepts and thoughts about interactivity within architecture. The analytical processes used in the research distinguished and refined, eight modes of interaction: (1) interaction as a participatory process; (2) cybernetic mutualism; (3) thematic interaction; (4) human-computer interaction during architectural design production; (5) interaction during digital fabrication; (6) parametric interaction; (7) kinetic interaction with dynamic architectural forms; and (8) interaction with façades. Out of these, *cybernetic mutualism* is the mode of interaction proposed by this thesis.

Keywords:
Interaction, architectural space, software, cybernetics, social interaction, mutualism, cybernetic architectural environment, participation, parametricism, digital fabrication.

Table of Contents

Table of Figures:

Introduction

Interaction became the focus of my interest and research during my masters studies in the Netherlands. I was able to test some of my ideas regarding the layering and augmentation of architectural space with digital objects and to experiment with the creation of different spatial experiences by interactively changing the perception of space through sound. This novel way of understanding space initiated my involvement in the examination of the meaning of interaction for architecture and the possible further developments that could be accomplished in this field. There is an extensive body of research and experimentation regarding interaction within computer science, art and even some aspects of architecture. Nevertheless, there is a lack of substantial research and analysis regarding the meaning of interaction for architecture nor much of an attempt to find a structural array of mutual relations between the different qualities able to evaluate this emerging field of research. In doing the research for this thesis, I selected components from existing architectural and media theory in relation to how relevant it was for the field of *computational architecture* and put them to the test by considering a number of practical examples or case studies. I chose an approach that would entail finding a symbiosis between theory and practice because I wanted to achieve a balance between the two in order to find a common evaluation method for theoretical and practical work in this field. In my opinion, practical evaluation and the application of methods and theoretical knowledge and structure are both important constituents of architectural discourse, through which a proportional balance of application can provide innovative and imaginative results.

Therefore, in order to give a kind of a structure and form to this field, in the thesis I propose four theoretical qualities: Concept, Materiality, Digitization and Interactivity. These will provide a theoretical means for the analysis and assessment of different aspects of computational architecture. Within this wider area of research, the thesis then focuses on interaction as the main quality or condition for the creation of new architectural spatial modalities. The term *computational architecture* is an abstract expression that treats a kind of architectural space that is calculable and could be processed by means of a computer but which is not essentially numerical. This means that the calculable numeric values of an architectural space are not an essential consequence of the design process, but the aesthetic qualities of the digital processes used, are. Among other things, this implies the production of architectural artefacts with aesthetic qualities that are distinct for different digital production processes, such as computer drawing and digital fabrication. It can be said that computational architecture implies the creation of an architectural space with a distinct aesthetics that is a quality of the computational process used during the architectural design production or interaction with the cybernetic architectural environment. The term *cybernetic* is used to describe a direct and continual process of communication between the components of an interactive architectural environment and its inhabitants. In this regard, and in relation to the term *computational architecture,* it can be said that *interactive architecture* implies the conception of cybernetic architectural environments that have multiple feedback loops as communication mechanisms and interact with the inhabitants directly or indirectly, in real-time and on a number of levels.

The interaction that happens between the participant and the distinct process within interactive architecture shapes the relationship with the space. Therefore, observation of the kinds of influences which, through interaction, software processes have on architectural design and space was one of the underlying characteristics of the research done for this thesis. In these terms, computational architecture concerns the design of architectural space that is shaped, moulded, fabricated and operated by different software processes. Differentiation of the software processes occurs according to the modes of interaction that happen during while they are being used in the various elements of the computational architecture. The moment of interaction can therefore determine the aesthetic attribute that may continue to change as the interaction process continues. This means that an aesthetic attribute of an architectural artefact is constantly changing and is in a state of flux. This may also change the notion of the perceived aesthetic criteria within architecture considering the debate that is present throughout architectural history between the discourse that supports the prevalence of function, or the program of the building, versus discourse that supports the form of the building as essential for architecture. Introducing interaction into this debate will not only refresh the notions of what architecture is, but may also give an incentive for its evolution.

It is interesting to include interaction in the debate because it deals with the process of architectural space formation through the digital means of production, and it can influence the character of an architectural space and provide for meaningful relationships between inhabitants and the environment. It can also determine the influence of digitized interactive building façades on their surroundings. This may not be exclusively comprehended as an aesthetic evaluation of architectural artefacts, but can be also understood through the design of architectural spaces as generators of events and social activity that can form around these kinds of buildings. In this regard, the architect's aesthetic expression is also important, although the focus here should primarily be on the continuous process of redefinition and reinvention of activities that can happen within the cybernetic environment. In this regard, the self-organizational aspect of interaction is very important for the observation because it indicates the quality of the dynamic relationships established through interaction within the digitized architectural space. Self-organization as an interactive process can determine the aesthetic quality of an architectural artefact. In this thesis, *aesthetics* is considered to be the development of an architect's idea into an artefact that, through interaction with material, obtains its architectural form, which may be a digital façade or a cybernetic environment. Another emphasis is on the design process performed through interaction with the software and involves shaping and moulding the material which materialises architect's idea and is expressed through the architect's work. This process of materialisation of an architect's idea through digital processes is considered as poetical.

In this regard Anthony Dunne, in his book "Hertzian Tales", recommends a starting point to observation of digitized architectural space in terms of everyday electronic objects and their poetic employment. He notices that the most fruitful reflection on material culture is to be found not in anthropology or sociology but in literature that is concerned with the poetry of everyday objects[1]. In this regard, Gaston Bachelard in his book "The Poetics of Space" gives a good example in the analysis, or even psychoanalysis, of wardrobes, chests of drawers, and diverse unnoticeable objects that people frequently use while being unaware of their non-material connotation in the form of the memories that are sometimes carried by these objects.[2] Dunne defines *hertzian space* as *a medium for carrying information, an invisible alternative to wires and cables*.[3] In his opinion, literary writers give a more poetic view of an art object, which formal aesthetic criticism sees as a material object. He introduces the term *hertzian*

[1] Anthony Dunne, *Hertzian Tales: Electronic Products, Aesthetic Experience and Critical Design*, The Royal College of Art & Anthony Dunne, 1999, 17.
[2] Gaston Bachelard, *The Poetics of Space*, Beacon Press, Boston, 1969, 45.
[3] Dunne, *Hertzian Tales*, 21.

space in its very general and broad conception, leaving in this way a designer to decide what kind of poetics of interaction s/he wants to achieve. In terms of cybernetic architectural environments, interaction is a crucial component of the invisible electromagnetic forces inside the hertzian space because it defines the ways in which these forces shape people's relationships with the environment. This implies that through interaction architectural space can become tunable, changeable and fluid.

With the digitization of architecture, the poetics that is constituted within architectural artefacts through the memory is translated into visual and/or auditory sensations that can be perceived and experienced in real time through interaction with the artefact. These digital architectural artefacts can literally memorize the imprinted representation and replay it a number of times. Their poetics is expressed through the social interaction in which different architectural artefacts obtain their meaning in the collective action that may challenge the different sensibilities that participants have. This means that the poetry can be reflected in the way participants relate to the architectural artefacts and to each other. In these terms, the significance of the interaction lies in its initiation of a process of ongoing conversation with the environment ameliorated by exploration and learning of oneself through the knowledge about the environment and vice versa. Interaction is important because it creates a link between the participants and this link can be formulated through the quality of the established connection. This can provide a base for the creation of architectural spaces that can be formed and shaped through continuous processes of changeability and participation. These kinds of spaces are not simply considered as assemblages of physical objects with geometric properties, which is the traditional notion of an architectural space. The important aspects of this interaction modality are the mutual relationships established between the space and its inhabitants.

In this thesis, mutualistic interaction is regarded as more generative in relation to the social interaction that happens within architectural cybernetic environments, and more spontaneous in respect to the performance of participant's identity, than the basic mode of human-computer interaction. The starting point in the development of mutualistic interaction was taken from the concept of mutualism as first proposed by Gordon Pask,[4]

[4] Gordon Pask, "The Architectural Relevance of Cybernetics" in Neil Spiller (ed.), *Cyber Reader: Critical Writings for the Digital Era*, Phaidon, London, 2002, 310.

that according to him was the main bonding element that could be regarded as an interactive moment between humans and their surroundings. The concept of mutualism that is proposed in this thesis is viewed as a social instrument able to enhance the intensity of social interaction in terms of the diversity of possible options one can chose from in the course of the interaction. An advantage of this concept is that it contains the possibility for both natural and artificial systems to learn about each other's actions inside an architectural cybernetic environment as well as to adapt to the relationships that occur between the inhabitants. The meaning of social interaction for architectural spaces is crucial because of the activity performed inside these spaces. This implies the fluidity and spontaneity of connections established both between the participants and between them and the space. The meaningfulness of these relations is related to the self-organizational aspect, which in architecture results in a specific approach towards the composition of form through form-finding.

Another important aspect of interaction for computational architecture, which in this thesis is treated as more important than form, is the possibility of interaction initiating the processing of form. This moment of creation is, for McCullough, in a state of flux[5] because as one learns through interaction with the material that is being shaped, one develops an understanding of the means of production and its possible creative use. In the traditional mode of production, interaction was with pen and paper while in the digitization of architectural design production this is achieved in different modes of human-computer interaction with an appropriate software application. In this regard, interaction is important because it presents a constituent which determines the prospect for the architect’s aesthetic expression. This expression can be achieved through creative approaches in software utilisation in which case there can be multiple levels of interaction. The first and basic level is human-computer interaction during the creation of an architectural composition; secondly there is an interaction between the software and the material that is being shaped; and the third level concerns interaction between the composing layers of the material used for the architectural form creation. The complexity of the interaction during the production of an architectural design provides many diverse ways of formal expression. In these terms, the accent should be on an exploration with interaction mechanisms in which the form becomes its spontaneous

[5] Malcolm McCullough, *Abstracting Craft: The Practiced Digital Hand*, The MIT Press, Cambridge, Massachusetts and London, England, 1998, 178.

result instead of a goal.

The most evident influence of interaction on architecture is manifested through the formalisation of the Digital Façades. In their development, digital façades evolved from mere advertisement tools to playful and interactive urban artefacts that can establish relationships with their surroundings and with the people that inhabit it. The importance of these interactive urban artefacts lies in the initiation of participation and substantiation of relationships that are formed around events, which are the main actuators of interaction. In these terms, they present open social platforms that invite people to participate in the events that take place on the building's façades. Through the interaction with the façade people may also interact with each other. The quality of an urban or architectural space created around these digital façades can be defined as a multi-cyclical cybernetic environment of continuous conversation. Another significance of this interaction lies in the quality of the content that is emitted into the surroundings and the influence of this content on the inhabitants. This means that an interaction that occurs between a digital façade and potential participants depends on the balance between content, location and type of façade that is created. A potential diversity regarding the design of different types of digital façades may be achieved through creatively envisioned and socially oriented modes of interaction that are suitable for development. In some respects, these façades can be regarded as hyposurfaces[6] that reflect the balance between the different physical and interactive states achieved through the cycle between their fluid and solid condition. This conditionality determines the way in which they communicate with their surroundings and the aesthetic expression they indicate in the moment of interaction. Some of the digital façades may be regarded as *transparent buildings* in terms of the possibility they offer for a large number of people to participate and in terms of the degree of freedom of expression that is capable of being displayed.

Chapter Overview

As the importance of interaction for architecture can be observed through its diverse materialisations, the thesis develops as follows: I establish, in the first chapter, the

[6] Mark Goulthorpe, *The Possibility of (an) Architecture, Collected Essays by Mark Goulthorpe/dECOi*, Routledge, Taylor & Francis Group, London and New York, 2008, 97.

previously mentioned theoretical qualities for evaluation of architectural cybernetic buildings and environments. *Concept* is considered as a process in which the architect's idea is contemplated and brought to the level of realization in a physical form. As a signifier of interaction, concept can shape the idea and give an interaction process its order. This concerns the creation of the concept structure, which can be observed as an algorithm. As it is observed within an architectural discourse, the concept quality is also discussed in relation to the important architectural concepts, such as those of the Futurists, Archigram and the Metabolists, that are significant for the introduction and development of interaction in architecture.

Materiality regards the relation of the materials employed in building construction and the developed modalities through which the materiality of the building has changed with the digitization of distinct processes in architecture. It provides a basis for the definition and discussion of, the new attributes of *digital materiality*, introduced by Gramazio and Kohler.[7] The theoretical work of Gottfried Semper provides an interesting approach to materiality in architecture, one that can become a basis for the further development of digital materiality. The Materiality quality also defines the differences between natural, virtual and digital materials that are used for the construction and finalisation of buildings and it distinguishes the points in architectural history that have influenced the occurrence of these new material conditions.

Digitization concerns the occurrence of different digital media within architecture that have influenced the aesthetic quality of digital façades and cybernetic environments and also established a basis for the potential poetic accomplishment of the social and cultural events formed within these interactive architectural spaces. Katherine Hayles gives an interesting account of people's involvement in the process of digitization.[8] This quality concerns the forms in which the digital image has changed the aesthetic perception of architectural imagery and also the ways in which the work is performed within architectural practices. One aspect of the digitalization quality is observed through database development. Database evolution is considered to be important for the creation of cybernetic environments, digital façades and the digitization of the architectural design process because it directly influences occurrence of the new modes

[7] Fabio Gramazio and Matthias Kohler, *Digital Materiality in Architecture*, Lars Muller Publishers, Baden, Switzerland, 2008, 79.
[8] Katherine Hayles, *Writing Machines*, The MIT Press, Cambridge and London, 2002, 67.

of interaction. And also because it is one of the important mechanisms that allow for improved and more complex modes of interaction to happen.

Interactivity establishes the difference between the definition of human-computer interaction and all other modes of interaction that can occur within cybernetic architectural environments. This quality considers forms of participation as the main mechanisms for interaction to happen and the creation of architectural spaces as *generators of social activity*.[9] It proposes a novel approach towards the design of an architectural space not only in terms of a spatial ambiance or a sense of a space but also through the kinds of relationships, besides functional ones, that people inside such a space can have and what the relations between the different constituents of the space are. The creation of these new relationships is possible within the so called *smart* spaces within which the new relation between architectural space and the human body can be established. This is relative to the performative and interactive attributes that architectural cybernetic environments can have.

In the second chapter the analysis starts with the introduction of the science of cybernetics and its concepts which Katherine Hayles[10] considers to be essential for understanding the definition and development of *environments*. Homeostasis, reflexivity and virtuality are the concepts that gradually emphasize interaction as essential for observation. Paul Pangaro and Gillian Hunt provide their observation of interaction in relation to architecture creating a basis for the definition of the interactive modalities that can occur within architectural cybernetic environments. The discussion includes an extensive analysis of examples, presented chronologically, that combine architecture and cybernetics in various symbiotic relationships, of projects such as those of Buckminster Fuller, Gordon Pask, Yona Friedman, Archigram and Cedric Price. The accent in this regard is on the Pask's *Colloquy of Mobiles*, Price's *Fun Palace* and *Generator Project* and Lars Spuybroek's *Fresh Water Pavilion*, which are analysed in more detail. Through definition and examination of interaction modalities that occur in these projects there is an underlying thought that social interaction can be fully expressed through the concepts of self-organisation and mutualism. Self-organisation is considered to be important because it is a process that occurs between people when they

[9] Stanley Mathews, *From Agit-prop to Free Space: The Architecture of Cedric Price*, Black Dog Publishing, London, 2007, 118.
[10] Katherine N. Hayles, *How We Became Posthuman: Virtual Bodies in Cybernetics, Literature and Informatics* University of Chicago Press, Chicago and London, 1999, 56.

are gathered together to learn about each other and each other's environment.[11] The learning process occurs through interaction with the environment. In regard to architectural form, self-organisation is important because it can initiate the form-finding process, which means that it characterizes and determines the pattern formation, and it underlies the process of simulation that is important for the representation of architectural projects. The main objective of the second chapter is to analyse different aspects of interaction and to define the new interactive modality: Cybernetic Mutualism.

The third chapter is concerned with the exploration of human-computer interaction and its possible developments through the software used in architectural design production, digital fabrication processes and parametric design software. Throughout the chapter human-computer interaction during the production of architectural design is analysed in comparison with traditional modes of architectural drawing. The discussion also considers the possibility of how the architect's expression is conveyed aesthetically through the new digital means of production and how the aesthetics and structure of a drawing change due to the introduction of software. Discussion of the architectural dichotomy between the prevalence of a building's function/programme, or its form, is part of this chapter. This discussion is important for understanding the underlying architectural thinking during the design of a building. Human-computer interaction is also analysed through the way the computer mouse and the keyboard are used in regard to the different representations they have on the computer interface and the command line. Ivan Sutherland's[12] *Sketchpad* programme is an important constituent in consideration of the influence of software on the architectural design production. This programme was created to provide swift *conversation* between man and computer through the medium of a line drawing. It also created a basis for the development of Computer-Aided Design, Computer-Aided Manufacturing and Computer-Aided Engineering, all of which are used in architectural design production in its different stages. The reconfiguration of drawing production created a direct link between architectural design concepts and processes of building construction utilised through the file-to-factory processes of CNC and Rapid prototyping fabrication. These processes are interesting because of the multiple levels of interaction that occur during fabrication.

[11] Gordon Pask, "Heinz von Foerster's Self Organisation: the Progenitor of Conversation and Interaction Theories", *Systems Research*, Volume 13, 1996, 10.
[12] Ivan Edward Sutherland, *Sketchpad: a Men-Machine Graphical Communication System*, Technical Report No 574, University of Cambridge, Computer Laboratory, September 2003, 8.

The process of parametric design, Schumacher's concept of *Parametricism*[13] and Cache's concept of *Non-standard architecture,* as the most advanced level of design production, is also considered in this chapter.[14]

The fourth chapter is concerned with the material implications of the digitization process in architecture that is actualised in the form of digital façades. This is addressed through the influence of digitalization on the urban environment of cities and the people who inhabit it. The essential factor for observation is interaction, and its diverse modalities, with these urban artefacts. The analysis here offers a novel approach which combines the previously mentioned qualities as essential relations that link together different aspects of the analysed interactive façades and give form to this theoretically disregarded area of research. As part of the analysis, the façade's transforming materiality will be observed through the digital material's layering and incorporation into natural materials. The transformation of the building's materiality that implies the façade’s aesthetic qualities and their mutualistic relation is observed through the interactive qualities that the digital façade can contain. Through architectural history, the oldest and most essential question (which has defined architectural thinking) is to find the most appropriate position in order to define the relation between a building and its outer surface.[15] Therefore the fourth chapter is also concerned with the variety of relations which can be established between digital façades and the programme of the building through the activity performed inside the building. This analysis is conducted with reference to a number of examples, those of the *Tower of Winds, the Institute du Monde Arabe, the KPN building, Aegis Hyposurface, the BIX Façade, the Galleria Department Store* and the *Dexia Tower*, which are presented in chronological order in order to follow the development of architects’ concepts, the change in the buildings’ materiality and to distinguish between the different modes of interaction that have occurred as a result of the former and the influence of digitalization.

[13] Patrik Schumacher, *The Autopoiesis of Architecture: A New Framework for Architecture*, John Wiley & Sons Ltd. Publication, Chichester, West Sussex, UK, 2011, 73.
[14] Bernard Cache, *Earth Moves: The Furnishing of Territories*, MIT Press, Cambridge, 1996, 25.
[15] Gottfried Semper, *The Four Elements of Architecture and Other Writings*, Cambridge University Press, New York, 1989, 64.

Chapter 1: Modes of Interaction – Identifying Physical and Digital

Cybernetic buildings, as will be described and discussed further in the second and fourth chapters of this thesis, have existed for more than three decades. They have been chosen for their distinct modes of interaction integrated through digital qualities in their periodic emergence in time. The expression *cybernetic building* refers to an architectural structure perceived as a system that can interact with the conditions in its environment by means of a distinct action performed by the system/building. This action induces a modification, which is then manifested to the system as information and which returns to the system as feedback. This feedback then causes an adaptation of the system/building to the newly formed conditions. In this way the system changes its behaviour and is in a state of constant information, looping with a continual and changeable feedback between the system and the environment and resulting in an interaction. Different qualities of feedback can influence different levels in such interaction. Interaction and its qualities as regards the different modes of its development and application in architecture through the creation of diverse events will be discussed in the second chapter. Beyond this, the discussion engages with two architecturally significant themes, both of which are concerned with different ways in which software has influenced architecture, as observed through interaction and presented in different segments of architectural design.

The first subject (which will be discussed in detail in the third chapter), is about interaction during the architectural design process and how it has changed in the development from hand produced to computer-aided drawings. It is also about the different interactive modalities that emerged due to software's influence on architectural design at the different stages of its conception, elaboration and finalization before the construction starts. The second topic, to be discussed in the fourth chapter, is about interaction with architectural elements that are cultural artefacts contained in the urban condition of cities. It is concerned with software's influence as applied to actualised buildings through its utilisation on façades and consequentially how it has influenced the surrounding urban tissue and its inhabitants. This differentiation is important in order to understand the diversity of software's effects on architecture, which can appear habituated because of the general interpolation of computer technologies into everyday life, as well as to highlight different interactive modalities that occur in different situations in outdoor and indoor environments. The chronology by which cybernetic façades appeared as discussed in the fourth chapter is important in order to trace the development of the technological means and how they have been applied in architecture. Also significant are the diverse approaches these façade concepts adopt in order to communicate in different ways with a particular environment or people. In order to constitute the criteria necessary in order to analyse cybernetic buildings it is necessary to establish a set of qualities that will help us to determine further developmental potentials in the field of interactive architecture. These aspects of investigation I have named Concept, Materiality, Digitalization and Interactivity.

The *Concept* quality is significant because of the potential cultural meanings that projects may contain. More often than not these kinds of ventures have been accused of being too *technical* and lacking in deeper meaning, possibly because they involve the usage of contemporary technology (i.e. hardware and software), that is typically seen as being too dry and automatized. The question of a cybernetic building's representation in terms of its symbolic meaning for the cities they reside in will be analysed through this quality, as well as the kinds of aesthetics that are ascribed to the observed cybernetic environments in relation to the effects they produce as they concern the inhabitants. Part of the project of the thesis, then, is to develop a vocabulary for understanding of the poetics of such buildings, which work with their technicity as a cultural form.

The *Materiality* quality is important because it describes the physical characteristics materials have when applied to the façades and the way in which they are structurally implemented. It also involves the physicality of the applied digital materials and processes involved in either the production or actualisation of cybernetic buildings. In this regard, an interesting case is the virtual materials whose layering with natural materials results in distinct architectural aesthetics and forms to be regarded as hypersurfaces. By summarising the materials applied on the building's façades an overview will be given of the new technologies involved in the development of digital and other contemporary materials and the aesthetic potential they have. The materiality of digital materials is concerned with the augmentation and integration of digital processes into natural materials so that a symbiosis is created between the two scales of materiality, visible and discrete. The visible materiality is the structural materials that provide the skeleton of the cybernetic environment, while the network of digital objects layered and integrated into the structural system of the environment are discrete.

The *Digitization* quality includes how the impacts involved in the implementation of digital processes are differentiated, as in the case of architectural design, and is also concerned with discussion about the aesthetics of digital materiality. That is, digitization quality implies the effects of the digital processes as they are employed in different aspects of interaction and the aesthetics produced by these processes. This involves consideration of the level of the different forms of media involved in the life of a building, the diversity of potential mediators in the process of interaction, the novel modes of database implementation, the kinds of software used and its performative characteristics, the differentiation in the modes of operation (such as in relation to the different periods of day and night), etc. This quality implies digitality in its different connotations that contribute to the overall atmosphere in which the building resides and the novel character that is reflected in its urban and architectural environment.

The *Interactivity* quality is concerned with different modalities of relations between the entities in interaction and their mutualistic connection, such as between the cybernetic building and its environment, between the constituents of the dynamic interactive architectural space and the people who use them as well as between the digital façade and events that emerge in the process of interaction. The cybernetic building interpolates different kinds of qualities created and implemented through the links randomly or intentionally established between those entities contained in the dynamic system, the diverse ways of cybernetic environment adapts to the environment, people or events, the evolutionary potentials of the dynamic system as it is integrated into the cybernetic environment in terms of its learning capabilities and its relation with the inhabitants, etc. Here interactivity is treated in cybernetic terms as a circular, self-organising and mutualistic process through which the actual world is invented and not discovered and in which shared meaning is created through intelligence that acts by means of a social and collaborative capacity.

These four qualities are introduced and discussed further in the following pages.

1.1 Concept

The term *concept* is not treated in terms of philosophical discourse and meaning,[16] but only in the context of how it is used in architecture with an intention to give my explanation of its meaning and reference.

In modern history many architectural movements (for instance Cubism, Expressionism or Art Nouveau)[17], had conceptual premises based and intermingled with ideas first of all formed in art.[18] As described in the "Stanford Encyclopaedia of Philosophy", most conceptual art aims to challenge and probe its participants so that they will re-examine their relation towards art and question its given assumptions, and because of this they actively set out to be controversial. The main goal of conceptual art is to make us question our assumptions not only in that part that relates to what may properly qualify as art and what the function of an artist should be, but also about the role of the observer, how the spectator should relate to art, and question his/her position as regarding subject.[19] The architectural position, transformed by the influence of art, established its own interpretation of these basic concepts by creating links through formal manifestations, spatial constructs and expressions in the way building materials were used. This historical relation between art and architecture was at times based on interactional ideas and responses to actual social and political situations. The significance of the meaning and application of *concept* in architecture is understood by the way it was used by Frank Lloyd Wright,[20] who conceived the building's form before he thought about its purpose. This evolved into the ideas of Conceptual architecture.

Conceptual architecture introduced ideas and concepts about the roles of architects and architectural projects[21], taken from outside the discourse of architecture in order to expand and refresh the discipline. *Conceptualism* was introduced into architecture during the 1960's through the work of Archigram in the UK, Superstudio in Italy, the Metabolist Movement in Japan and it was later continued with the work of Peter Eisenman, Rem Koolhaas, Zaha Hadid, Bernard Tschumi, Diller + Scofidio (+ Renfro), etc. The most recent of those architects mentioned belonged to a generation that symbolised the paradoxical nature of architecture, which is reflected in this dilemma: should one focus on art or function, imagination or practicality, aesthetic unity or social

[16] i.e. as in Gilles Deleuze and Felix Guattari, *What is Philosophy?*, Verso, London and New York, 1994.
[17] These movements were not ones that created conceptual art.
[18] Kenneth Frampton, *Modern Architecture: A Critical History*, Oxford University Press, Oxford University, UK, 1981, 84.
[19] Retrieved March 16, 2009, from http://plato.stanford.edu/entries/conceptual-art/#ConArtWhaIt
[20] Ibid., 1.
[21] Peter Eisenman, "Conceptual Architecture II: Double Deep Structure I" *A+U 4*, Number 39, March 1974, 83-88.

viability? Some answers to these questions were initially given by Archigram and Superstudio in the form of so called *paper architecture* through visionary projects that were without physical manifestation in the form of an actual building, which implies that the physical feasibility of these kinds of concepts was never tested. Later projects, such as the *Blur Building* at Expo 2002 in Yverdon, Switzerland and *Parc de la Villette* (1983-98) in Paris, France, shown in figures 1.0 and 1.1 below, did come to fruition. If analysed, these projects reflect the fact that what is called *conceptual architecture* does not comprise one unifying concept which all of the architects referred to above follow but is rather a way of thinking that introduces the conceptuality of the project in terms of its cybernetic doctrine in a way that makes one question one's understanding of architecture.

Figure 1.0: *Blur Building,* Elizabeth Diller and Ricardo Scofidio, Yverdon, Switzerland, 2002.

Figure 1.1: *Parc de la Villette,* Bernard Tschumi, Paris, France, 1983-1998.

The results of this novel way of thinking are projects that are essentially different than those that use a traditional approach in which an architect acts more like an engineer. The profession of an architect has a dual aspect: s/he is expected to be both an engineer and scientist (able to understand how a building is constructed, and solve technical and business problems[22]), and as a craftsman/artist with an innovative approach to establishing meaningful relations between different fields and activities through the production process.[23] The relation between the concept and the craftsmanship lies in the creative process through which the craftsman deals with the material used to manufacture a piece of work. This means that a craftsman needs to interact with the material in order to learn about its possibilities and formalise and materialise a

[22] Daniel T. Koenig, "The Engineer Entrepreneur", *American Society of Mechanical Engineers*, New York, 2003, 14.
[23] Richard Sennett, *The Craftsman*, Penguin Books, London and New York, 2008, 9.

particular concept. In terms of my research, the material an architect interacts with is software and the craftsmanship is part of the creative process by which it is explored – through the production of architectural drawings, for example. Richard Sennett regards craftsmanship as a way of life and a basic human impulse, the desire to carry out the work well for its own sake.[24] If understood in this manner, craftsmanship did not perish with the advent of industrial society; it merely transformed and adjusted to contemporary cultural, social and labour conditions. An important characteristic of this is in regard to ideas and concepts introduced with the development of technologies that changed the relationships between an architect and a building and consequentially also changed architectural space. This saw the development of ideas which conceived of architectural space as fluid and interactive.

In the process of design, the *idea* presents a moment of enlightenment in which, at a conscious level, a number of patterns of thinking encounter, collide and merge into each other so creating the idea. The idea is a moment in which a connection is established from which a meaning happens. The idea is created before the concept and as such does not have a structure. The concept gives structure to an idea. What is unclear is how the different meanings connect together and reflect our knowledge of the world and why particular meanings emerge rather than others. Reconstruction of the process by which the idea was formed can happen at the level of knowledge that has been gathered through previous experiences and the accumulation of knowledge learned from books. For now, we could say that this process happens rather spontaneously and emerges into consciousness only at the moment of its birth. In architecture ideas are often understood through images of an object,[25] that is of a building and/or its elements. The concept gives this image its structural composition, making its understanding possible. John S. Gero and Ashok K. Goel argue that the key process in problem solving, artistic output, creativity and other types of human activity and interaction, is how mental imagery is used since it concretises internal mental activity subconsciously or consciously used during the creative process. Perception, imagination, interpretation and recall, which are essentially internal, function interactively with events, such as bodily movements, sketching, modelling, that occur *outside* the mind. Internal representations are forms of imagery constructed by means of mental visualisation and

[24] Ibid., 9.
[25] Regarding an idea, see Rene Descartes, translated from the Latin by Donald A. Cress, *Meditations on First Philosophy*, Hackett Publishing Company, Inc., Indianapolis, Indiana, Third edition, 1993, 97.

synthesis, which consequentially produce models.[26] In this regard, an early phase of the design involves reading the design brief and understanding the problems associated with the particular site. This is usually followed by a visit to the site in question. Once this is done and mental and photographic visual imagery of the site and its context is established the first sketches are made following which the client design brief can be negotiated. This creates a basis for the creation and development of the architectural design, whose production process will be analysed in chapter three.

The *Concept* occurs when the idea has been developed further and brought to a rational level where it is thought through more thoroughly and developed in a more refined manner. It is therefore the stage when the idea is brought to the level of materialisation. This rationalization of the idea is followed by its dissection into smaller, more manageable, parts and is concerned with the creation of the concept structure. The process of conceptualization may also be abstract if the experience one wants to provoke in the observer is purely emotional. To do this successfully is rather challenging because stimulation of emotions and feelings requires a more complex level of engagement than if we would like to induce a rational cognition in a piece of art or architecture. Three aspects of the concept are very important: the first concerns what the idea communicates or what kind of message an artist or architect wants to send out; the second considers why the idea is important, what aspects of reality it addresses and how consequentially it can influence reality; the third is about the materiality of an idea and how the material structure that springs from the concept responds to a particular context, how its material representation reflects the core concept, what materials are employed in it, and how they reflect and mediate what an artist or architect wanted to achieve. From what has previously been said, it can be concluded that the concept is the process or mechanism of bringing the idea to realisation so that it can be clearly communicated to the observers be materialised as *the work of art* or *the architectural achievement*. Depending on the essence the idea should reflect, it can be represented on canvas, screen, building or wall or in words, sculpture etc. The concept of a building can contain several ideas, for example, in its form, context, materialization, construction, etc.

Buckminster Fuller once noted how modernist architects, and especially those of the

[26] John S. Gero and Ashok K. Goel (eds.), “Idea Development Can Occur Using Imagery Only” in *Design Computing and Cognition 2008*, Proceedings of the Third International Conference on Design Computing and Cognition, Springer, Heidelberg, 2008, 145.

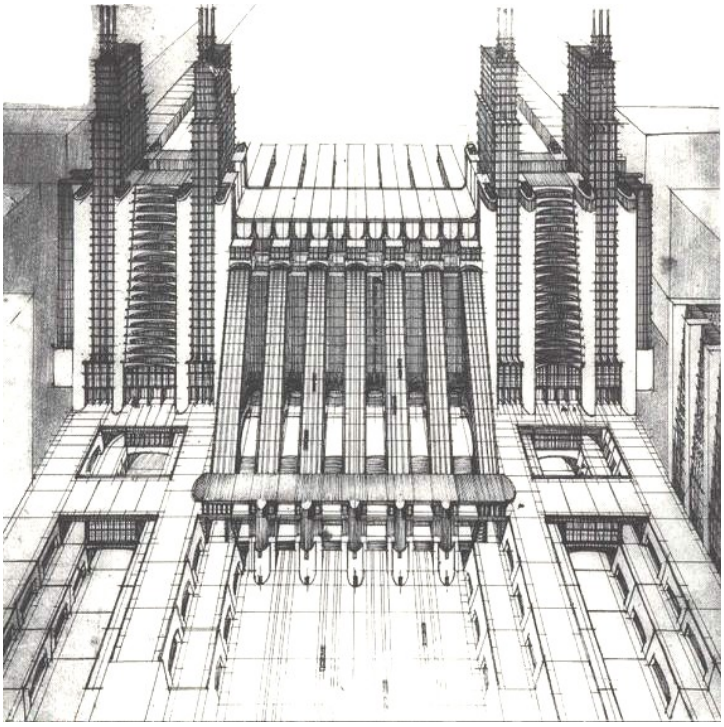
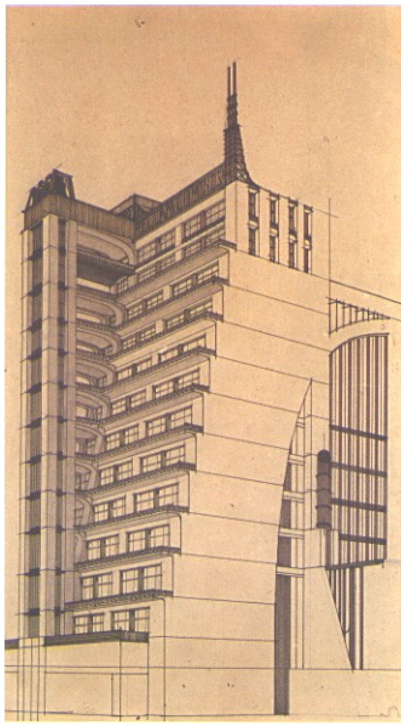
International Style, were more concerned with economic factors in construction than with *conscious aesthetic innovation*[27]. He stated that they had a lack of knowledge *about the scientific fundamentals of structural mechanics and chemistry.*[28] Their *simplified* treatment of wall surface was superficial for him. His critique was aimed at the continual concealment of the building's structural elements, serving only as invisible skeletons that carry the outer glitter of the building or the decoration in form of the façade. Fuller's critique was that by simplifying the formal elements of the building the architects of the International Style did not make any essential difference to the building as a whole was treated, that is as a formal and a structural entity. By simplification of building's artistic style they made only an illusory modification, which Fuller calls *'stark motif walls' of a vast super-meticulous brick assemblage,*[29] which does not correspond with the *tensile cohesiveness of its own bones*.[30] Much of his critique could be applied to today's buildings which position themselves in terms of interactive architecture, except that instead of brick modules, they are covered with pixelated digital walls that, in most cases, utilise the play of light as their primary motif. However, not all Digital Façades can be put into this category. For instance, the digital façades to be discussed in the fourth chapter are characterised by their interactivity. This quality involves the creation of dynamic forms composed on a skeleton that is fluid and changeable and that influences the form of the artefact through interaction. These architectural artefacts result from the conscious aesthetic innovation Fuller wanted.

1.1.1 The Concept of Interaction Through Architectural Ideas

This section introduces the architectural ideas of the Futurists, Metabolists and the Archigram Group relevant in formalisation of the concept of interaction within architecture. The discussion will address interaction as it is transformed through these ideas in different social, cultural and architectural contexts. The concept in regard to interaction can set up a framework for possible action within the space. These developments create a basis for the evolution of ideas and concepts that will later come to symbolize the digitization of architecture in various aspects, such as through design and built form.

[27] Buckminster Fuller in "Conclusion: Functionalism and Technology" in Peter Reyner Banham, *Theory and Design in the First Machine Age*, The MIT Press, Cambridge, Massachusetts, 1980, 326.
[28] Ibid., 326.
[29] Ibid., 327.
[30] Ibid., 327.

1.1.1.1 The Futurists' Technological Imagination

Figures 1.2 and 1.3: *Futurist House,* Antonio Sant'Elia, from *La Citta Nuova*, 1914.

Prior to Buckminster Fuller's activity in the US, a new movement emerged in Europe, the Futurists. The leader of the movement was Filippo Tommaso Marinetti, while Antonio Sant'Elia was their leading architect and the message with that later to be developed by Fuller, with a difference that they were preoccupied with the machine, which was in the focus of their manifesto, and not the structure. They argued for a new architecture not based on linear composition and without the historical continuity that usually inherits the flaws of past times. The Futurists were struggling for the new and fresh state of mind that would introduce a completely novel architecture, one which would not seek answers in the different decorative building elements or in diversification of the finishing of the façade merely to differentiate the age in which building was constructed. Nor would it seek variations merely in formal appearances. Instead they were looking for a *Futurist house*,[31] that would be constructed with all the resourcefulness of technology and science and authoritatively satisfy peoples' habits and spirits while rejecting *tradition, style, aesthetics* and *proportion*[32] in favour of a new

[31] Antonio Sant'Elia and Filippo Tommaso Marinetti, "Futurist Architecture" in Ulrich Conrads (ed.), *Programs and Manifestos on 20th Century Architecture*, The MIT Press, Cambridge Massachusetts, 1975, 34.
[32] Ibid., 34.

harmony of profiles, new lines, forms and volumes, as shown in figures 1.2 and 1.3 above.

The Futurists denied history altogether and so they abolished any aesthetic conceptions about what a building with futuristic attributes should be. In my pinion, a relation with history and before all its social and cultural imprints is essential for contemporary reflection and development of concepts which can draw conclusions and find inspiration in it. The inspiration here is not a mere mannerism of the formal expression of past styles but an interrogation about the state of being in the actual environment with its characteristic attributes to which innovative concepts should respond to. Sant'Elia's "Manifesto of Futurist Architecture" illustrates a very brave notion of what architecture should be but do not include the complexity of society and culture in their or future times. The idea of architecture not being related to history or natural change is very totalitarian in its character and theoretically it could be applied to an ideal kind of society in which all people in the community have exactly the same qualities and ideas about their environment as existing in ideal political and economical conditions. It can be concluded that the celebration of technology without consideration of the social and cultural aspects of its context can not lead to concepts with significant architectural and urban strategy. It is necessary to distinguish the specific conditions and needs of a particular culture and society in their evolved historic modalities as subjected to various influences over time. In this regard the Metabolists took a further step in their conception of what an architecture in social terms should focus on.

1.1.1.2 The Metabolist's Synthesis of Nature and Technology

Unlike their Italian predecessors, the Japanese Metabolists, although they also lionised technology, had a more humane cultural position in respect of the standardization of architecture as a social milieu. Early evidence of this can be found in their theoretical background from which they perceived society as a vital process. They did not glorify technological devices like cars, aeroplanes and such, as the Futurists did, but amplified the potential significance of the process as a constituent that is a part of every device but also could be comprehended as a living entity evolving through society and becoming integral to it. Metabolists see society in a constant growth *from atom to nebula.*[33] The

[33] Kisho Kurokawa, "The Origin and History of Metabolist Movement" in *Metabolism in Architecture*, Studio Vista,

reason they use the word *metabolism* is that they believe *design and technology should denote human vitality.*[34] For them, in the development of society, metabolism means encouraging active metabolic processes that are in harmony with nature and not only suggest adapting to a natural, historical process. Thus, they did not consider their concepts only to be applied to built physical forms but also to processes of cultural development which are not imposed on society but flow along with it, so allowing the change to come naturally and not through force.

An important aspect of the Metabolists' theory is to regard human society as a constituent of a perpetual natural entity consisting of plants and animals as well as humans. Furthermore, unlike their Western colleagues, they saw technology as an extension of humanity and not as in conflict with it. They were concerned with population growth, variations in age structure, different types of mobility among the inhabitants, the transportation systems and networks, the existence of information-communication networks, street organization, historical contexts, political structures and systems, the level of economic development, the extent of the relevance of technology, agriculture, the level of industrialization, etc. as very influential factors that shape the nature of the cities and their architectural spaces. Conscious that urban life in the period immediately after the Second World War needed to be revitalised and how to accommodate the population in Japan, where land is a limited resource and therefore very precious, is central to their propositions.[35] They were significantly more mature than the Futurists in conceiving of the direction of urban, architectural and technological development. Their work is however considered as technocratic and their design as avant-garde with a structural expressive style. The technocratic designation was attached to the Metabolists because of their technically oriented building solutions and the view that important societal problems could be solved through technology.[36] Gunnar K. A. Njalsson states that technocrats are primarily impelled by their cognitive *problem-solution mindsets* and only slightly by a special occupational group interests. Their activities and the prosperity of their ideas are important factors that influence modern extensions of technology and the ideological concept of the *Information Society*.

London, 1977, 41.

[34] Ibid., 41.

[35] Zhongjie Lin, *Kenzo Tange and the Metabolist Movement: Urban Utopias of Modern Japan*, Routledge, New York, 2010, 137.

[36] Academic Dictionaries and Encyclopedias, “Technocrats”, Definition by Gunnar K. A. Njalsson, Retrieved May 15, 2009, from http://dic.academic.ru/dic.nsf/enwiki/658051

1.1.1.3 Archigram's Concept of Mobility

The projects of the Archigram group could be referred as works of so called *paper architecture* or architectural design that never reached physical manifestation. Unlike the Metabolists who left built reference behind them making their design more realistic in practical terms, Archigram members drew their inspiration from the Futurists, particularly from Sant'Elia, as well as later architects like Buckminster Fuller and Yona Friedman. Like the Futurists, their projects were oriented towards experimentation and were based on a vision of reality emerging from a sound technological background. They drew inspiration from technological developments happening during 1960's with the intention of creating a new architectural imagery made explicit through hypothetical projects.[37] Although their intentions could equally well be comprehended as a reaction against the problematic aspects of technology if it is overexploited. Archigram's conceptualization relied to a great extent on infrastructural and lightweight structural experimentation. Their experiments comprised possible and diverse means of mobility through the environment, the use of space capsules, modular technology and a mass-consumer imaginary.

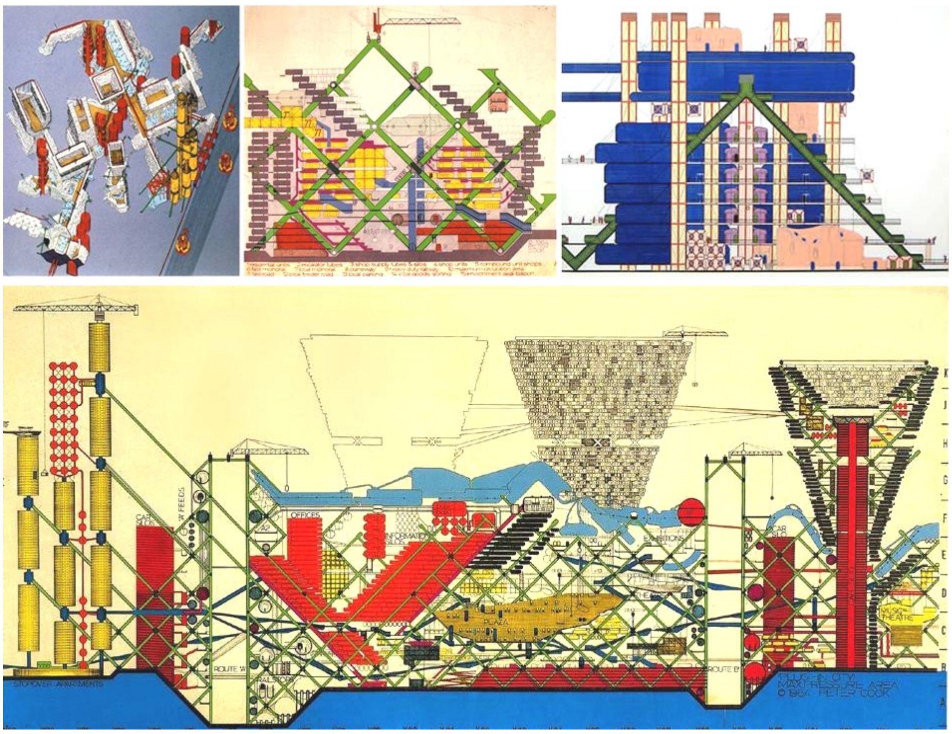


Figure 1.4: *Plug-in City*, Archigram, 1964.

[37] Simon Sadler, *Archigram: Architecture Without Architecture*, The MIT Press, Cambridge, Massachusetts, 2005, 42.

Archigram's projects reflect their relation with a physical built structure perceived in such a way that the whole structure is composed of digital pixels. This is particularly evident in Peter Cook's *Plug-in City* (1964), shown in figure 1.4 above, in which he was concerned with buildings able to be transferred from place to place and with environments not composed of the complex and gigantic hardware of the built form.[38] In line of this investigation there were projects such as the *Capsule Homes* (1964) of Warren Chalk and the *Gasket Homes* (1965) of Warren Chalk and Ron Herron.[39] In these projects interior spaces and imagery of plug-in dwelling modules inspired by early prototypes made for the aviation industry homes by Buckminster Fuller were examined.[40] A more rational extension of Archigram's ideas is the *Fun Palace Project* (1961) conceived by Cedric Price, which is discussed in more detail in the second chapter. As an Archigram's project, *Fun Palace* proposed an instant catalytic environment conceptualised in such a manner as to interact with the community in order to bring about change. The main difference between the *Fun Palace* and Archigram's projects lies in Price's thorough involvement in the modalities of the building structure able to deal with issues of changing size and the operation of spaces and services.[41] Even nowadays the building is structurally and constructively still the same as it was in Modernist times made with the use of hidden steel and concrete elements.

The Archigram, similarly to the Futurists, had an approach that almost negated the significance of historical architectural discourse and embraced the Zeitgeist of the period, which in their case was technological advancement, consumerism, and cultural divergence. Like the Futurists and unlike the Metabolists, they did not think about the social, cultural or environmental aspects of their building's conceptualisation and therefore their projects merely have a formal quality with an evident visual prominence, which meant that their works were very recognizable and distinctive. One of the themes emerging from their projects is the issue of nomadism as a dominant social force. They saw a nomadic way of life as becoming predominant in the future where commutation and transfiguration will replace inactivity. They were promoting a lifestyle in which consumerism would be the main driving force and constitute a programme involving a

[38] Robert Kronenburg, *Houses in Motion: The Genesis, History and Development of Portable Building*, Wiley Academy, Chichester, 2002, 111.
[39] Ibid., 111.
[40] J. Baldwin, *BuckyWorks: Buckminster Fuller's Ideas for Today*, John Wiley & Sons Inc., New York, 1996.
[41] Kronenburg, *Houses in Motion*, 114.

state of transience. For Archigram members, the public realm was an electronic surface enclosing the globe.[42] Their projects set up the basis and the present conceptual inspiration upon which a number of creative individuals interested in exploring the influence of technology on urban and architectural environments have drawn.

Figures 1.5 and 1.6: *The Pompidu Centre*, Renzo Piano and Richard Rogers, Paris, France, 1971-1977.

The project that clearly reflects the influence of the architecture announced by Archigram and its successors is Renzo Piano and Richard Rogers's *Pompidou Centre* (1971-1977) in Paris, as shown in figures 1.5 and 1.6 above. The technological aestheticism of the façade elevations is very noticeable on this building. It is evident that all of the steel structure elements, the escalator tube and facility ducts are openly exposed without any attempt at concealing them, as is usual in architectural projects because these infrastructural elements of the building are considered aesthetically repellent. Another example is the *Lloyds Building* (1978-1986) in London, whose façade indicates the high-tech spirit of the age in which it was constructed, as shown in figure 1.7 below. The conceptual innovation of this building lay in having services, such as its staircases, electrical power units, lifts and different sorts of pipes located on the outside, while the space inside is free from all of the infrastructural elements that are usually excessive in interiors.[43] This building has an interesting *inside-out* relationship to its material representation and its purpose. The fact that it is an insurance company is not apparent from its metallised façade, the aesthetics of which have greater

[42] Denis Compton (ed.), *Concerning Archigram*, Archigram Archives, London, 1999, 159.
[43] Kenneth Powell (ed.), *The Lloyd's Building: Richard Rogers Partnership – Architecture in Detail*, Phaidon, London, 1994, 53.

resemblance to an industrial factory.

Figure 1.7: Lloyds Building, Richard Rogers, London, United Kingdom, 1978-1986.

Different urban and architectural concepts, ones physically formalised and ones that are not, provide understanding about the social and cultural aspirations of the period in which they were created. Nowadays, with rapid technological development and the invention of new and advanced materials, the so called *technological utopias* of the past times have greater potentiality for realization.

1.2 Materiality

Materiality in architecture is concerned with the utilization of diverse and applied materials in building construction. Before the *Information Revolution*, the definition of materiality in architecture was quite simple because the materials to be applied were well known and had been used for construction for centuries. These are **natural** materials like: stone, earth, wood, brick, and later industrially created glass, iron, steel, concrete and plastic. Nowadays with the developments in the construction industry, followed by constant improvements in the technology of materials so called **smart** and **virtual** materials emerged. Smart materials are defined as multi-functional sophisticated material systems with the capacity to manifest active effects and maintain optimum conditions in response to environmental changes.[44]

[44] Yasubumi Furuya, "Reasearches of Smart Actuator Materials in Japan" in P. D. Mangalgiri, A. R. Upadhya and A. Selvarajan (eds.), *Smart Materials, Structures and Systems – ISSS-SPIE '99*, Allied Publishers, New Delhi, 1999, 23.

Some natural materials, like clay, have been substituted with others. For others, like brick, the production technology changed. Glass, concrete, steel and plastic are constantly being improved. In a continual search for new and more sophisticated materials some are created only to fulfil a certain purpose and be energy efficient while others can constitute additional layers and become more than passive construction elements. Natural materials will, however, always constitute the base of construction. This allows for possibilities in the novel fields of research that experiment with diverse ways of digital production by using natural materials in new ways. This parallel existence of digital and physical materiality can create, in cybernetic terms, a dialogue by which each is enriched through creative modes of interaction.[45] The emergence of so called *digital materiality*[46] should address different levels of human perception and induce intuitive understanding.

According to Gramazio and Kohler, the expression *digital materiality* does not have its root entirely in either the physical laws of the material world, such as gravity, or in material properties. This term is reinforced by the digital logic of the immaterial world, that is its processual nature or calculatory precision.[47] This implies that the interconnectedness of the material and the digital can lead towards new means of expression. This *digital materiality* is commonly regarded as immaterial, also noted by Gramazio and Kohler, yet the concept of digital immateriality is not tenable in so far as we can visualize the process of computation only when its representation is the result of a direct action. For example, we can say that digital processes are immaterial only because we cannot observe the electrons routed and diverted inside the computer as it functions in real time, but they still have an indisputable physicality. *Digital materiality* in architecture can therefore present, besides the new condition of digital production, the emergence of the new mode of materiality or digital micro-materiality whose most evident model is digital fabrication. The background for the new mode of materiality can be found in the work of Gottfried Semper, who emphasises how processes of textile production are essential for the fabrication of architectural elements and spaces.

The theoretical work of Gottfried Semper offers an interesting approach to materiality in

[45] Gordon Pask and Gerard de Zeeuw, *Interactions of Actors, Theory and some Applications_A Series of Volumes*, OOC/CICT/Universiteit Amsterdam, Volume 1 of this series, an introductory monograph Outline and Overview, Gordon Pask, Latest Edit. Nov.12.1992. Nov. 17th. 1992, latest dec 23 1992, Completed, June,1992. Filename.Gordonsbook, in WN.2.0.
[46] Gramazio and Kohler, *Digital Materiality*, 6.
[47] Ibid., 7.

architecture. He suggests that understanding of the material presence of the wall structure should be observed through textiles precisely because here the interrelation of matter and geometry is most visible. He makes a distinction between meaning (idea) and materials and therefore is critical towards those whom he calls *materialists* for tying to bond the meaning (idea) too tightly to a notion of the material. Semper states that architectural form is not determined solely by the material and structural conditions. For him, the material is not the only way for the embodiment of an idea in the physical world, which to a great extent relies on sensual cognition. Through form the idea becomes visible and the form should not be ambivalent towards the material out of which it is created. On the other hand, the material should not be spectacular in its appearance and so it should not add to the artistic appearance of the form.[48] The form and its materialization should accompany each other and relate to the original idea through clear expression. If the form already has a dramatic effect on the observer an additional spectacularity of the material can present the observer with a perceptive abundance.

Bernard Cache, one of pioneers in digital media and architecture, relates his work and theory with that of Gottfried Semper through their shared connection between technology and history. This, is related to anthropological aspect of Semper's conception of history. Focusing on Semper's theory, Cache summarizes it in four propositions: firstly, that technical arts are field in which architecture, among other fine arts, discovers its rudimentary motivation; secondly, that the four main technical arts are textiles, ceramics, tectonics and stereotomy;[49] thirdly, that textiles lend many aspects to the other three techniques of the four main technical arts and, fourthly, that the *knot* is the fundamental mode of textiles and consequentially also of architecture, because it corresponds to what in architecture is called the *joint*.[50] The complexity of Semper's theory is reflected in his further articulation of materials into four categories relational to their physical criteria. In addition he discusses how their structure and texture implies the potential performativity of these materials. Later he engages with what he calls *activities* or *procedures* among which are what we have previously mentioned as the

[48] Gottfried Semper in Andrew Benjamin, "Notes on the Surfacing of Walls: NOX, Kiesler, Semper" in Lars Spuybroek, *NOX: Machining Architecture*, Thames & Hudson, London, 2004, 163.
[49] Stereotomy is the science or art of cutting solids in to certain figures or sections, such as arches, and particularly it can mean the art of stone cutting
[50] Bernard Cache, "Digital Semper" in William W. Braham and Jonathan A. Hale with John Stanislav Sadar (eds.), *Rethinking Technology: A Reader in Architectural Theory*, Routledge, New York and London, 2007, 398.

four main technical arts.[51] Semper suggests that these materials and procedures should not be combined only in traditional way or in a way that is proposed by the historical usage of these materials but more freely through the many and mutual relations that connect them together. The importance of Semper's theory for digital materiality lies in his understanding of materiality as a processual mechanism with elements or discrete units that that can shape and articulate the structure composed of these units.

Semper explains that each technical art should be analysed from two directions, *the general-formal aspect*[52] and *the technical-historical aspect*[53]. The first concerns the purpose of what is created and the second makes a historical overview and analysis of diverse techniques used in the past to create the purposeful object. In his times, Semper's theory was based on four materials which he later expanded to six when glass and metal were added. Currently his theory could be formalised by complex structures containing new materials that have appeared, like plastic, rubber, concrete, etc. This means that if Semper's theory is applied through analysis of the collection of materials that can be accumulated today, it is possible to discover more interesting results in their conceptualisation in combination with the old ones. Cache finds Semper's theory potentially even more abstracted through the possibilities information technologies can offer. He proposes that textiles should be understood as procedures that can regulate material to go over and under, like the modem in information technology. In this way ceramics, which are distinct from pottery, could manage revolving the solids and operations concerned with radial coordinates. Tectonics can handle non-rotational transformations by forming in a Cartesian coordinate system. Stereotomy would than be the result of Boolean operations and could be comprehended as the art of finishing and paved surfaces.[54] These abstracted notions of architectural materiality and the combination of appropriate materials is related, among other things, to their application to the building's façade.

1.2.1 Materiality of the Façade

In architecture the choice of materials for building construction differs from those designated for the façade or for interior completion. The materials used for the

[51] Ibid., 398.
[52] Ibid., 399.
[53] Ibid., 399.
[54] Ibid., 403.

construction of the building's structure have to satisfy different attributes, such as resistance to pressure, tension and torsion forces. For example, brick that is used for wall construction has different qualities from those used for the façade. This can determine the porosity of a brick and therefore its mechanical qualities and statical possibility of being able to tolerate the pressure and tension of the construction bearing load. The selection of materials greatly influences the form of the building, which means that materials with greater flexibility allow the realisation of free forms to a greater extent. Materials arranged on the building's façade and on its interior walls have functional as well as aesthetic requirements because the façade represents the *face of the building*[55] towards the outside while the interior is the enclosed space within which people reside. These materials therefore reflect the beauty of the idea, give flavour to the building's concept and show the architect's intentions. They are therefore an important part of the design and determine its character.

Architects had started thinking about the façade as a conceptual premise at the time buildings were structurally developed enough to have thinner walls and therefore more openings and consequently more light inside.[56] After the Industrial Revolution[57] and under the influence of architectural movements, which glorified technological progress and extolled the development of glass, steel and concrete and influenced designs such as *Garage Ponthieu* (1905) in Paris by Auguste Perret, shown in figure 1.8 below. This was the first building that articulated the essence of construction with reinforced concrete, which frees the building's structure from heavy walls. Consequentially this new mode of construction allowed the façade to have more and larger openings.[58] The introduction of concrete and steel initiated the emergence of prefabrication in the construction industry. Later on *prefabrication* and *mass-production* processes resulted in exploration with the façade walls as much as with the functionality of the building. Designs created at Bauhaus, for example, were focused on how to produce most rationally the building and objects inside it, such as furniture and utility fittings, and the preoccupations with light and glass influenced creation of so called *Glasarchitectur* whose leading figure was Bruno Taut with his *Glass Industry pavilion* (1914) at the Werkbund exhibition in Cologne, Germany,[59] shown in figure 1.9 below.

[55] The word façade originate from French and means face of the building. See Johnson O'Connor and Human Engineering Laboratory (US), *English Vocabulary Builder*, Volume 2, Human Engineering Laboratory, US, 1948, 73.
[56] Reyner Banham, *The Architecture of Well Tempered Environment*, The Architectural Press, London, 1969, 132.
[57] Friedrich Engels, *The Condition of the Working Class in England in 1844*, Cosimo Classics, New York, 2008, 102.
[58] Banham, *The Architecture of Well Tempered Environment*, 40.
[59] Ibid., 124-132.

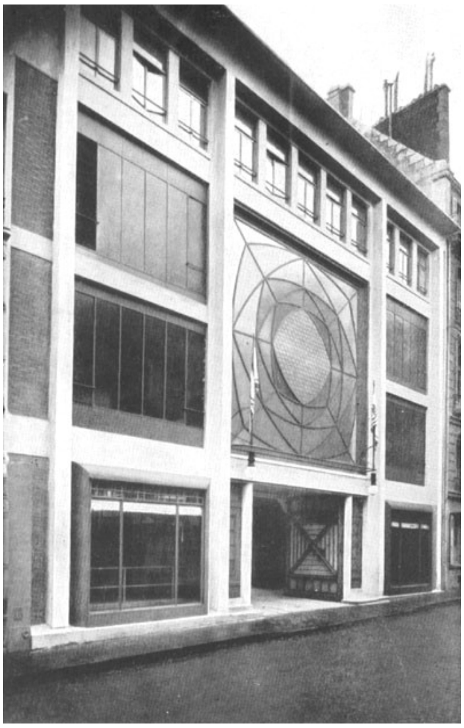


Figure 1.8: *Garage Ponthieu*, Paris, France, 1905.

Figure 1.9: *Glass Industry pavilion*, Bruno Taut, Cologne, Germany, 1914.

Later, the emergence of structural curtain-wall façades, as shown in figure 1.12 below, led to progress in the prefabrication of construction elements and new concepts in architectural designs of the de Stijl members, with Theo van Doesburg and Piet Mondrian as leading figures. Then Walter Gropius at Bauhaus and Gerrit Rietveld with the design for *Bioscoop Vreeburg cinema* (1936) in Utrecht, shown in figure 1.11 below, made the first attempt to illuminate the façade in a novel way. Mentioned façades will delineate developments in 20th century architecture and strongly influence the appearance of a new type and form of building: the sky-scraper.[60] Modularity and the flexibility of curtain-wall frontages will inspire explorations in the combined fields of media and architecture and will result in the emergence of different types of Digital Façades. These façades present a new mode of articulation of the building's outer surface and originate from technological developments in digital systems largely founded on explorations in new ways of hardware and software integration. In this regard, the prefabrication process marks the beginning of early notions of digitalization, because prefabricated elements present discrete units of construction.

[60] Kendra Schank Smith, *Architect's Drawings: A Selection of Sketches by World Famous Architects Through History*, PhD in History Theory Criticism and Representation, Architectural Press, Oxford, UK, 2005, 97.

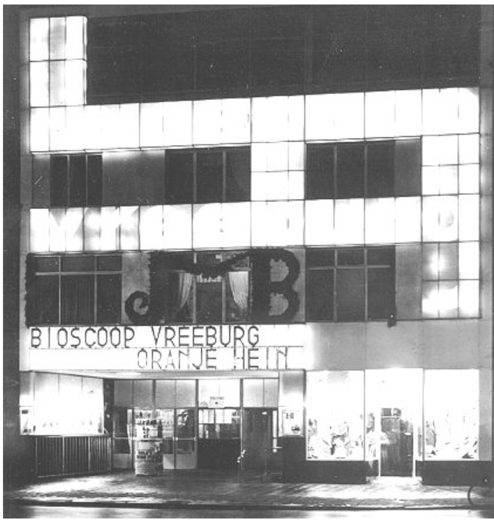


Figure 1.11: Gerrit Rietveld, *Bioscoop Vreeburg cinema*, Utrecht, The Netherlands, 1936.

Figure 1.12: Example of glass-curtain-wall façade, Le Corbusier and Oscar Niemeyer, *UN Headquarters*, New York, USA, 1950.

1.2.2 The New Materiality of Digitized Fabrication Processes

The re-appropriation of activities distinguished during and after the Industrial Revolution resulted in the appearance of **virtual** materials that offer combinations of the different media printed or projected in unusual ways onto **natural** materials by means of evolving digital technology. Without primary utilisation of natural materials architects would be unable to find an appropriate application for their use. The difference between natural and virtual materials depends on the way the environment is perceived. Virtual materials add an extra layer to the aesthetic qualities of natural materials due to their texture, colour, tactile qualities, etc. An additional digital layer contains several different meanings besides the silent meditative character of pure natural materials. Consequentially this additional layer of virtual materiality induced the emergence, among other things, of Stephen Parrella's hypersurface architecture.[61]

Formerly, new technologies, like the telegraph, telephone, typewriting machine, camera, printing-machine, tape-recorder, radio, computer, etc. opened a whole range of explorations in the artistic, social and cultural fields. The products of these technologies (pictures, photographs, prints and reliefs), only recently started to inspire architecture, especially with the appearance of computer and digital technologies. Processes of

[61] Stephen Parrella (ed.), "Hypersurface Architecture II", *Architectural Design*, Volume 69, Issues 9-12, John Wiley & Sons, London, 1999, 81.

prefabrication and mass-production gained new equivalents in *digital fabrication* and *mass-customization*. Digital fabrication is a computerised process of production performed by machines that can create objects described by digital data through utilisation of automatised processes. These machines are called digital fabricators or *fabbers*. They are 3D printers or rapid prototyping machines.[62] Mass-customization offers a combination of flexible Computer-Aided Manufacturing systems and the low cost of mass-production allows each produced unit to be customised.

The concept of mass-customization was anticipated by Alvin Toffler in his book "Future Shock" in 1970, in which he asserted that the democratic ideal is to offer the utmost individual choice and he declared his anxiety about the emergence of standardized mass culture and lifestyles.[63] The term itself was apparently coined by Stanley Davis in 1987 in his book "Future Perfect", in which he depicted the world of mass customization as one of paradox with practical implications. This is because, whether it is a product, a service, a market or an organization, each is understood to be simultaneously part, or customized, and whole, or a mass. In order for there to be mass customization of markets, and for products or organizations the technology has to be such as to make it economically feasible in every case.[64] In 1993 Joseph B. Pine II systematized the general methods of mass customised products and services. He regarded mass customization as a synthesis of two long competing systems of management: the mass production of individually customised goods and that of services.[65] For Masa Noguchi mass-customization, if viewed as a 'system' for design, cannot occur without customisable products or communication services.[66] Noguchi conceptually formulates the *mass customisation system* in a formula [MC=f(PS)], in which P is the product or sub-system facilitating housing suppliers to mass-produce housing components, S is the service or sub-system involving interaction with users that assists in customising the end product, and MC is the product or resulting mass customisation system.[67] This model emphasises the interrelationship between products

[62] C. K. Chua, K. F. Leong and C. S. Lim (eds.), *Rapid Prototyping: Principles and Applications*, World Scientific Publishing Co. Pte. Ltd., Singapore, 2003, 160.
[63] Alvin Toffler, *Future Shock*, Bantam Books, USA, 1984, 9.
[64] Stanley M. Davis, *Future Perfect*, Addison-Wesley, Reading, Massachusetts, 1987 and 1996, 84.
[65] Joseph B. Pine II, *Mass Customization: The New Frontier in Business Competition*, Harvard Business School Press, Boston, USA, 1993, 43.
[66] M. Noguchi and C. Hernandez, "Mass Custom Design, Approach to Upgrading Traditional Housing Development in Mexico", *Journal of Habitat International* 29, 2005, 325-336.
[67] M. Noguchi and A. Friedman, "Mass Custom Design System Model for the Delivery of Quality Homes: Learning from Japan's prefabricated Housing Industry", *Proceedings of International Council for Research and Innovation in Building and Construction*, Syllabus Joint Conference: Measurement and Management of Architectural Value in Performance Based Building, Hong Kong, 6-10, 2002a, 229-243.

and services, indicating that these elements are not mutually exclusive.[68]

Figure 1.13: Detail from the *Herculaneum depicting Amphitrite* mosaic

Figure 1.14: *Battle of Lepanto* in stucco, Palermo, Italy

Figure 1.15: Mural wall in Philadelphia

Information layering is not novel in architectural formal approaches because even before Modernism there was a tendency towards *imitation*, which means to resemble visually the texture and colour of marble by using wood, for example. As a process, imitation in architecture relates to the process of *skeuomorphism* and conceptually to the idea of remediation as will be discussed in the fourth chapter. The historical correspondence of the tendency towards imitation and the initiation of an early remediation in architecture can be found in *mosaic* art which creates of images on walls, floors or ceilings using small pieces of coloured glass or stone[69] (see figure 1.13 above). Then *stucco* techniques, consisting of mixtures of lime, cement and sand, enabled plasterwork to be used for the fine external decoration and ornamentation[70] (see figure 1.14 above). *Murals*, in which a painting or other art form is placed on large permanent

[68] Masa Noguchi, "Mass Custom Home: The Mass Custom Design Approach", MEARU, Mackintosh School of Architecture, The Glasgow School of Art, 2, Retrieved March 23, 2009, from http://www.masscustomhome.com/.
[69] Austen Henry Layard, "On Mosaic Decoration" in *Papers Read at the Royal Institute of British Architects*, Session 1868-1869, Printed at the rooms of the Royal Institute of British Architects, London, 1869, 31-57.
[70] William E. Wyatt, "General Architectural Drafting", The University of Michigan, C. A. Bennett Co., Peoria, IL, USA, 1976, 238.

surfaces like walls and ceilings,[71] (see figure 1.15 above) is also significant. Yet, the surface treatment in architecture gained a new formalization with the introduction of digital technology.

1.2.3 Virtual Materiality and Smart Materials

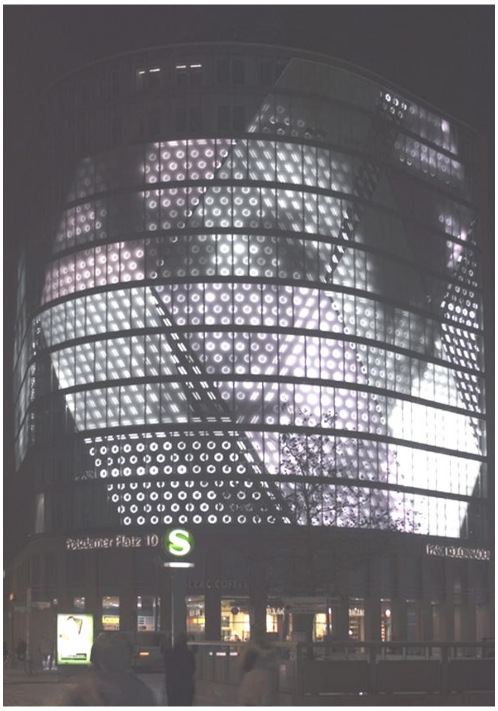


Figure 1.16: An example of the Digital Façade, *SPOTS* façade, realities: united, Potsdamer Platz, Berlin, 2005.

Unlike those in the past, today's virtual materials make possible an enrichment through digital culture and by overlapping new kinds of craftsmanship are created. In the past craftsmanship was about handling real and tactile materials but now it is as much to do with simulated and virtual materials using hardware and software as a medium. *Virtual materiality*[72] emerges from these processes as an interplay between simulation and representation. Katherine Hayles discusses how the delicate line between the virtual image and one that has an equivalent in the real world emerges into virtual materiality. Through time, what was once a picture or a relief printed or attached to a wall now becomes numerous pictures displayed on one screen surface, as shown in figure 1.16 above. This gave the wall a completely new aesthetic dimension as a primary element in architecture that had previously reflected only a particular style, dependant on the time of construction, the architect's ideas, materials employed, the client's financial

[71] Mary Korstad Mueller, *Murals: Creating an Environment*, Davis Publications, Worcester, Massachusetts, 1979, 38.
[72] Hayles, *Writing Machines, 38.*

circumstances, etc. Digitalization brought the possibility for multiplicity and introduced the qualities of moving images and the spectacularity of film to be combined with architectural elements such as façade walls. Once seen as having a static composition, the façade wall now achieves an effect of fluidity and dynamics on the environment.

A step forward in the evolution of digitally augmented materials occurred with so called **smart** materials and more direct implementation of digital technologies. Smart materials sense and respond to changes in their environment. They have diverse physical properties, such as viscosity, conductivity or volume, which can be substantially altered over time due to diverse physical determinants, such as applying small differences in temperature or changing electric and magnetic fields. Existing smart materials include thermo-responsive, magneto-rheostatic, piezoelectric, electro-rheostatic, electro-chromic, photo-chromic and thermo-chromic materials and shape memory alloys.[73] If mechanical stress is applied to piezoelectric materials they can generate a faint electric current. In wide use are piezoelectric microphones, which can transform alterations in pressure caused by sound waves into an electric signal. Thermo-chromic materials can change colour in response to changes in temperature in their immediate surroundings, while photo-chromic materials can change colour as a consequence of changes in light conditions in the environment. Shape memory materials can remember their original shape after it has been deformed and return to it when heated. Electro-rheostatic and magneto-rheostatic, also called magneto-rheological, materials are fluids that can change into solids when placed in magnetic or electric fields. These can be fitted into buildings or bridges in order to prevent destructive natural events, like earthquakes or high winds.[74] This group of materials also comprise so called *self-cleaning* or *super-hydrophobic* materials that combine features like waxiness and a range of microscopic bumps, only a few microns in size, cover them and prevent water from infiltrating the material.

These materials present different developments in nano technology and self-aware materials based on, among other things, their chemical structure. The new materiality emerged from a combination of previous substances and was developed to involve new modes of interaction between those substances able to work not only with each other but

[73] Educational Software for Micromachines and Related Technologies (eSMART), "Smart Materials", 2, Retrieved March 28, 2009, from http://www.cs.ualberta.ca/~database/MEMS/sma_mems/smrt.html.
[74] Parliamentary Office of Science and Technology, 1, Retrieved March 28, 2009, from http://www.parliament.uk/documents/upload/postpn299.pdf.

also with an electronic potentiality for transference or for directing programmed electronic flows. Consequentially the new materiality provides for ways other than the traditional ones for materials to be perceived. This creates a basis for modification of the representational qualities of materials and for changing their practical applications in architecture. Nowadays, with the scientific research and an accelerating development of new kinds of materials, it can be said that so called *soft-materials* are gradually introduced into the construction process in different ways. Soft-materials are essentially electronic or chemical particles usually not visible to the naked eye and because of this often called *invisible* and *non-material*.

1.2.4 Materiality of the Digitized Surface

Materialization in architecture is tightly bound with the notion of *surface*, or the external skin of the building. The skin/surface is interesting because it presents a boundary between interior and exterior, between virtual and physical materiality. It symbolizes a border between secure and unprotected space. At the moment a building’s surface gains autonomy and independence of other structural elements; it becomes a *free façade*,[75] in technical terms known as a *structural curtain wall façade*. The discovery of the free façade was accompanied by transformations in its tectonic and material qualities, as previously discussed. Interestingly, the surface can also be explained in terms of *envelopes* and *skin*. The descriptions of the surface in this way directs the discussion to a more performative, technical, programmatic and environmental way of speaking about the term. In this regard, Marcos Novak proposes the notion of Transarchitectures and Hypersurfaces, which as a conceptual bridge between the solid architecture of Modernity and the ephemeral architecture of the virtual relates to the idea of the *transmodern*. In this way Novak refers to spaces created computationally inside the computer that continuously unfold conceptual spaces.[76] Another interesting comprehension of a digitized surface, as mentioned previously, is Stephen Perrella's notion of hypersurfaces, which comprise different superimpositions onto complex topological surfaces and electronic imagery. Furthermore, Bernard Cache in his “Plea for Euclid”, provides a good account of how the topological resources of Euclidean geometry are available for architectural design.[77] With the emergence of new

[75] David Leatherbarrow and Mohsen Mostafi, *Surface Architecture*, MIT Press, Cambridge, Massachusetts, 2005, 8.
[76] Marcos Novak, “Transarchitectures and Hypersurfaces” in Perrella, *Hypersurface Architecture*, AD, 47.
[77] Bernard Cache, “Plea for Euclid”, 1, Retrieved October 10, 2010, from http://architettura.supereva.com/extended/19990501/index_en.htm.

materials, such as Fabcell, Sensacell, Super Cilia Skin or Sun-Tec Film[78], it is possible to develop a new set of relationships with people and materials based on direct interaction. This is what Andrew Benjamin identifies as a material event in a form of a surface and which he regards as the moment when the interconnectedness between programme, geometry and the materials occurs. For Benjamin, the notion of 'event' conveys an opportunity for the singular to be conceived so that the particular change of integrity between geometry, programme and materials resists any form of generalisation except as an abstraction and thus as a diagrammatic representation.[79]

Interestingly the concept of singularity in mathematics relates to the general point at which a given mathematical object is not defined, or the point at which a particular collection of objects, considered as unified in an object in its own right, miscarry the instruction and act in antithetical way.[80] This means that singularity represents a point at which an equation or a surface explodes or become degenerate.[81] Singularity theory in mathematics is the study of the omission within the manifold structure.[82] This structure presents a mathematical space in which every point has a neighbourhood that resembles Euclidean space but in which the global structure may be more decomposable. [83] Manifolds are spaces without singularities which those occur through degeneration of manifold structures. This degeneration is, in mathematical terms, a limiting case in which a class of object changes its nature and begins to belong to another, usually simpler, class. For example, a point is a degenerate case of a circle when the radius approaches 0, a circle is a degenerate case of an ellipse eccentricity approaching 0, etc.[84] In this way, through changes in the object's condition, when a radius that had positive value and in time approaches 0, the object changes its qualities and by so doing transforms into an object with simpler parametric values. This can be related to the question of virtual materiality present during the construction of a three-dimensional representation of a building by means of 3D software.

[78] *Fabcell* is a fabric that changes colour when conducting an electric charge; *Sensacell* is a dynamic interactive surface that can detect people or objects up to 2 inches form its surface and react; *Super Cilia Skin* is a tactile and visual system that consist of an array of computer-controlled actuators that are anchored to an elastic membrane; *Sun-Tec Film* is a electro-conductive transparent film that contains small mounted electronic devices like LED’s and infra-red sensors. See Blaine Brownell (ed.), *Transmaterial 2: A Catalogue of Materials That Redefine Our Physical Environment*, Princeton Architectural Press, New York, 2008, 72.
[79] Andrew Benjamin, “Notes on the Surfacing of Walls“, in Spuybroek, *NOX,* Thames & Hudson, London, 2004, 342-343.
[80] Ray Kurzweil, “Superintelligence and Singularity” in Susan Schneider (ed.), *Science Fiction and Philosophy: From Time Travel to Superintelligence* , Wiley-Blackwell, Oxford, UK and Malden, MA, USA, 2009, 215-216.
[81] WolframMathWorld, “Singularity”, 1, Retrieved May 15, 2009, from http://mathworld.wolfram.com/Singularity.html.
[82] Kurzweil, “Superintelligence and Singularity” in Schneider, *Science Fiction and Philosophy*, 216.
[83] Richard Bishop and Richard Crittenden, “Geometry of Manifolds”, American Mathematical Society, USA, 2001, 2.
[84] WolframMathWorld, “Degenerate”,1, Retrieved May 15, 2009, from http://mathworld.wolfram.com/Degenerate.html.

For example, a point in space is defined with three coordinates (x, y and z) in a Cartesian system. It has three numeric values assigned to it. Circle, as the more complex, is defined by Centre, which also has x, y and z, and its Radius. When circle degenerates into a point it looses a radius or it loses one of the parametric numeric values that describe it. In this regard, it can be said that a singularity is a state of change, an interactive process of transformation/degeneration from one form to another where each form has distinct but changeable values. Consequentially the simplest form is a point. Illustrative examples of singularities can be found in the *projections* of three-dimensional objects onto two dimensions, as inside our eye when we see a projection of reality re-created by our visual apparatus but do not perceive reality as it is. Another example is *caustics,* which present an envelope of light beams either reflected or refracted by the manifold,[85] in a way similar to the patterns emitted light produces at the bottom of a swimming pool. If we consider our reality as manifold and variation of singularities as a disturbance in this manifold and if we create a cybernetic architectural environment resembling mathematical abstracted space, we could produce these singularities through their material changeability and interaction and so unfold a whole new scope of interactive space formulation.

The potential Cache sees lies in creating CAD software which would perform abstracted procedures described by Semper. If electrons could be activated to perform different procedures through the different materials they operate with, these procedures could be controlled by the software. Spaces that can be created through the mechanisms of software can be referred to as *anexact spaces*[86] or spaces that do not have precise metrical value but emerge from relationship-based distances of particles, for example. These non-quantitative spaces do not have a traditional height, width and length but are determinable through the relationships of the elements in the space. DeLanda distinguishes these spaces as characterised not only by a set of points, in a mathematical sense, but also by the proximity between them and the relations that define this proximity which, in combination with the points, can form a neighbourhood. He notices that the space is described as metric, which can be curved in non-Euclidean or flat in Euclidean geometry, in case the proximity is defined as a minimum length. In this case

[85] Christopher G. Morris (ed.), “Academic Press Dictionary of Science and Technology”, Academic Press, London, 1992, 379.
[86] Manuel DeLanda, “Materiality: Anexact and Intense” in Spuybroek, *NOX,* 371. Interestingly, DeLanda knows such material through his experience programming MAYA.

the neighbourhood can be formed with points that are less then a given distance away from a centre. In this regard the space is described as non-metric, as in differential, projective or topological geometries, if different criteria are used in specification of the proximity between the points and the choice of parameters by which specific groups of points are close to another group.[87]

The potentiality of this theory lies also in its application to the creation of new materials. If we take an atom of some substance and say that it can form matter by multiplying and composing itself according to a procedure able to regulate it to go over or under, as Semper suggests, new material can be created. One procedure can control the positioning of an atom in the imaginary structure, another can determine the criteria for the proximity of atoms, etc. The operation and combination of these procedures may create a non-metrical space that is still physical in its substance, as it is composed of self-regulating atoms. Space could be generated and composed of molecules through another procedure that can determine what kind of composition or neighbourhood these molecules can compose. For example, these procedures may be defined through forces, like magnetism. This kind of space can be build in an animated and dynamic way, in continuous change between solid and fluid states. In this case, matter would be composed of different or the same molecules able to communicate between themselves by means of software applications that control and execute written procedures. New procedures would then determine the proximity of the molecules not only in terms of the distance between them but in how they relate to each other through molecular intercommunication.

1.3 Digitization

Digitization is a process that is not inherently calculable but happens through computational means of interpretation. The objective of interpretation is the translation of code integrated in a constituent, which can be an image, object, word, sound, signal, etc., into a meaningful form able to be read by both humans and computers. A distinct number of people perceive computers as artificial simulation engines, which does not mean that processes of simulation that operate inside it are entirely artificial in character. These processes can be considered natural but run in an artificial medium, as

[87] Ibid., 371.

Artificial Intelligence researchers note.[88] Hayles's interpretation of Talan Memmott's text “Lexia to Perplexia” gives an interesting view of humankind's involvement in the process of digitization. Hayles notes that computers are much more than an assemblage of hardware and software; they are simulation machines that produce *environments*, from objects that sit on desktops to networks across the globe. In her opinion, to construct an environment makes it possible to anticipate and structure the user's interaction with an environment and in this sense to construct the user as well as the interface.[89] Hayles's understanding of an *environment* is that it is a construction for the creation of imaginary worlds in which engagement occurs through a range of sensory inputs that structure bodily interactions with a simulated environment. An environment becomes simulation relative to the modes of interaction that happen between the user and it.[90] The sorts of environments Hayles talks about are virtual and are created to offer forms of literary and narrative engagement with fictional worlds, as in computer games. In this thesis, the term *environment* refers to the digitally augmented architectural space that through multiple feedback loops creates playful and engaging interaction with the participant.

An information exchange formulated through algorithmic feedback loops between computers and humans raises questions of embodiment and the level of engagement with the digitized material necessary for continuous interaction to emerge. An interesting question occurs about the level digitization reaches not only in the environments people use and through the limits of visual imagery people can perceive, but also in the complex processes of metamorphosis people experience through digitized physical environments. Digitization reinvented interaction in the sense that the subtlety and sophistication of this process transformed what was unrefined and mechanical into an engaging, elusive and fluid experience. This implies the creation of cybernetic architectural environments, as well as environment creation through the use of software in the architectural design production. Environments/buildings created in this way are simulations of the physical world that are to be build. The digital materiality of these environments is formed through images, which can be raster and vector based. Vector images are based on mathematical formulae while raster have a finite set of digital values, which are called pixels mapped within the grid on a screen.[91]

[88] Hayles, *Writing Machines*, 48.
[89] Ibid., 48.
[90] Ibid., 49.
[91] Longin Latecki, “Discrete Representation of Spatial Objects in Computer Vision”, in *Computational Imaging and*

Vector and raster digital qualities of images present materialization instruments for different stages of the architectural design, as will be discussed in the third chapter. They also concern the use of different file formats and extensions.

Relative to the specific digital form described through the file extension, the computer recognises the appropriate software application(s) within which a certain file can be opened. This means that the computer interprets the file type and the quality of data stored inside it by means of the file extension name. Another aspect of digitization is to transfer information in different file formats. In this way, the same file may be opened in several software applications with the same efficiency and with same file properties that can be transferred to create other degrees of information.[92] This effect of digitization is important for the production of architectural drawings which need to use several software applications, such as combinations of applications for two-dimensional drawing, three-dimensional modelling, or the rendering and creation of illustrative images in software applications. Considering that architectural design commonly needs large files, different options and functions are contained in the distinct software offered. For example Microstation, introduced novel conceptual properties, such as *reference files*, that can enable the redirection of information and helps handling large file sizes without additional CPU usage. An increase in the number of possibilities through digital production introduced a diversity of representational qualities within an image. Filters, that is the functions which execute nominal sequences of commands (in Photoshop or Illustrator for example), make it is possible to create visual effects that were impossible with hand-drawing.

This means that the digitization of the architectural design production includes software applications, which are collections of computer procedures, programmes and documentation written and designed for specific tasks operated by means of a computer.[93] There are different software applications that are used in architectural design, from two-dimensional drawings and three-dimensional geometric modelling to parametric design and digital fabrication. Parametric modelling is interesting because it presents an evolution in drawing production resulting from new modes of interaction

---

Vision, Kluwer Academic Publishers, Dordrecht, The Netherlands, 1998, 149.

[92] Denis McQuail, *Mass Communication Theory: An Introduction*, Thousand Oaks, Sage Publications, London, 1994, 106.

[93] P. C. Clements, “From Subroutines to Subsystems: Component-Based Software Development”, *The American Programmer*, Volume 8, Number 11, 1995, 19.

with the elements of a drawing, and also because it can establish and change relations between these elements. In terms of digitization, parametric design also includes a novel use of databases, without which this mode of interaction would not be possible. According to Timon C. Du, the database is a repository for related data and does more more than data maintenance as is the case for the traditional filing approach. For him a database should be able to maintain data, preserve a self-describing nature, share data among multi-transactions, and provide support for multiple views of data. In the period from the 1970s and 1990s, the hierarchical database model and the network database model were in most application areas replaced by the relational database model.[94] During this period, another important point of reference was the emergence of the *object-oriented databases*. This was initiated by the need for data-intensive applications, such as Computer-Aided Design and Manufacturing (CAD/CAM), Computer-Aided Software Engineering (CASE), Office Information System (OIS) and Computer-Integrated Manufacturing (CIM). In the field of database evolution the developmental direction is towards storage of more complicated data and using databases in other activities, for example an active database may not only be perceived as a passive data storage, but as one able to monitor environmental conditions.[95] This aspect of digitalization is important for the creation of cybernetic environments, digital façades and architectural design process, which will be discussed later, because in real time it influences possible developments in these fields.

The creation of database systems for information storage, also, enabled digitized collaborative documentation that simplified work on conjunct projects, such as architectural design. This improved the organization of work flow through the creation of task specific folder structures and the file reposition within them. An important digital property for architectural collaborative process is that all participants use the same file formats in order that everyone has access to the information and the chance to alter it. The next step in the representational shift from paper to screen was the expansion and relocation of the screen to the surface of the building façade and augmenting urban space with new modes of idiomatic characterisation of space. *Urban Screens* is the field of research that deals with the influence of screens on the urban environment. In order to understand how digitization influenced architecture it is

[94] Timon C. Du, "Emerging Database System Architectures" in Cornelius T. Leondes (ed.), *Database and Data Communication Network Systems: Techniques and Applications* , Volume 1, Elsevier Science, San Diego, California, USA and London, England, UK, 2002, 1-2.
[95] Ibid., 8.

necessary to address the concept of customisation.

1.3.1 Customisation as Digitization Process

The core advantage of digitization is the possibility to repeat the same result a number of times without a change in the quality of outcomes and with an option of a circumstantial variation in each result. A direct outcome of this is a customization that allows a consumer product to be tailored. Customisation satisfies customers' requirements by using non-standard components. This usually means that the core component of the product and design remains standard and the options are subject to modification.[96] The aspect of *tailoring* the product is not new and first appeared with Taylorism[97] or *Scientific management*, a theory developed by Frederick Winslow Taylor who thought that management decisions should be done by precise procedures developed after research into individual behaviour at work in order to optimise work tasks. By applying this method the work flow became repetitious and incoherent. It is also closely associated with the *mass-production methods*[98] introduced by Henry Ford in the early 20th century in which standardised products are made on a production line. It results in high rates of production per worker and results in a large number of low-cost products.

Standardisation was introduced into the construction industry with the process of prefabrication that enables the manufacture of the building's standardised elements beforehand in a factory which are then quickly assembled on site.[99] Prefabrication can be seen as an early notion of digitization because elements of it involve discrete units of construction. This allows codification of the construction elements and the creation of specification documentation, similar to the table of rules in a Turing machine, which determines how the construction elements will be assembled. The result is that modern life becomes saturated with digital products, such as computers, Internet, digital (photo)cameras, mobile phones, GPS devices, I-phones, I-pads, I-pods, game consoles, etc. Digital saturation went beyond a simple use of the display and sharing of

---

96 Masa Noguchi, "Mass Custom Home: The Mass Custom Design Approach", MEARU, Mackintosh School of Architecture, The Glasgow School of Art, 2, Retrieved March 23, 2009, from http://www.masscustomhome.com/.
97 David Harvey, *The Condition of Postmodernity: An Enquiry into the Origins of Cultural Change*, Blackwell Publishing, Malden, MA, USA, Oxford, UK and Victoria, Australia, 1990, 66.
98 Ibid., 67.
99 Alistair G. F. Gibb, *Off-Site Fabrication: Prefabrication, Pre-Assembly and Modularisation*, John Wiley & Sons Inc., New York and Toronto, 1999, 2.

information. It became so interwoven into everyday life that it is almost impossible to imagine life without surveillance cameras, traffic control systems, swipe cards, bar codes, biometric readers, etc. In all of this electromagnetic sea of information we float as futuristic biological codification of a homotechnicus.

Architecture, electronic environments and transportation infrastructure all originate in the distinctiveness of cities and symbolize places where the communication takes place. Broadly implemented digital technologies with the greatest influence on society are those at airports, traffic infrastructures, hospitals, universities, museums, libraries, banks, etc. The current intensification of the mathematisation of space and spatial processes no longer allows us the option to treat cities in a simple modernist manner. It means that within cities there is a chain of overlapping and constantly changing digital processes and complex systems. A city today consists of an almost infinite network of agents and discrete instruments that measure, control, track, guide, navigate, etc. Cities, as cultural heritage, present far more complex systems than those we actually recognize in everyday life and we use many of their utilities on a global and local scale. With their fine stratum of digital attributes they become a mixture of materialities in the form of buildings, built over thousands of years, and the emerging layers of invisible electromagnetic noise visualized through GPS mapping and art projects.

Examples in the field of locative media are Amsterdam Realtime,[100] Bio Mapping[101] or Urban Tapestries[102] and digitalization became interlinked with our lives to a such a degree that in time it becomes concealed. This means that it becomes habitual in the way that people stop to notice the ways in which life habits change under its influence. This habituation acquires its form in different types of software applications, such as those for traffic control, the regulation of congestion density and possible collision zones within the city, to regulate driving speed on highways, and regulates complex infrastructural systems like metro and train traffic within large cities like London or Tokyo, etc.

[100] Waag Society, “Amsterdam RealTime”, 1, Retrieved May 16, 2009, from http://www.waag.org/project/realtime.
[101] Bio Mapping , 1, Retrieved May 16, 2009, from http://biomapping.net/.
[102] Urban Tapestries / Social Tapestries – Public Authoring and Civil Society in the Wireless City, 1, Retrieved May 16, 2009, from http://urbantapestries.net/.

1.3.2 Digitization of the Environment

In architectural terms and through its scale, which involves interaction with the immediate building's surroundings, the influence of digitalization is present through so-called *ubiquitous* or *pervasive* computing. This is computing spread through an overall environment by means of miniaturised computers,[103] which is achieved through the integration of microchips into objects of everyday use and so influences everyday activity and changes how humans deal with reality. This paradigm envisions computers located everywhere in the environment in various appearances and magnitude rather than being restricted to the desk-top computers. It also involves a number of participants using many computers rather than on person using one computer, so the possible interaction can be on multiple levels. The geographical disposition of participants may be different as they could be located in different parts of the world and participate in the event.[104] As a standardisation of pervasive computing, the National Institute for Standards and Technology in 2000 defined it as a collection of a casually accessible number of concealed computing devices, which are frequently mobile or embedded in the environment and connected to an increasingly ubiquitous network structure.[105]

Research in this field started with Mark Weiser at Xerox Paolo Alto Research Centre[106] and today it has spread through scientific, architectural and artistic explorations of communication and computation utilization. Architectural involvement is present, mostly in terms of performing utility services, like opening a door or switching on the lights as one walks into a room, and then through provision of different kinds of information about current temperature, air humidity, etc. These services can be divided into two groups: a) one that requires an action of *pushing a button* in order to interact and get feedback and b) one, more spontaneous, comprises different sensors used to react to body gestures or movement. Feedback can be automatically provided without the consent of participants, which provides assistance in the performing of a voluntary action. The consequence of these functional solutions can be various, from essentially accommodating those that can induce the hibernation of the participant's activities and in this way cause habituation of the current perception of reality. Computational devices

[103] Mark Weiser, "The Computer for the 21st Century", *Scientific American*, September 1991, pp. 94-110, Retrieved October 17, 2010, from http://www.ubiq.com/hypertext/weiser/SciAmDraft3.html
[104] Mark Weiser, "Some Computer Science Issues in Ubiquitous Computing", Communications of the ACM, July 1993, 45, Retrieved October 17, 2010, from http://www.ubiq.com/hypertext/weiser/UbiCACM.html
[105] Malcolm McCullough, *Digital Ground*, The MIT Press, Cambridge, Massachusetts and London, England, 2005, 7.
[106] Mark Weiser, "Ubiquitous Computing", 1996, 3, Retrieved April 15, 2009, from http://www.ubiq.com/hypertext/weiser/UbiHome.html.

of an accommodating nature incorporated in the environment can assist elderly people or those with disabilities to perform everyday routines. On the other hand, devices embedded to help with the performance of very simple tasks, like opening a door, can cultivate new human cultures which will over a period of time neglect the gesture of opening the door because there will be no reason to learn how to do it.

Adam Greenfield suggests that care has to be taken with the embodiment of these high technological artefacts[107] in our surroundings because of our inability, as a culture, to channel the complexity, subtlety and richness of everyday life into merely functional objects. Greenfield suggests that problems can occur with an attempt to redefine and remodel the complex relationships we have with other people and the environment through technological assistance that has no means of situation evaluation or ability to make decisions. This complexity becomes even more disturbing because the experience and conditions of life are under constant change, in constant flux. By redefining certain aspects of life and establishing them through technological means humans can restrict their possibilities for direct involvement with each other and the environment if communication becomes constantly mediated through or capsulated in digital objects like mobile phones, laptop computers or iPod's.[108]

An increasingly emergent coexistence between the built and mediated reality, first distinct in its macro materiality and then in its micro or soft materiality, brings new modalities of social involvement into the public domain. The two realities are intermingled with each other on such a scale that it is very hard to distinguish clearly between what belongs to one or to the other. In this regard, digitalization has generated new means of surface treatment in architecture. It has revived the use of ornamentation with a modern application and has introduced novel patterns on façade walls, sometimes applied as simple prints, in the case of Herzog's and de Meuron's *Library* in Eberswalde, Germany, shown in figures 1.17 and 1.18 below, or as bas-relief, as in case of Wiel Arets's *Library* in Utrecht (see figures 1.19 and 1.20 below). Another novelty is that the surface is no longer observed as static, in the visual impression it makes, but as fluid and changeable. Earlier examples were passive attempts because the material used was not augmented with the digital materials, so it did not have any performative

[107] Adam Greenfield, *Everyware: The Dawning Age of Ubiquitous Computing*, New Riders, Berkeley, CA, USA, 2006, 3.
[108] Interview with Michael Bull, 5, Retrieved May 16, 2009, from http://agents.sci.brooklyn.cuny.edu/scp50/papers/prof-ipod-25feb04.pdf.

qualities. The material is static and not interactive, but the picturesqueness of the façades came directly from the pattern forming tendency reflected in its repetitive attributes, which characterise computer generated images. It attempt to make an undynamic representation of a moving picture on the wall of the façade.

Figure 1.17: *Library* in Eberswalde, Germany, Herzog and de Meuron, 1999. Figure 1.18: Façade detail.

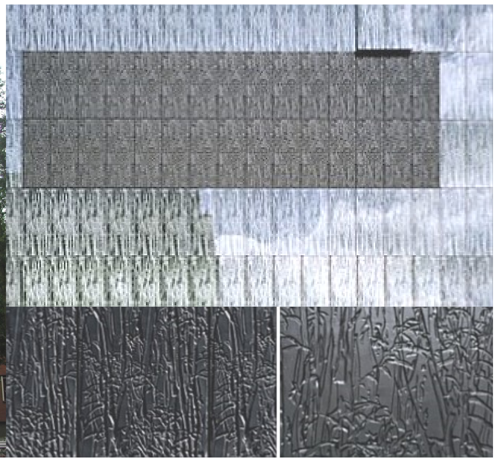


Figure 1.19: *Library* in Utrecht, The Netherlands, Wiel Arets, 2004. Figure 1.20: Façade detail.

As an evolutionary step in the utilisation of pictures and patterns as architectural elements on a building's façade, is augmentation of the façade with digital screens, as one mode, and integration of interactive kinetic elements as another. This resulted in the emergence of so called *digital façades*, to be discussed in the fourth chapter. The current hype about public spaces and the augmentation of façades with digital screens has its root in the human need to know and inform themselves about the immediate or distant environment. Modern man overlaps space with different degrees of information although this is no longer essential for his survival and often is nothing but entertainment. One bothersome consequence of this fusion between physical and digital is the hypnotic influence screens can have on the observer in public spaces. Whether necessary or not, this information is brought to the observer with intense velocity. The surface becomes layered with information so forming digital displays which contain not one image at a time, but hundreds which are selected without any kind of meaningful criteria.

At times, screen surfaces in the public domain can be distracting and therefore unsafe. Just as industrialists did not take responsibility for the pollution of the city caused by the smoke and grime of factories, so those who pollute space with unnecessary information do not take responsibility for the kind of influence this can have on people. McCullough notes how proactive information feeds invade the quiet time and space as something that needs filling. There are a number of portable and embedded devices that can take data streams from a computer screen into the world, making them difficult to turn off.[109] In 2003 Jakob Nielsen highlighted the significant impact information pollution has on people while defining it as *information overload taken to the extreme*. He considers that an absence of information prioritisation mutates the Internet into a *procrastination apparatus*.[110] If information pollution on the Internet and through email exchange has a time consuming dimension that distract us from our work because there is a limit to the amount of information we can process before decision making deteriorates, raising a serious question about the kind of impact it will have when it becomes an inherent condition in the physical environment in which different sorts of actions are barely controllable.

1.4 Interaction

Interaction has a presence in other sciences but is also a term frequently connected with computer science as HCI or Human Computer Interaction.[111] Human-computer interaction may be said to be a responsive state of existence that provides for an action-

[109] McCullough, *Digital Ground*, 17.
[110] See Interview with Jakob Nielsen, 3, Retrieved May 16, 2009, from http://news.bbc.co.uk/1/hi/technology/3171376.stm.
[111] Brenda Laurel (ed.), *The Art of Human-Computer Interface Design*, Addison – Wesley, Reading, MA, USA, 1990, 58.

reaction kind of relationship: individual action is connected with an object's or subject's activity in a way that can lead to a reaction if the process is controlled by a computer programmed through a set of algorithms which can model a desirable outcome(s). I will argue for another definition as relates to interaction in architecture in which diversely specified modes of interaction can happen between two or more natural and/or artificial agents brought into a relationship with each other. The essential aspect of interaction is that the relationships between agents are established by means of multiple feedback loops. The simplest example of interaction in everyday life would be a conversation between two or more people.[112] In regard to architectural space, it is a spontaneous participatory process by which participants intuitively learn about the environment through observation of their actions in relation to the multiple feedback loops the embedded system[113] provides. In these terms, interaction frames the conversation between the participant and the environment.

In this regard, the different modes of interaction and the potential methodologies able to make these interactions operational can be observed. In terms of basic HCI, the design of an interactive system in the physical sphere of architecture can have points of interaction positioned deliberately or intuitively in order to trigger the action-reaction loop. The meaningful output is system's predetermined substantive reaction to the user's input in form of an action, like touching or stepping on a point of interaction. The objective should be more than just implementation and optimization of the functional aspects of a space. This is because certain simple functional human actions are replaced with automatised interactive digital assistants. The automation of these kinds of processes through augmenting space with digital objects can be referred to as the *hyper-modernisation of space*. This develops from a tendency that was a signifier of modernism, which was to build *a house as functional as a machine.*[114] Consequentially, the hyper-modernisation of architectural space can involve extreme amplification of functional processes through the application of a basic action-reaction model of interaction.

[112] Gordon Pask, *Conversation, Cognition and Learning: A Cybernetic Theory and Methodology*, Elsevier, Amsterdam, 1975, 68.
[113] Embedded system is a computer system designed to do one or a few dedicated and/or specific functions often with real-time computing constraints. Steve Heath, *Embedded System Design*, Newnes – Elsevier Science, Oxford, Amsterdam, Boston, London, New York, Paris, San Diego, San Francisco, Singapore, Sydney, Tokyo, Second edition, 2003, 2.
[114] Le Corbusier, *Towards a New Architecture*, Dover Publications, UK, 1986, 29.

There are many propositions about what interaction is and how it can be developed. In the most general terms interaction involves a complex relation between humans and computers. Steve Harrison, Deborah Tatar and Phoebe Sengers identified three paradigms about this interaction. The first is from engineering research, the second from cognitive science and the third they named *situated perspectives*.[115] The first deals with the direct human-computer relation in the sense of manual control, and is concerned with the physical involvement of humans in the performance of computer modulated actions, or in other words, direct human – machine coupling. The second concerns the speed of information transfer between human and computer, deeming that information processing in humans and machines is equivalent. The third deals with interaction as a form of meaning making not analogous to information processing and transmission. In this kind of interaction the artefact and its context are subject to multiple interpretations, which are at the same time mutually defining. The makers of meaning in the situation of use are both designers and analysts, as along with the users and other participants in the interactive process.[116]

One of the central and most interesting points in the third paradigm is that the construction of meaning derives from information but is not based on pure mapping of the information flow as in the second paradigm. Rather it is based on phenomenological qualities that can, when combined in different ways, influence and explain human behaviour and experience. Harrison, Tatar and Sengers think that the substance of this combination can be analogous to a biological matrix. This has a compatible environment which influences the specific structures of diversified variety and connects them to one another.[117] The nature of these relationships can determine the meaning of an interaction within a specific context. The context acts as a base with specific attributes and elements in which, through different connections, different relationships can be created. This can determine the direction of the interaction relative to the phenomenological qualities that can be designed within a certain context. In the case of architectural spaces, the phenomenological qualities can influence the participant's experience of the space, which can be positioned relative to the designer's conceptualisation of it.

[115] S. Harrison, D. Tatar and P. Sengers, *The Three Paradigms of HCI*, Proceedings of CHI 2007, San Jose, CA, May 2007, 1.
[116] Ibid., 2.
[117] Ibid., 8.

1.3.1 Informed Participation as Interactive State

According to Nancy B. Solomon, there have been three waves of architectural design evolution: in the first one the master's atelier was the environment in which architects designed in creative isolation until the design was finished and ready for display. The second wave became evident with the Modern movement, in which the design environment shifted into the corporate studio or office, although the design work was still performed in isolation. In the third wave, still present today, design is transferred to virtual space in which clients, architects and other project stakeholders co-create the design. These include low-tech spaces for brain-storming and idea generation, and high-tech workstations for the creation, display and manipulation of digital models and simulations, both of which can be regarded as collaborative environments able to support a wide range of team activities.[118] The third wave also interpolates human-computer interaction into the architectural design process through using computers for design production. In this interactive process, the architect is involved in a design of a design process concerned with the organization of the team work as it proceeds from defining goals and formalising an architectural vision through concept generation to design refinement. This new mode of design production emerges as a consequence of digitalization, which has, in part, transformed architectural design into a participatory, fluid and emergent process with different interactive modalities from those that occur inside architectural cybernetic environments or with digital façades.

Human-computer interaction during architectural design is mainly focused on the user's relationship with the software's interface which, as Florian Cramer and Matthew Fuller describe it, creates a connection between software and hardware and provides accessibility, along with other sources of data, to those who use them. Cramer and Fuller distinguish a typology of interfaces in five main types, most significant of which is the fifth type, which they describe as the *symbolic handles* making software accessible to users. Symbolic handles are also called *user interfaces* and often within media studies are erroneously treated as interface as a whole.[119] As Cramer and Fuller notice, for the average designer the interface is the only interactive meeting point with

[118] Nancy B. Solomon (ed.), *Architecture: Celebrating the Past, Designing the Future, Commemorating 150 Years of the American Institute of Architects*, Visual Reference Publications Inc., New York and Washington, USA, 2008, 160.
[119] Florian Cramer and Matthew Fuller, “Interface” in Matthew Fuller (ed.), *Software Studies: A Lexicon*, The MIT Press, Cambridge, Massachusetts and London, England, 2008, 149.

the digital reality and the software is integral to it. The interaction is determined by the architect's software literacy and the combination of software parameters and functions/commands determine the aesthetic quality of a drawing, collage or 3D rendering. The line weight and type, the attributes of a surface, its texture, colour or light overlay, are properties determined by the parameters of different software applications, though many can be read by more than one application.

Bill Moggridge notes how interaction in human-computer relations is less direct than when operating, for example, a radio dial in looking for a station. This is due to our alienation from what is occurring inside the computer at the moment of the interaction and the lack of physical feeling necessary for real-time experience of the process.[120] In terms of this kind of material quality, human-computer interaction during architectural design involves the execution of a predetermined set of commands through a series of mouse clicks on the software's interface positioned on a computer screen. This implies that there is a lack of direct engagement with the material being shaped, inside the computer's virtual space, but at the same time this mode of interaction comprises a different kind of material quality, a different *feel* to that of operating a radio dial. This *feel* involves the use of both hands to implement different activities: one interacts through by clicking the mouse, and the other by typing letters on the keyboard. There are therefore different qualities of materiality that influence the character of the interaction in terms of people’s experience of it.

According to Moggridge, a good interaction design needs to address several parameters. Firstly, there should be a clear *mental model* of what one interacts with. Secondly, the interactive system should have a *reassuring feedback* in order that the outcome of the activity is known at the moment the command that follows is executed. Thirdly, the system should have a clear and well organised *navigability* in order for those interacting to know where they are going and how they can come back. Furthermore, the whole system should have *consistency,*[121] so that a particular command in one part of the system has the same effect in other part(s). The interaction should not involve too much thinking about how the system functions, that is it should be *intuitive interaction*.[122] The previous attributes of the interactive design can in certain aspects be applied to the

[120] Bill Moggridge, “Good Interaction Design” in *Designing Interactions*, The MIT Press, Cambridge, Massachusetts and London, England, 2007, XV.
[121] ibid, XV
[122] Ibid., XVİ

design of cybernetic architectural environments relating to the system's intuitiveness, consistency and navigability. The conceptual quality of the interaction may require the environment to be intuitive with unanticipated outcomes. The starting point of the navigation through an environment should be clear, which means there should be a visible entry point. Other navigation points should be flexible to enable spontaneous exploration of the environment. Consistency may involve a specific gesture; a body movement or a sound implies the same feedback but this can also be flexible and the feedback can be random.

In the process of interactive system design, a designer needs to plan how the system will behave and what the quality of the interaction between the system and the user will be. In this regard, I agree with Brigitte Kaltenbacher's interpretation and understanding of Bergson's idea of the intuition as a mode of contemplation that postpones bodily action and opposes the common tendency of thought towards utility, so providing an opportunity for change or difference. Interaction therefore offers a mode of experience composed of perception, as an external, material experience, and intuition, as a virtual, inner experience.[123] If we speak about interaction as a virtual, inner experience, it would relate to how people experience the sense of place and space created by architects or urban designers within buildings or cities. This experience occurs through interaction with the spaces, which in traditional architecture is based on their functional aspects. This means that the architectural space is experienced through its use, as a living, working or entertainment environment. Apart from its functional aspects, the condition of the space depends on the particular atmosphere and character an architect or designer wants to achieve. For emerging digitized spaces the goal is to create a space able to provoke different modes of interaction between people or to create a space with a strong social distinctiveness that would attract people to use it and develop new ways of communication conditioned by digital means. A new aspect of the digitized space is concerned with an architectural cybernetic environment whose properties and interactive modalities can stimulate people to re-examine their actions within it. The accent is on the interaction that generates social activity.

[123] Brigitte Kaltenbacher, *Intuitive Interaction: Steps Towards an Integral Understanding of the User Experience in Interaction Design*, PhD dissertation, Centre for Cultural Studies, Goldsmiths, University of London, London, England, 2008, 83.

1.3.2 Architectural Interactive Modalities

The idea of creating architectural space as *a generator of social activity* was conceived by Cedric Price in his *Fun Palace* project.[124] Everyone can participate in the creation and re-creation of this space, which has a precise set of parameters, while imagining individual activity that is immediately conveyed. An important aspect of architectural interactive spaces, that of the *relationship* arises from this project. It is no longer enough to think in terms of a spatial ambiance or a sense of a place[125] but also about the kind of relationships, besides functional ones, people inside such a space can have and the relations between different constituents of the space need to be considered.[126] This means that tendencies to create sensitive interior walls, floors and ceilings with an addition of computer controlled infrastructural elements such as mechanical and lighting systems are not, on their own, sufficient. These buildings are called *smart* and the building automation that is an attribute of them describes the functionality provided by the control system, which is a computerised network of intelligent electronic devices designed to monitor and control the different properties inside the building.

According to Frances K. Aldrich a *smart home* can be defined as a residence supplied with information and computing technology able to prognosticate and react to the needs of its inhabitants, operating to support their comfort, security, entertainment and suitableness through the management of the available technology within the home and connecting with the world outside the building.[127] The first official use of the term *smart house* was by the American Associations of House Builders in 1984, although hobbyists in the early 1960s actually built the first *wired homes*. For Harper, the home is smart because of the interactive technologies it contains and not because of how effectively it uses space or because of its construction quality, nor because of its sustainable properties such as utilisation of solar power or recycling waste water, although smart homes can contain these technologies.[128] As a development of the strictly functional attributes of these kinds of spaces is considered a simple improvement of the action-reaction model of interaction, the second chapter will discuss how to develop ways in

[124] Mathews, *From Agit-prop to Free Space*, 64.
[125] Henry Lefebvre, translated by Donald Nicholson-Smith, *The Production of Space*, Blackwell Publishing Ltd., 1991, 195.
[126] This thesis supports Lefebvre's proposition of the self-conscious construction of new subjective environments. This kind of environments would involve the spatial exploration and celebration of subjective domains of life, such as imagination, spontaneity, creativity, humour, play, street life and carnivals, passion and history.
[127] Frances K. Aldrich, “Smart Homes: Past, Present and Future” in Richard Harper (ed.), *Inside the Smart Home*, Springer – Verlag, London, 2003, 17.
[128] Harper, *Inside the Smart Home*, 1-2.

which the aesthetic qualities of these kinds of architectural cybernetic environments can be developed and consequentially what kind of interactive modalities they can contain.

In terms of the building's relation with the outside there are some with interactive digital façades and some that are computer controlled, without an interactive component. Interaction here is an aspect that an architect or a designer may choose to introduce into the design. In cases where interaction can be analysed in relation to the digitized exterior of the building, or its digital façade, it can be observed through digital objects or *smart* objects people use everyday, like mobile phones, iPod's or laptops.[129] The question is what are the main characteristics of digital objects, besides their primary functional purpose, that challenge their utilisation while provoking curiosity about exploring their more creative employment? The starting point in interaction is, metaphorically speaking, the action of *pushing the button*. The main motivation to do so is basic human curiosity and the decisive part of *pushing the button* is the moment of resolution. After the action is executed the participant is in a state of anticipation. The quality of the feedback may influence the participant's state of mind and provoke an emotional response while the reaction to it may determine the further path this relation will take. This can be related to Harrison, Tatar and Sengers's third paradigm of HCI which they called *situated perspectives* in relation to the context forming a basis for the combination of different phenomenological qualities influencing human behaviour. For McCullough, architecture as well as interaction design deals with the variety of changes that can shape our action in a space with a specific context. According to him, one of architecture's qualities is that it frames intentions. At its core, interactivity links these mental states to available opportunities for participation. McCullough regards these processes as ambient, the benefits of which are not in the seductive objects of attention but are to be found in the quiet periphery.[130]

An interesting notion concerning human-computer interaction is that the process can take unpredictable directions and is different for each individual, so it cannot be absolutely guided or controlled. In the general excitement over new technological achievements, the observer's reaction can in some cases be scaled down to an exhilaration with technical performativity. For example, when touch-screens were

[129] Dunne, *Hertzian Tales*, 31.
[130] McCullough, *Digital Ground*, 47.

introduced for public use, the change in the mode of interaction from pushing a button to touching a responsive flat surface in order to get feedback gave excitement at how the technological appliance functioned. The principle was the same but the way people interact with the object changed because the screen was felt through touch. Technical performance is as important as functional instrumentation but cannot be perceived as qualitative where interaction is concerned.

In order to understand what kind of interactive modalities can occur inside the architectural cybernetic environments it is necessary to address the relationship between the human body and architectural space, as discussed in the next section.

1.3.3 Interactive Relationships Between the Human Body and the Architectural Space

Natural interaction with architectural space has a long history and started long before computers appeared. Through time, architectural space has gone through many transformations in terms of the social engagement within it and its different forms of performative qualities in regard to the activity inside it. From ancient times, architectural space did not lose its primary principle, which is to serve as shelter from the weather, animals and people from other tribes. Different needs and climate influences produced diverse answers to the primary principle and constant progress in technology and material construction allowed human civilization to create more advanced engineering procedures and therefore more advanced shelters. Lieven de Cauter noted that humans tend to *capsularize*[131] their environmental contexts by protecting themselves with stable or mobile physical capsules that maintain processes and actions during their lives. Houses, cars, trains and airplanes are among these capsules for our fragile bodies and yet in our ability to misuse them they also harm us. With the emergence of digital technologies, capsularization not only occurs through built physical structures but also from the socio-technical bubbles that form around an individual when s/he uses digital objects.

Recalling our earlier discussion of the space-body relationship in its interactive

[131] Lieven de Cauter, *The Capsular Civilization: On the City in the Age of Fear*, NAi Publishers, Rotterdam, The Netherlands, 2005, 49.

potentiality, the emerging condition of the embodiment of virtual and physical space overlaid with digital characteristics becomes an interesting new topic representing a shift from traditional space-body relationships. Da Vinci's *Vitruvian Man* (1487) (see figure 1.21 below), and later Le Corbusier's *Modulor* (1943) (see figure 1.22 below) are examples of traditional architectural approaches to the body through its physical calculable characteristics, like size and volume, and by determining its dimensional correlative proportions scaled relative to geometric figures like the circle or square. The *Vitruvian Man* attempts to define the mathematical proportions of human body, which are crucial for scaling and proportioning of architectural space, both in its appearance and functionality,[132] while Le Corbusier's *Modulor* asserts that the form of the human body can be inscribed in geometries developed from the Golden Section and the Fibonacci series.[133] Le Corbusier developed this claim in three texts, “Modulor” in 1943, “Modulor 2” in 1955 and the third that was never completed. These texts provoked different responses. Some, like German art historian Rudolf Wittkower in 1954 called the *Modulor the first consistent synthesis since the breakdown of the older systems,*[134] implying that what had been developed in the Renaissance had come to an end. Others, like English architect Peter Smithson,[135] identify Wittkower and Le Corbusier with a moment of crisis that emerged within architecture in the 1940's when architects were looking for something to believe in and briefly found it in their texts, shortly transcending their mid-century crisis of faith.

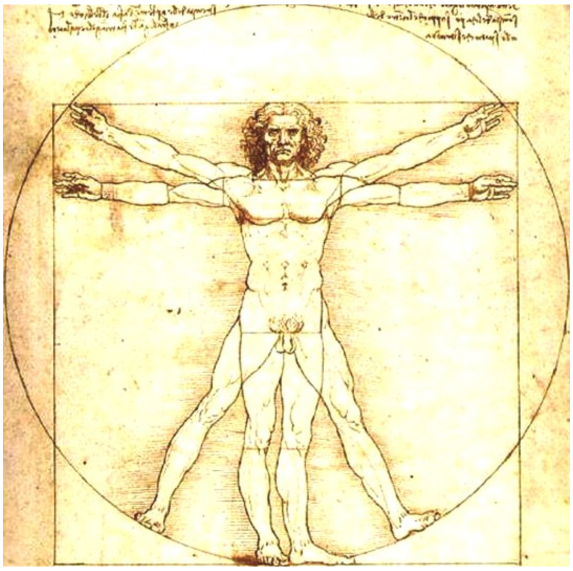


Figure 1.21: The *Vitruvian Man*, Leonardo da Vinci, c.1487.

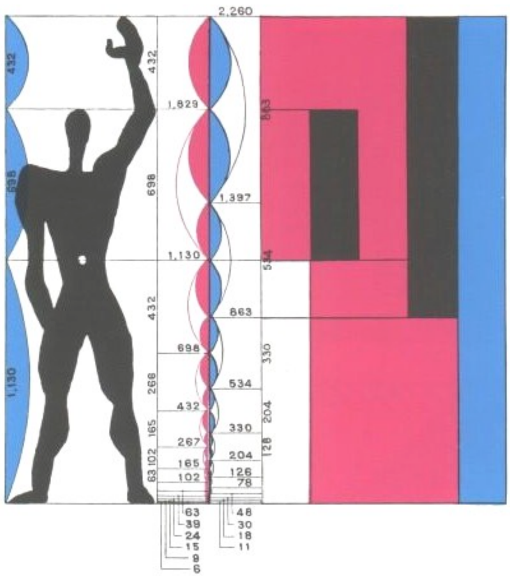


Figure 1.22: *Modulor Man*, Le Corbusier, 1943.

[132] Christopher Hight, *Architectural Principles in the Age of Cybernetics*, Routledge, Taylor and Fransis Group, New York and London, 2008, 55.
[133] Ibid., 57.
[134] Rudolf Wittkower, “The Architectural Principles of the Modulor” in Hight, *Architectural Principles*, 78.
[135] Peter Smithson, in “Report on a Debate About Proportion”, *RIBA Journal*, 18.

Vitruvian Man and *Modulor* are important reference points in the history of architecture. They represent a stream of thought that evolved and changed as society and culture was transformed, something partly reflected in the cities and structures architects design. Importance was then placed on the human body and its proportional relationship with the built structure and they both symbolise a determination of the calculable aspects of space in relation to the human body. This was a basis for today's evolution towards computational features of architectural space which set up new relationships with the body made possible by technology and knowledge leading to yet unexplored extents, and able to develop distinct modes of interaction with our environment. This means that the digitization of architectural space through interaction can bring embodiment to another level introducing other attributes besides body size and scale, such as sensory qualities, into the conception of architectural space. These new parameters can elicit a straightforward phenomenological and physiological experience of space. Besides interactivity, digitization initiated a new image of the human body within the virtual space of a computer.

A new kind of reality and relationship between the body and the environment is presented in the work of Daniel Lee. Both of his works *Nightlife* (2001), illustrated in figure 1.23 below, and *Jungle* (2007), illustrated in figure 1.22 below, derive from his series of portraits *Manimals* and present a contemporary portrayal of intrinsic animal interactions between people in today's urban environment.[136] Images from this series of portraits are marked as being iconic representations of hybridity between the body and its potentially technological sub-parts. This kind of relationship replaces Vitruvian Man's humanist image of the human body as consolidation of parts into a greater whole through a *seamless organization of disconnected parts*,[137] according to Ben van Berkel and Caroline Bos. *Manimals* are based on the Chinese zodiac[138] and are generated through use of computer software made to merge human and animal bodies. All images are rasterized into a matrix inside the computer in such a way that each pixel can be addressed and altered individually and is interchangeable with any other point. In this way, as Mitchell suggests, it is very hard to determine what belongs to the original source or even to locate the resemblance of parts, as there is no part or whole to be

[136] Daniel Lee's website, "Manimals", 1, Retrieved September 07, 2009, from http://www.daniellee.com/RecentWk.htm.
[137] Ben van Berkel and Caroline Bos, UNStudio, "MOVE", vol. 2, Good Press, Netherlands, 1999, 85.
[138] Daniel Lee's website,"Manimals", Retrieved September 07, 2009, from http://www.daniellee.com/Manimal.htm.

made.[139] A body generated in this way is an information based generic combination, allowed by statistical typologies and produced by recombining the hue and tone values of simulacra, while Vitruvian Man is a representation of geometric organicism made from the contours of an ideal subject.

Figure 1.23: *Nightlife*, Daniel Lee, 2001.

Figure 1.24: *Jungle*, Daniel Lee, 2007.

In these terms another approach towards the body-space relationship is more immediate in its actualization. Interaction has the potential to diminish the scale of the space and to focus attention on more engaging aspects, like to influence a certain kinds of action to happen. Through computer based information exchange interaction can encourage substitution of knowledge about different sorts of subjects or it can create non-representational and entirely experiential occurrences. It can help in the conception of new ways that spaces can develop, like new ways in which spatial elements could be composed and re-arranged. The process of interaction can include lively somatic activation of the observer through a set of intuitive tasks one needs to go through and in this way one can discover new modes of engagement with the space. How urban and architectural context can influence interactivity with the space people inhabit will be discussed in the next section.

[139] Hight, *Architectural Principles,* 11.

1.3.4 Urban and Architectural Context for Interaction

In the previous discussion, urban and architectural contexts were an important factor in the conception and design of interaction. There are several levels of interactive occurrence in an experience of a building or part of the city. If the relationship between the building and its surroundings is observed at the level of cybernetic theory, it can be seen as a mode of communication between building and environment or the people that use it. Such a cybernetic notion is concerned with the discovery of different aspects of interaction at different levels of communication. Two aspects of interactive architectural spaces can be identified when applied to diverse built structure.

The first aspect is the building's responsiveness to the climatic influences, for example if the building reacts to sunlight, wind, rain, temperature. This is related to the computerised control of the building's service facilities and functions, such as ventilation, heating and focuses on direct interaction between the building and its surroundings. Conceptually it amplifies the primary aim of architectural space of forming a shelter from weather conditions except, in the case of a climate sensitive space, when it constitutes an intelligent entity aware of certain environmental properties. Additionally, response not only happens inside the space, for example when closing a window, but can also be computationally instructed to enable a particular action to occur if, for instance, it starts raining.

The second aspect is the increase of the building's natural sensitivity to people and what they do inside or outside it. This may be through the building's skin or elements of its interior augmented digitally, for example when an SMS is sent to a computer controlled building façade and displayed on its surface. This allows people to interact with it, whether in terms of a simple building reaction (for instance, automatic doors), or in more interactive ways that go beyond functional logic. The field of interaction design has opened new issues and has shown that simply focusing on the performative capabilities of the interface and improving its technical features may be ineffective. Preoccupation with visual interface design involves an intense investment in the development of screen technology and appearance of these projective surfaces everywhere possible, whether it is necessary or not. This had a strong influence on façade aesthetics.

It is almost inconceivable to imagine Piccadilly Circus in London, Times Square in New York or Ginza, shopping and entertainment district in Tokyo without the striking large screen-like façades displaying non-interactive imagery lacking any meaningful content. This kind of public space has brought about new relationships between space and people due to its complete deluge of visual sense and the intensification of the moving image's seductive quality. This has also increased people's alienation from their surroundings, because it created artificial phenomena that overwhelms the senses but does not engage any emotional or intellectual processes. Turning attention to the way technology accumulates locally and becomes an ambient and social medium has been one of the urgent questions in architecture and urban design over the past twenty years.[140] It is no longer an option to use screen surfaces irresponsibly for commercial purpose without thinking of the consequences it might have on people.

In the first and the second aspects digital elements serve people, helping them to act and make an event happen. The third aspect, for which built examples still do not exist, is something for future exploration. It arises from Buckminster Fuller's conclusion that the structure of a building remains intact, in that there are no attempts to make it, or the construction elements of the building, interactive or reactive either to people or the surroundings. However, one design for a proposed building in Dubai has rotating floors that would allow the inhabitant to get the best view of the surrounding environment.[141] However, in this case no attempt was made to make beams and columns, ceilings and floors, individually interactive and in motion, to create an interactive building in which all parts, even the constructive elements, have changeable integrity.

A project with a corresponding motif is Archigram's 1964 *Walking City* project[142] as shown in figure 1.25 below, in which Ron Herron proposed a city composed of intelligent buildings with robotic attributes forming a vast, self sustainable pod for living in which, besides dwelling, one could independently wander through. The form of the city would be a combination of insect and machine appearance, based on Le Corbusier's statement that a house should be designed as a machine for living, but quite

[140] Struppek, "Urban Screens", 4.
[141] Chad Randl, *Revolving Architecture: A History of Buildings That Rotate, Swivel and Pivot*, Princeton Architectural Press, New York, 2008, 188.
[142] Peter Cook and Michael Webb, *Archigram*, Princeton Architectural Press, New York, 1999, 50.

literally by re-imagining *living*. If realized this project would represent the sort of total social and cultural capsularization de Cauter discusses,[143] although formally it presents a very futuristic and innovative way of conceptualizing the city. Part of the critical investigation of architecture and pop culture that Archigram represented was conducted in Italy by the Archizoom Group and Superstudio. Their criticism took shape in literary/collage projects, such as the *Continuous Monument* and *No-Stop City*, which seemed to parody Archigram's projects. They argued that the systematic attempts to facilitate spontaneity in Archigram's projects resulted in inexorable structures constituting a withdrawal of architecture.[144] Archizoom criticized Archigram and the Japanese Metabolists for creating work that was the image of technology. This critique of Archigram's projects could be extended in terms of the inadaptability of their structures to specific contexts. The rigid modularity of the structures necessary to accompany the *living capsules* or *pods* imply a level of standardization that would potentially cause people to be disoriented in such a city. Capsularisation could also cause social estrangement and an absence of people's interaction.

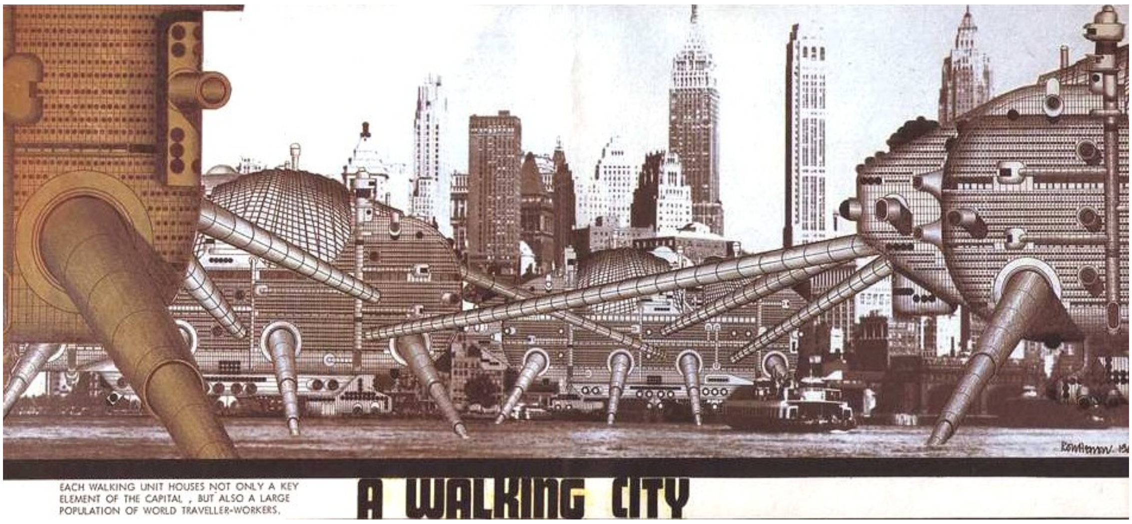


Figure 1.25: *Walking City,* Archigram, 1964.

Another project along these lines was Buckminster Fuller's *Autonomous living unit*[145] from 1949 also known as *Autonomous Dwelling, shown in* figure 1.26 below. Although not automotive and with no portable elements, this project was actually built and in its time functioned as a completely independent unit in relation to the centralised servicing infrastructure of the city without which any built structure intended for human usage

[143] de Cauter, *The Capsular Civilization*, 84.
[144] Sadler, *Archigram,* 137.
[145] Michael John Gorman, *Buckminster Fuller: Designing for Mobility*, Skira, Milan, italy, 2005, 76.

could not work. In this respect the project was able to be detached from the ground and therefore separable from the city structurally and administratively. Therefore this project offered a democratisation of architectural space in relation to the functional, structural and administrative apparatus of the city.

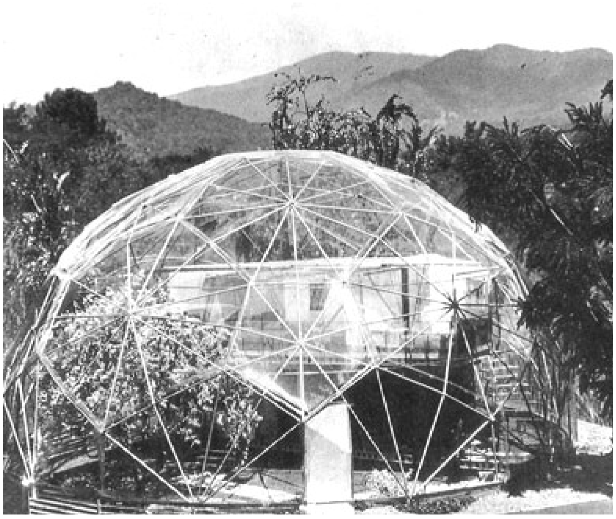


Figure 1.26: *Autonomous Dwelling*, Buckminster Fuller, 1949.

A possible direction for thinking about digitalized interactive spaces could be through algorithmic processes that are at the core of any software application's data processing.[146] If we think about an alteration as a starting point in dealing with this, that is, if we designed an architectural space as an empty box in which a certain set of actions could be performed depending on the purpose of the space the questions would be: what kind of action and for what purpose it should be performed; what is this altered space expected to do that existing architectural space does not do already? The possible answer is to imagine an algorithm as a means for this alteration. This opens a possibility to think about the space as a kind of a digital machine, but in a way unlike the Modernistic conception of space which it is made to resemble a machine and be purely functional as a machine. The digital space machine can have poetic aspects that add qualities making it more than purposeful and functional. These poetic aspects could be completely non-functional.

The performativity of architectural cybernetic environments can be seen in two ways. Firstly the space can change itself through a metamorphosis of its numerically

[146] Matthew Fuller and Dragana Antic, “Calculation Space”, *De Witte Raaf*, Antwerp, Belgium, 2007, 23.

distortable properties, such as colour, sound, size, shape, geometry and texture. The change is strictly physical, meaning that only its physical attributes so the quality obtained is merely formal in its essence. In this case, the problem is that no conventional materials could support its creation of such a space, so a parallel experiment should occur with creation of the specific material that could perform each suitable action, possibly within nanotechnology. Evidently this material would contain features of all known construction materials with enhanced parametric attributes and a chemical structure. The second option for the algorithmic conceptualization of space is through phenomenological modifications that would require cyclical change of the inhabitant through his senses and known perceptual mechanisms. To inhabit and co-construct such a space would be a significant way of both coupling and uncoupling sensual and cognitive experience in a vivid interplay generated by a momentary degree of emphasis in working with the space. The potential of such a space would be to intensify experience through estrangement of sensual stimulation.

After the establishment of the theoretical qualities, which are concept, materiality, digitalization and interactivity, further analysis will be conducted in regard to the respective themes of interactivity related to architectural cybernetic environments, architectural design process and digital façades. The analysis will concern the utilisation of previously discussed parameters in relation to these themes. The respective themes mark the transition from analogue to digital impressions of architectural space, from the point of the design stage to the phase of physical application and utilisation in the form of a building.

Chapter 2: Cybernetic Environments – Interactions of The Digital and Physical

The second chapter of the thesis is concerned with the discourse of cybernetic environments. Understanding of cybernetic concepts and processes is essential because it can help in defining what an cybernetic architectural environments are and what is their meaning and purpose as architectural artifacts. Throughout this thesis, interaction presents the main parameter for the observation and analysis of specific architectural processes, beside its relational parameters: concept, materiality and digitization. Interaction is introduced as a cybernetic process and in this regard is evaluated in relation to architectural discourse. Therefore, an comprehension of cybernetics will provide a fuller understanding of the different modes of interaction that can occur in an architectural environment augmented with discrete modalities of computer embedded apparatus as well as human-computer interaction occurring during the architectural design process. In order to examine the evolution and historical reference points of the cybernetic environments development until present times, in architectural terms, it is necessary to go through the development of the meaning of the term cybernetics and its relational concepts through history, not as an overview or a summary but in the context of the ideas that will be developed through this thesis.

The meaning and significance of cybernetics for architecture will be discussed further in the chapter through concepts that are architecturally formalised in the projects of Cedric Price and actualised in the case of Lars Spuybroek's *Water Pavilion*. The former will be supported by the discussion about the diverse modes of interaction that happen in specific contexts.

2.0.1 Development of Cybernetic Concepts

Historically there were several attempts to define the meaning of the term *cybernetics*. In her approach to its genealogy as a term, Katherine Hayles identified three waves of cybernetic development symbolised by three different concepts. The first wave happened in the period between 1945 to 1960 and was centred around the concept of homeostasis. The second one came about between 1960 to 1980 and explored reflexivity as the main theme. The third wave extends from the 1980s to the present times and highlights virtuality and self-organisation as the main interest for exploration.[147] In this regard, the definition of cybernetics, as a multidisciplinary science, used in present times have developed and evolved compared to the one used by the first order of cyberneticians with mathematician Norbert Wiener, neuropsychiatrist Warren McCulloch, neurobiologist Arturo Rosenblueth, engineer Claude Shannon and polymath Walter Pitts as its representatives. They used the Greek word *Kybernetes* that means helmsmen or steersman, to describe general principles of control and communication that can be found across different kinds of system or material instantiation. In 1943 Arturo Rosenblueth's collaboration with Walter Bradford Cannon and Norbert Wiener resulted in the text he wrote with Wiener and Julian Bigelow, “Behaviour, Purpose and Teleology” that will, according to Wiener, create a base for the new science of cybernetics.[148] Several years later, Norbert Wiener defined cybernetics as the science that studies communication and control in living organisms and machines in his book “The Human Use of Human Beings” first published in 1948 and revised in 1961.[149] During the WWII postwar period at the Macy conferences (1946-1953) the previously mentioned theoretical and natural scientists were joined by representatives from the human sciences such as Margaret Mead (anthropology), Lawrence K. Frank (social science), Gregory Bateson (social science), and later Roman Jakobson (linguistics), Paul Lazarsfeld (sociology) and Kurt Lewin (psychology).[150] A strong emphasis during these conferences was on the concept of *homeostasis*.

2.0.1.1 Homeostasis

The concept of homeostasis was one of the central doctrines for a variety of theories of self-regulation and internal organization in complex open systems. In more general terms, homeostasis is a property of a system that regulates its internal environment and tends to maintain a stable and constant condition. This concept was firstly defined as *milieu de l'interieur* by Claude Bernard and later, in 1926, characterized and named *homeostasis* by Walter Bradford Cannon.[151] Cannon differentiated the meaning of the term homeostasis from that of equilibrium, describing it as a condition that contains

[147] Hayles, *How We Became Posthuman,* 7.
[148] Arturo Rosenblueth, Norbert Wiener and Julian Bigelow, “Behaviour, Purpose and Teleology” in Frank George and Les Johnson (eds.), *Purposive Behaviour and Teleological Explanations*, Gordon and Breach Science Publishers, New York, London, Paris, Montreux and Tokyo, 1985, 1-9.
[149] Norbert Wiener, *The Human Use of Human Beings: Cybernetics and Society*, Sphere Books, London, 1968, 48.
[150] S. J. Heims, *The Cybernetics Group*, The MIT Press, Cambridge, Massachusetts, 1991, 12.
[151] Charles G. Gross, “Claude Bernard and the Constancy of the Internal Environment” in *The Neuroscientist*, Volume 4, Issue Number 5, 1998, 380-385.

properties which can vary, but which is relatively constant.[152] For example, during high temperatures the human body produces sweat and in this way internal body temperature remains relatively stable. Among the mentioned cyberneticians, McCulloch was concerned with communication within the observer and between the observer and his environment. In 1965 McCulloch and Pitts are first to propose a synthesis of neurophysiology and the possibilities for development of the logic that could connect the capabilities of brains to the limits of Turing's computability.[153] Consequently, during the period of Macy conferences the concept of homeostasis was extended to machines. It was considered that machines can maintain homeostasis using feedback loops, similarly to animals.

What cybernetics sees as feedback loops and which were only later theorised as such, reached a high level of development between the middle and the end of nineteenth century with the growing sophistication of steam engines and their accompanying control devices. They had been exploited to increase the stability of mechanical systems much before their formulation and use in cybernetics. Only from 1930s and 1940s feedback loop started to be explicitly theorised as a flow of information. At its beginning, the informational feedback loop was linked with the concept of homeostasis but throughout its development it initiated a revolutionary idea of reflexivity.[154] Besides the efforts to define and develop science of cybernetics in the west, there were attempts towards this accomplishment in the east as well, in the former USSR. In the 1955 July-August edition of “Questions of Philosophy” (“Voprosi Filosophy”) Sergei Sobolev, Anatlii Kitov and Aleksei Liapunov defined cybernetics as a science of the transmission process that calculates and stores information.[155] They saw the cybernetic mind-machine analogy from a functional rather than philosophical point of view. They also adopted technical use of terminology such as homeostasis, signals or feedback, entropy, reflex and the binary digit and accentuated a special importance on the central processor as capable of memory, responsiveness and learning.[156] Some Soviet cyberneticians, such as physiologist Nicolai Bernshtein with his *psychology of activity*, wanted to liberate organism from the role of *reactive automaton*, which was in opposition with the

[152] Walter Bradford Cannon, “Homeostasis” in *The Wisdom of the Body*, (1932), Norton, New York, 1939, 75.
[153] Warren S. McCulloch and Pitts H. Walter, "A Logical Calculus of the Ideas Immanent in Nervous Activity" in Warren S. McCulloch, *Embodiments of Mind*, The MIT Press, Cambridge, Massachusetts, 1970, 66.
[154] Hayles, *How We Became Posthuman*, 8.
[155] Sergei L. Sobolev, A. I. Kitov and A. A. Lyapunov, “Osnovnie Cherti Kibernetiki” (“The Main Features of Cybernetics”) in *Journal Voprosi Filosophii* (“*Questions of Philosophy*”), Akademia Nauk USSR Institut Filosophii, Moscow, Issue Number 4, 1955, 136-148.
[156] Ibid., 141–146.

established Pavlovian reflex theory.[157] According to mathematician Mikhail Bongard, if this theory is subjected to cybernetic test, it failed to explain pivotal physiological mechanisms, such as learning.[158] This discussion put an emphasis on the participant in the cybernetic process, or the observer, which was a clear modification of the previous concept of homeostasis. As a discursive extension of the concept of homeostasis, cyberneticians explored the concept of reflexivity.

2.0.1.2 Reflexivity

In second order cybernetics or the second wave, the meaning of the term reflexivity was developed by, among others, scientist Heinz von Foerster, cybernetician Gordon Pask and psychiatrist William Ross Ashby. In second order cybernetics or *cybernetics of cybernetics*[159], as von Foerster put it, he considered that cybernetics emerges as the result of the activity of effectors, such as an engine, a motor or muscles, connected to a sensory organ which as a reaction to effector's action, acts with its signals upon effectors. This kind of cybernetic system with its circular organization distinguishes itself from other systems, which are not organized in the same manner.[160] Von Foerster's comprehension of cybernetics implies the concept of *reflexivity* and focused application of feedback loops. According to K. Hayles, reflexivity is the movement whereby that which has been used to generate a system, through a changed perspective, becomes a part of the system it generates. In this regard, reflexivity has subversive effects because the boundaries that humans impose on the world in order to make sense of that world are entangled and disordered. In these terms reflexivity tends toward infinite cyclical alterations.[161]

This means that if a cybernetic process needs a time period or a cycle for its execution and during or by the end of the cycle another process is triggered by the self-alteration within the system, this means that the process starts again but not as contained within a loop of a previous process. It continues as an extension of the previous cycle by inheriting random or chosen parameters in which the change in the system can influence the change in the path or algorithm, speed of the process, emergence of new processes,

[157] Slava Gerovitch, *From Newspeak to Cyberspeak: A History of Soviet Cybernetics*, MIT Press, Cambridge, Massachusetts, London, England, 2004, 221.
[158] Ibid., 222.
[159] von Foerster, *Understanding Understanding*, 283.
[160] Ibid., 287.
[161] Hayles, *How We Became Posthuman*, 8.

the rhythm of the cyclical repetition until the new alteration occurs which can direct the system to change again. In this way the system is in a state of constant interaction through which it can continuously change itself. In other words, it is in the process of continuous evolution which happens with each cycle containing the self-alteration or self-organization moment embedded in the system. This approach to observation is similar to the one proposed in this thesis in relation to cities that are seen as a complex systems of many other systems that contain new systems and so on. An action or a movement produced within one system is not linear and commonly influence a number of other systems. For example, the climate conditions can influence changes in traffic systems, which then influence changes in other systems, such as food and water distribution, peoples' travel arrangements, etc.

Heinz von Foerster proposes three concepts as an evolutionary development of the meaning of cybernetics. The first one is the existence of an *observer* who is characterised as one being able to make descriptions by means of what s/he says. The second concept is that of *language*, meaning that the two observers can be connected through language. A third one is that of *society*, in which two observers form an elementary nucleus for society.[162] By putting society in the centre of the discussion regarding the societal problems as central, Von Foerster recognized the second order of cybernetics as social cybernetics. For Hayles, reflexivity entered cybernetics primarily through discussions about the observer. The cybernetic environments proposed by this thesis imply that the observer is in conversation with the environment and/or other observers involved in interaction with the environment. Conversation with an environment is facilitated through effectors or sensors that are embedded into an environment and connected to the central processing unit that provides different feedback loops depending on the participant's action. Therefore, proposed cybernetic environments are, among other things, envisioned as generators of social activity. In these terms, they are social because through interaction with the system participants can spontaneously engage in interaction among themselves in which collaboration and self-organization are main constituents of interaction. During interaction participants may obtain different roles that can be translated as system of signals activated through different gestures. Different roles may concern different goals that individuals need to fulfil. In this way participants can be self-observant at the same time observing actions

[162] von Foerster, *Understanding Understanding,* 287.

of other people.

Questioning the properties of the observer Von Foerster discarded *objectivity* as the cognitive 'blind spot' within the Western tradition because for him it would not be possible to make a description if the observer does not have the properties that allow for the description to be made. Instead, von Foerster claims that the observer needs to observe his/her own observing and account for their own accounting.[163] Here he makes a differentiation with the first order of cybernetics by defining cybernetics as the cybernetics of the observing systems rather than observed systems. In this regard von Foerster consents with Gordon Pask's formulation given in his text “The Meaning of Cybernetics in the Behavioural Sciences (The Cybernetics of Behaviour and Cognition: Extending the Meaning of 'Goal')”. The cybernetic environments proposed by this thesis stipulate self-observation of the observer's actions through the introduction of mechanisms that will allow for different modes of interaction with the environment. Because the proposed environment is a digitized architectural space augmented with different computational artifacts and the natural agents in this space are people, action can concern spontaneous body movements, gestures, sounds or touch that can trigger interaction with the system. In the first order of analysis that Pask describes as the *first-order stipulation*,[164] the observer enters the system by stipulating the system's purpose and in the second order of analysis, considered as the *second-order stipulation*, the observer stipulates his own purpose.[165] The observer in the system is allowed to stipulate his/her own purpose and therefore is autonomous.[166]

According to Niklas Luhmann and John Bednarz, there is an aspect of self-observation that is built into all social systems. It is built into a construct that social systems consist of a complex interconnections of the communicative processing of information, which are in the respective social system reduced to actions. Because of the condition required by communication that depends on a *theme,* communication is open to the variety of possible reactions.[167] Through an understanding of communication and conscious comprehension of physical reality autonomous observers within social systems can presuppose relations within reality. One of the important issues in the process is the

[163] Ibid., 287.
[164] Gordon Pask, “The Meaning of Cybernetics in the Behavioural Sciences” in J. Rose (ed.), *Progress in Cybernetics*, Volume 1, Gordon and Breach, New York, 1969, 15–44.
[165] Ibid., 18.
[166] von Foerster, *Understanding Understanding*, 157.
[167] Niklas Luhmann and John Bednarz, *Political Theory in the Welfare State*, Walter De Gruyter & Co., Berlin, 1990, 119.

theme that can inspire communication, as noted by Luhmann and Bednarz. The theme can determine the direction and quality of interaction between the observer and the environment, as well as, between two or more observers. This implies a thematic dialogue as an opening point in the conversation between two people. Through a dialogue a number of observers in interaction, exchange information about their experience with the system and consequentially can reach a consensus about the action they will perform within this system. In consideration to the theme of the dialogue and the number of possible decisions regarding a possible action the conversation with an environment can be established through an computational system embedded within the environment.

This mode of thematic interaction is illustrated through discussion of the *Water Pavilion* further on in the chapter. The theme of interaction can determine conditions of materiality in terms of utilisation of natural, virtual and digital materials that can react to macro and micro material qualities. For example, in the case of *Water Pavilion* the main theme is water and therefore designers of the system interpolated its visible and tangible material properties, such as weight, transparency, density, colour, etc., with its virtual materiality, such as different projections of water patterns that can be disturbed by a body movement. These two different interpretations of one material modality are both inspired by the same theme.

Acknowledgement of an autonomous individual as a self-observer within the society that is a complex system, can be considered as an anomaly regarding the imperative to concentrate power in a central apparatus of the state, as the only way to solve problems in a society.[168] This is one of the concluding thoughts from William Ross Ashby's book “An Introduction to Cybernetics” published in 1956. Instead Ashby proposes a social condition in which only a variety can master variety by reduction of disturbances and promotion of harmonious order. This implies that within a flexible system a number of inputs should have an equivalent number of output options. Meaning that the stability of the system depends on the number of states of its control mechanism that should be greater than or equal to the number of states in the system that it controls. With this, Ashby introduces the concept of *variety,* which is according to him inseparable from the

[168] Ashby, *An Introduction to Cybernetics*, 142.

concept of information.[169] Ashby perceives his Law to be directly connected with the Claude Shannon's *Information Theory*. *The Law of Requisite Variety* allows for an application of measurement to regulation.[170] One of Ashby's conclusions was that an unregulated flow of information from the external world to an observer can result in observer's saturation with superficial and trivial information and can effect one's daily activities. Therefore, employment of the regulator R will transform or re-code content harmful for the observer. Considering that regulator's or controller's purpose is to keep the system stable, the more options the regulator has the better it is able to deal with fluctuations within the system and cope with the constantly changing environment. System's possibility to adapt to constant changes within the environment can imply its possibility to endure in the environmental conditions.

The point of Ashby's argument is that in every exchange of information there should be an information filtering through a regulator that would determine the kind of qualitative attributes an information should contain that will not endanger an observer. Information filtering is a subject of research that Clay Shirky, among others, differentiates as important and related with an individual's privacy, as discussed in the fourth chapter. Introduction of regulators as filtering parameters for quality of information is an important factor in communication process between the observer and his or her environment. Through the development of the reflexivity another concept emerged and that is virtuality.

2.0.1.3 Virtuality

The third wave of cybernetics with the revolving concept of *virtuality*, as noted by Hayles, started appearing in the moment self-organization began to be understood as emergence and not merely as the (re)production of internal organization. For Hayles, virtuality is the cultural perception that material objects are inter-penetrated by information patterns. This definition exemplifies the duality in the essence of the condition of virtuality, which is materiality on the one hand and information on the other. Virtuality is often associated with computer simulations that place the body into feedback loop with a computer generated image.[171] An artifact, such as a building,

[169] Ibid., 140.
[170] Ibid., 209.
[171] Hayles, *How We Became Posthuman*, 14-15.

materially expresses the concept it embodies, but the process of its construction is far from passive. In case an unexpected deformation within a construction appears that can concern a material that exhibits unexpected properties, this results in an emergent behaviour of surfaces and the deformation has to be fixed otherwise a building can collapse. A solution to any of the difficulties occurring can initiate a new concept, which results in another generation of the artifact, which leads to the development of further new concepts. This creates a feedback loop between the concept and the materiality of the building. In this regard, cybernetic approach with a strong constructivist perspective is much more applicable to architecture because of its direct link to technology and industrial materials. Development of architectural concepts formalised through buildings with interpolation of digital technologies by means of cybernetic principles of non-hierarchical and circular processes is an approach supported by this thesis. This is because through an expansion of knowledge about contemporary technologies and materials an architect can express his/her individuality and creativity through creation of interactive cybernetic environments.

For Pangaro, cybernetics is primarily an epistemological stance that is characterised as *the science of describing*, which means that it has a formal approach to the purpose and nature of this human activity. According to him, cybernetics disclose science as a process, rather than a research for 'truth' and it shows that it can operate not necessarily within the realm of the real world. Pangaro claims that cybernetics is primarily observable as an interaction in which the observer inextricably participates.[172] Regarding interaction, Pangaro argues that Sketchpad, which is the first computer drawing software application for drawing realistic objects by plotting pixels and polygons as well as scaling objects in relation to viewer's position,[173] has dramatically influenced human-computer interaction. He describes Sketchpad as having all of the essential elements of contemporary interaction involving the use of software. Pangaro defines the term *interaction* as a sequence of transactions that achieve a user's goal or a set of goals.[174] In this case transaction is defined as a minimal user's action that invokes a procedure in a serial digital computer. The user does not defines the goal(s) in advance, which results in a condition in which the beginning and end of interaction are

[172] Paul Pangaro, “Cybernetics: The Centre of Science's Future”, The Philosophical Society of Washington, 1991, 1.
[173] Sutherland, *Sketchpad*, 68.
[174] Paul Pangaro, “Beyond Menus: The Rats-A-Stratz or the Bahdeens”, Harvard Computer Graphics Week, Harvard University, Graduate School of Design, 1982, 4, Retrieved May 28, 2010, from http://www.pangaro.com/published/Beyond-Menus.html

not clearly specified. In case of specific and local goals, delimiters based on transactions may be useful but not strictly appropriate.[175] For Pangaro, the mode of interaction inherent to Sketchpad comprises the manipulation of drawn objects and requirement of user control. The differences he finds between Sketchpad and the interactive systems today are in the speed, size and complexity of systems. It is arguable whether today's understanding of human-computer interaction can be equated to Pangaro's definition in relation to software. Today, a kind of comprehension is considered as a relationship with a high level of computer's responsiveness to the user or his/her input, based on computer's reaction to user's commands. This kind of action-reaction relationship is far from being interactive.

According to Gillian Hunt, cybernetics can be understood as a position that allows for comprehension of machines through analogy to organisms.[176] Such an approach involves the creation of machines that are more flexible and adaptive, at the same time operating in homeostatic mode with their surrounding environments and physical elements in order to deal with the growing complexity of our world. Through the studies of a living organism's organisational complexity, one of the concepts that emerged, in cybernetics' attempt to provide means of designing more adaptable machines, is that of self-regulated or homeostatic machine that has autonomous control over its behaviour. In cybernetics' relation to architecture, whether the built physical structure or the content of the spaces created by the structure, the improvement of the concept of intelligent buildings is perceived as a capacity reflected in a building's structural autonomy, which is the case with biological systems.

In cybernetic terms, a building can be perceived as a dynamic assemblage of components that are not separate or isolated elements from the whole system that the building makes with its inhabitants. The pattern through which the different processes within the building could be revealed is the organisation of relationships of its different elements. This includes humans as autonomous individuals or constituents that are already intelligent in themselves.[177] As Hunt perceives, the structure of such a building can be the result of its experience. This can be achieved through an internal interaction with the environment that is cyclical and external interaction that is developmental. The

[175] Ibid., 5.
[176] Gillian Hunt, "Architecture in the Cybernetic Age" in Neil Spiller (ed.), *Architects in Cyberspace II*, John Wiley & Sons, London, 1998, 55.
[177] Ibid.,55.

resultant response of the structure would be a continual modification process with building's behaviour as an outcome of sequential structural connections with the environment. John Fraser, who collaborated with Price on the *Generator* project, discussed later in the text, considers that the conception of evolutionary architecture inspired by cybernetics can be engaged in an open relationship with the environment in both socio-economic and a metabolic sense. What he terms evolutionary architecture will promote evolution in its employment of positive feedback and maintain stability with the environment through negative feedback.[178]

The proposition of this thesis in the development of the meaning of cybernetics and in relation to architectural space are cybernetic architectural environments discussed in the next section.

2.1 Cybernetic Architectural Environments

Cybernetic architectural environments present a symbiosis between actual, virtual and biological domains. In present times it is not possible to consider them as a binary opposition to the traditional physical conception of architecture. These environments introduce a fusion of built physical structure, embedded electronic devices, digitized properties, parametric attributes, virtual overlays, etc. that composite layers of materiality with different forms of aesthetic quality. Cybernetic architectural environments concern architectural spaces augmented with diverse kinds of computational devices through which a participant can establish a relationship with a space. These new relationships created through interaction can change perception of the space from an enclosed shelter that serves for performance of a certain function, such as living or working, to the playful and engaging ambiance. An important aspects of these cybernetic spaces are different kind of relationships that can be established between the elements of the space, between the participants in the interactive process and between the elements of the space and the participants. These aspects can determine what kind of computational system will be employed and what will be its function. Interaction in cybernetic architectural environments can be established through entry points or digital nodes of interaction. Digital nodes of interaction refer to the physical elements in space augmented with computational devices that can invite and maintain interaction

[178] John H. Frazer, *An Evolutionary Architecture*, Architectural Association Press, London, 1996, 21.

processes.

Gordon Pask gave the first propositions for the design of cybernetic environments in which he sees the upgrade from thinking about the house as a *tool serving the inhabitant*[179] refined towards a mutualistic relationship, as compared to pure functionalism, that happens between the inhabitant and his/her environment with which s/he cooperates and can externalise his/her mental processes. In his proposal for how this new architectural concept of interaction machines in man-environment dialogue should take place, Pask conceptualises five stages: a) Specification of the purpose the system will perform; b) Choice of environmental materials; c) Selection of variables relevant to the system; d) Specification of the environmental development and e) Selection of the plan for adjustment and growth of the system. In terms of the interaction of the system and the people who inhabit it, Pask leaves definition of all the stages quite open and flexible for interpretation with a strong proposition of evolutionary possibilities so the system can develop in the future and adapt to the new circumstances and conditions. Pask's further proposition is regarding interaction between the designer and the system he/she designs through a computer as a medium.[180] With the assumption that the design goal and approach can always be delineated in advance and that the computer actually controls the design process through a previously established set of parameters the designer no longer represents an authority in making decisions. Although the designer influences the constitution of the parameters that will control the design process he/she do not propose the prescriptive rules of the inhabitant's life habits, through development of functional schemes of the dwelling, but leaves this to the inhabitant.

In this thesis genuinely interactive cybernetic architectural environments are considered to be in the state of a continuous feedback loop that provides a constant communication between the participants and the space and vice versa, through the network of computational devices. These kinds of environments can be changed according to participant's individual interest and motivation and not only through space's functional attributes. Functional attributes regard regulation of ventilation, light, sound and other spatial parameters that contribute to space's usability. Cybernetic architectural

179 Pask, “The Architectural Relevance of Cybernetics” in *Cyber Reader*, 80.
180 Ibid., 80.

environments can express an aesthetic conception of the designer and can interpolate a collaborative social aspect, which can be reflected through the content of information that is communicated between participants and space. In order to reach its homeostasis this kind of space need to provide an equal or larger number of output options in relation to its input options. This concerns that depending on the way one interacts with the space and the kind of choices one makes there can be a multiplicity of possible effects that can determine different environmental qualities of a space. Environmental qualities are regarded as ambient characters that may determine a sense of the place.

In this regard, there is a distinction between *reaction* and *interaction*.[181] Reaction is an automatic preprogrammed set of actions performed by the system in relation to the input parameters. Interaction has another level of complexity because it involves two or more parties in the communication process of which one participant in interaction can be preprogrammed to perform certain actions, while the other participant has an autonomous characteristic when decision making is concerned. Because of this autonomy the process of interaction is different with each individual. Depending on the specific selection the system can contain a number of regulators within the distinct software application that can filter out the undesirable experiences usually represented through created sound and/or image. An important element in cybernetic architectural environments is the quality of interactive substance because through its acquisition these environments can obtain different characters and ambient properties and in this way be observed as aesthetic rather than functional entities. Achievement of aesthetics through self-organising processes and application of the concept of mutualism/symbiosis in the design process during the creation of such environments can potentially bring new ways in which interaction can happen. These different concepts established through diverse modes of interaction will be discussed further in the text.

2.1.1 Chronology of Cybernetic Architectural Environments

The architectural background for the design of cybernetic environments can be found in the first initiatives for realisation of modular building systems, originating in the late 1800s with Joseph Paxton's *Crystal Palace*.[182] Modular building systems were applied to

[181] Hague and Pangaro, "Paskian Environments" in *Game, Set and Match II*, 468-477.
[182] Robert Kronenburg, *Houses in Motion: The Genesis, History and Development of the Portable Building*, Wiley-Academy, Chichester, 2002, 47.

the structures that evolved with occupants changing needs.[183] Another application of these systems is for building types that have a long-term or short-term temporary use, like schools, classrooms, construction site facilities, different kinds of markets and fairs, residential buildings, etc. They are often adaptable for construction in rural and remote areas where conventional construction methods may be unfeasible and prefabricated construction elements are necessary.[184] An important aspect of prefabricated construction methods is utilisation of construction element's codification which is necessary for their correct assemblage on the construction site. Material specifications and construction elements codifications are created during the architectural design process. The building methods applied in construction of prefabricated modular buildings, which comprise manufacture of the elements in a remote factory facility and then transportation to the construction site where the elements are assembled, implies application of prefabricated modes of production that concern utilisation of repetitive material components. This tendency toward utilisation of prefabricated repetitive material components was a direct consequence of Taylorist and/or Fordist production models established following the Industrial Revolution, as discussed in the first chapter.

One of the proposals for conceptualisation of cybernetic architectural environments was made in the early 1930s by one of the pioneers in this investigation, Buckminster Fuller. He proposed a concept of a building that considered the demands of its occupants in a sense that provided adaptability and capacity for its reconfiguration, based on his *organic concept of a building.*[185] Projects that followed in the 1960s by Yona Friedman, Archigram and Cedric Price adopted the base ideas of responsive environments and mechanization. The formulation of their projects, among other, included mega structures that were capable of self-organisation and self-construction. Self-construction refers to utilisation of local, natural materials found on site or in the proximity of the construction site. For example, building a stone house in coastal areas where stone could be found in an abundance. The conception of their architectural proposals, each distinct in its formal attributes, reflect architecture as continuous technological evolution that can accommodate technical degeneration, functional changes in usage and flexible organisation.

[183] Peter Anders and Michael Phillips, "Arch-OS: An operating system for buildings", (paper for ACADIA conference 2004), 2., Retrieved March 21, 2010, from http://www.chrisoshea.org/files/cybrid/rp150.pdf
[184] Kronenburg and Klassen, *Transportable Environments*, 158-195.
[185] Buckminster Fuller, *Ideas and Integrities*, Collier Books, New York, 1963, 92-93.

This is particularly reflected in the proposal for *Mobile Architecture* by Yona Friedman in 1958. His proposal concerned provision of a continuous and flexible space enclosure with the provision of temporary constructions, so called agglomerations, rearranged periodically according to necessity.[186] Conceptual experiments with this kind of building technology systems were also conveyed through projects such as the *Generator* project in 1976 by Cedric Price. Later, in 1983, Fuller, together with Norman Foster, developed the *Autonomous Dwelling*. This project consisted of two independently rotating geodesic domes that opened and closed in relation to the Sun's disposition during the day, in this way providing an ideal climate for the inhabitants.[187] The previously described working methodology suggests that by the time computer technology becomes more developed in terms of its processing power, the entire process of construction elements assembly on the building site can be controlled by a computer. Further technological improvements has also created a base for the actualisation of architectural experiments such as ones conducted in 2007-2008 at ETH in Zurich by Fabio Gramazio and Matthias Kohler.[188] All these proposals introduced an interaction parameter in conceptualisation of cybernetic architectural environments, which will be discussed in the next section.

2.1.2 Modes of Interaction in Cybernetic Environments

One of the theoretical grounds for development of responsive and reflexive types of buildings was set by cybernetician Gordon Pask in the 1960s. He envisioned architecture as *fundamental conversational system in human culture*.[189] Good examples of his evolutionary theory Pask finds in the *vegetable surrealism*[190] of Art Nouveau and conceptualisation of Japanese Metabolism. For Pask, the *Fun Palace*, which was conceived in his collaboration with Cedric Price and the theatre director Joan Littlewood presents the beginning of *system-oriented thinking*[191] in architecture. It is important to point out that he became a chair of the Cybernetics Committee for the *Fun Palace*.[192] In setting up the status for his new theory in relation to previous *pure* architecture, Pask stated that cybernetics brings in a metalanguage for critical

[186] Hunt, "Architecture in the Cybernetic Age" in *Architects in Cyberspace II*, 53.
[187] J. Baldwin, *BuckyWorks: Buckminster Fuller's Ideas for Today*, John Wiley & Sons Inc., New York,1996, 26-28.
[188] Gramazio and Kohler, *Digital Materiality*, 35.
[189] Pask, "The Architectural Relevance of Cybernetics" in *Cyber Reader*, 77.
[190] Ibid,. 78.
[191] Ibid., 79.
[192] Cedric Price et al., *Re:CP*, Birkhauser – Publishers for Architecture, Basel, Boston, Berlin, 2003, 69.

discussion. He declared that cybernetic theory does not represent a mere extension of pure architecture but is a step further in this line of thought. For Pask, pure architecture was descriptive, meaning that it presents a taxonomy of methods and buildings, and prescriptive, meaning that through preparation of plans, sections and elevations it ordains a way people use the space, but was not predictive or explanatory.

Cedric Price's designs for the *Fun Palace* in 1961[193] and the *Potteries Think Belt* in 1964[194] in the United Kingdom, reflected a dynamic, changing modality of building's formalisation. *Fun Palace* was the first architectural project that implemented the concept of moving walls, floors and ceilings that responded instantly to the occupants actions. The concept of mobile and changeable components in a constant conversation with each other, located in an architectural space, Pask realised in his project the *Colloquy of Mobiles* exhibited at ICA, London in 1968 as part of seminal exhibition *Cybernetic Serendipity*. Besides the evocative character of the project, that reflects satirically illustrated human interactions through a mechanical embodiment, Pask created a base for a new mode of interaction that have been termed by Pangaro and Haque as *Paskian Environments*.[195]

Figure 2.0: *Colloquy of Mobiles*, Gordon Pask, ICA, London, 1968.

Figure 2.1: *Musicolour Machine,* Gordon Pask, 1953-1957.

In these terms, both of Pask's projects, namely *Colloquy of Mobiles* and *Musicolour Machine*, shown in figures 2.0 and 2.1 above, can be considered as Paskian

[193] Ibid., 69.
[194] Stanley Mathews, *From Agit-Prop to Free Space: The Architecture of Cedric Price*, Black Dog, London, 2007, 192.
[195] Hague and Pangaro, “Paskian Environments” in *Game, Set and Match II*, 468-476.

Environments. Both of the projects were staging an open-ended performative encounters between its participants with a difference, in case of the *Colloquy*, in the limited range of behaviour and fixed goals of robots. *Colloquy* highlighted the role of language, communication and signalling within cybernetics. This was evident in the combinations of different light and sounds that robots responded to, besides their reaction to the presence or absence of light and the thresholds in light intensity.[196] While in the case of *Musicolour* the input could range from a musician playing an instrument that can modulate the lights and marionettes on a stage (*Moon Music*) to a motion of a human dancer (*Nocturne*). While performing on the *Musicolour*, the performer, perfomatively rather than cognitively, learned about the machine and the machine learned about the perfomer. In this regard, Pask considered that one could scientifically learn about learning through *Musicolour* machine.[197]

Pangaro and Haque state that these projects indicate Pask's interest in exploration of what they call the double-loop model as opposed to a one-way reactive interaction model. For them, in the one-way reactive model the machine contains a finite amount of information and dictates the mode in which this information is revealed. In this model, a participant needs to navigate through pre-determined scenery in order to uncover the concealed information. Contrary to this, in the double-loop models the data is created by the participants inside the space and the data output is affected by the data input. If the conversation with the artifacts does not happen the data will not exist but once the conversation is established the data has no limits. A participant in the interaction with the environment is the one who creates the information. Pangaro and Haque consider the interaction process as a constant conversation between participant(s) and architectural space through the computer(s) embedded in an environment.

As Pask would say, human experimentations with novelty are oriented towards finding novel situations and then by learning about them through problem solving situations it is possible to create a base for knowledge accumulation. A learning through *problem solving*[198] Pask relates to the already existing *body of experience*.[199] In one's ability to solve problems or in acquisition to master and point to the mechanisms around the one,

[196] Andrew Pickering, *The Cybernetic Brain: Sketches of Another Future*, Chicago University Press, Chicago and London, 2010, 360.
[197] Ibid., 316-318.
[198] Gordon Pask, “A Comment, a Case History and a Plan” in Jasia Reichardt (ed.), *Cybernetics, Art and Ideas*, Studio Vista, London, 1971, 76.
[199] Ibid., 76.

s/he is urged to develop conceiving mechanisms to abstract meaning and essence. This results in an interpretation of the human environment on several levels that have a hierarchy of abstraction. For him, this presents an elementary constituent of curiosity and therefore the assimilation of knowledge, because curiosity presents an initiating factor in the search for knowledge. Curiosity causes one to reveal, research and experiment with his/her adjacent and remote surroundings. At a certain moment in time this adjacent or remote surrounding overlaps with the surrounding of another human being and they are lead into social communication of diverse disclosure that can be in form of conversation, gazing or other modes of human interaction. The meaning of Pask's statement is that through meaningful interaction with an environment there is a potential to achieve more meaningful natural interaction, one being between human beings.

In my opinion, a careful observation and a creative impulse is needed in recognising these novel situations, or potential moments for meaningful interaction, or even influencing their emergence. In the conceptualisation of future projects, the smoother transition between the two modalities, social and spatial, is needed. The first one should contain refined conclusions in regard to social needs and second one should contain careful decisions about their formalisation into spacial modalities. This is possible to achieve in a form of constant communication between space and people inside it who can change the space through continuous real-time interaction with it, which was indicated in its early form in the *Fun Palace* project for example. An intention to entrust the inhabitants to alter the space according to their needs and requirements is fairly utopian but it is a step towards spaces with no pre-prescription for their usage and therefore free for interpretation and exploration, spaces that can induce and initiate curiosity.

2.1.3 Soft-Architecture

A novelty that happened in Price's *Fun Palace* and later on in 1976 in a more developed concept for the *Generator* project is the introduction of computers as active and even autonomous control mechanisms within buildings. In it Price created conditions for shifting, changing personal interaction in a reconfigurable and responsive cybernetic environment. This building, which was never constructed, was to serve as a retreat and activity centre for small groups of visitors.[200] For this project Price developed a scheme of 150 re-combinable mobile cubes, dimensions 12x12 inches, with off the shelf infill panels, glazing and sliding glass doors, screens and board-walks, all of which could be moved by mobile crane as desired by the occupants to support their activities.[201] Gillian Hunt describes the project as a computer program that was developed to propose new arrangements with embedded electronics in each component that would enable connections to the foundation pads.[202] She identifies the building's site as a large working model in which the configuration of the processor had direct and real-time influence on the formal configuration it was modelling, as shown in figures 2.2 and 2.3 below. An idea that the controlling processor has the main role in automatic operation of the construction elements relocation in different positions within the physical structure by means of their digitization into computer controllable agents was introduced early in the project's conceptualisation. This was done by programmer-architects John and Julia Fraser who formed the foundation for building's intelligence by introducing embedded sensors that were controlled by specifically written software application. In case human interventions or an interaction with the structural elements did not occur frequent enough, an innovative anti-inertia software application was initiated, which involved the computer supporting unsolicited alterations. In the time it was designed the *Generator* project was publicized as the world's first intelligent building.

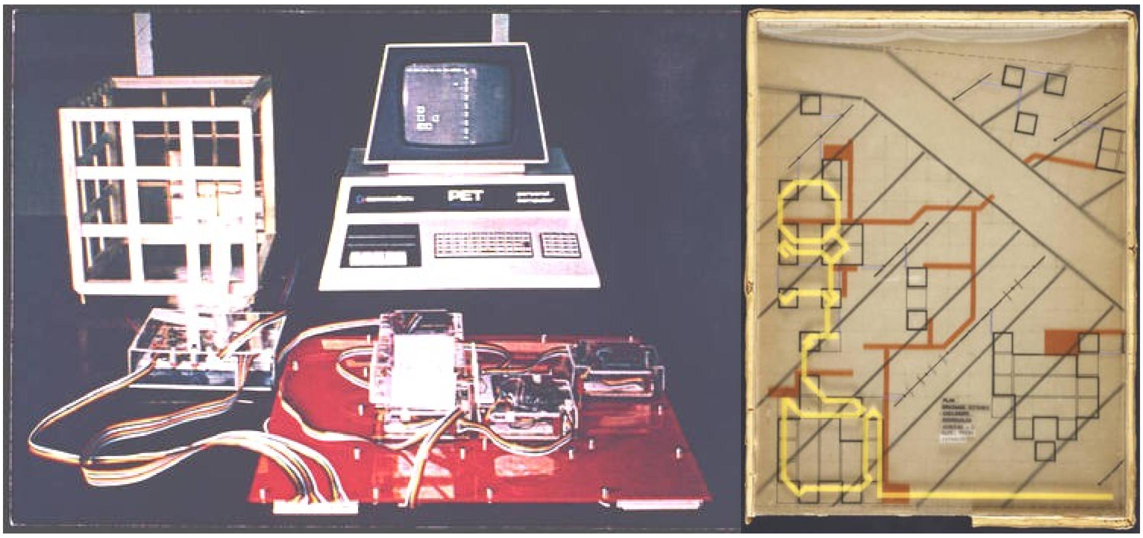


Figure 2.2: *Five Enclosures - Model and Baseboard* and Figure 2.3: *Plan of Service and Structure*, *Generator* project, Cedric Price, 1976.

[200] Paola Antonelli and Terence Riley (eds.), "Interview with Pierre Apraxine," in *The Changing of the Avant-Garde: Visionary Architectural Drawings from the Howard Gilman Collection*, Museum of Modern Art, New York, 2002, 150.
[201] Molly Wright Steenson, *Cedric Price's Generator*, 1, Retrieved March 22, 2010, from http://www.activesocialplastic.com/2007/08/cedric_prices_generator.html
[202] Hunt, “Architecture in the Cybernetic Age” in *Architects in Cyberspace II*, 54.

Price considered architecture to be a platform with changeable configuration allowing for the conditions for interaction to occur, instead of imposing a formal intention on the inhabitants of a certain place, which is a common disposition architects take regarding the design of an architectural space. Even today with accelerated development of computer technology Price and Fraser's technical vision still presents an a challenging task because of the project's scale and potentially questionable maintenance issues. In case of the *Generator* project, introduction of software applications as operators of building's hardware was useful regarding the possible and unexpected interaction that could potentially happen inside the building. Price's involvement in social issues regarding inhabitant's relationship with the building and inter-personal relationships inside the building, investigations in the realm of contextual significances and, at the same time, connecting this with the underlying cybernetic concepts for creation of the design, were primary grounds for this project to be positioned among the most important representatives of cybernetic architectural environments.

In 1967, this kind of behaviour of a building was characterised as *soft architecture* by architect Warren Brody. He describes buildings not only as responding towards its occupant's needs and requests but also as entities that can learn from the occupants and in this way anticipate their needs or movements.[203] A pragmatic interpretation of cybernetic ideas was carried out by Andrew Rabeneck in 1969 in his proposition to utilise cybernetic technologies in order to produce a changeable architecture that would increase the useful life span of a building through adaptation.[204] In 1972 Charles Eastman published the model of Adaptive-Conditional Architecture presenting an expansion of Pask's and Weiner's ideas in which architects interpreted spaces in symbiosis with the participants or users of the spaces as a complete feedback systems.[205] Eastman proposed usage of feedback in order to control a self-adjusting architecture that operates in such a manner so it can be suitable for the needs of its users. It is important to underline that Eastman's model was essentially based on a machine-led approach.

The previously mentioned cybernetic ideas basically describe such kinds of responsive

[203] Warren Brodey, “Soft Architecture: The Design of Intelligent Environments”, *Landscape 17*, Number 1, Autumn 1967, 8-12.
[204] Andrew Rabeneck, “Cybermation: A Useful Dream” in *Architectural Design*, Volume 39, September 1969, 497–500.
[205] Charles Eastman, “Adaptive-Conditional Architecture” in Nigel Cross (ed.), *Design Participation*, Proceedings of the Design Research Society’s Conference Manchester, September 1971, Academy Editions, London, 1972, 51–57.

actions of users and architecture as *dynamic stability*. Dynamic stability is the property of a body, in mechanics, such as rocket, aircraft or a ship, that can, when disturbed from a condition of equilibrium or from an original state of steady motion, develop counter-forces or restoring movements and gradually return to its original state. A dynamic stability in regard to the architectural space, presents a balance between user's needs and the possibility of the space to adjust or to bring itself in a state of equilibrium. The concept of dynamic stability has its root in the previously discussed concept of homeostasis, the cybernetic definition of which was firstly established by Walter Bradford Cannon.[206] There is a similarity of the concepts that Brody wrote about and Price designed by, both of which distinguish a computer processor as an entity capable of influencing the building not only from the design drawing aspect, as with software such as Auto CAD or Microstation, but from the aspect of the influence on the building's materiality and behaviour as well. This concerns computational system augmenting an architectural building which does not reply to an observer by a simple reflex that is at once relevant to the situation but stimulates an observer to participate in interaction with a system by providing many and varied actions from which the successful action is selected by a process of trial and error. The successful one will be that action which improves the system with respect to the situation in question.

Considering the materiality quality, Price introduced new layers of digitization to the existing construction elements, which are not regarded as passive in his conception of spaces, in either the *Fun Palace* or *Generator* projects. He makes elements manipulable and interactive through utilisation of computer processor and software applications as driving forces that can cause changes in the structure of the building regardless if the interaction is triggered by the inhabitants. The learning possibility of the system, that Brody wrote about points towards self-organisation in a sense that through time required for achievement of complex intelligence, which is one required for self-organisation, the system will become evolutionary, predictive, purposeful and active environment.[207] This made a base for the new model of architectural computing and re-defined a concept of computational architecture. This implies that processes with the potential for automation can be controlled by means of a computer.

[206] Cannon, *The Wisdom of the Body*, 112.
[207] Brodey, *Soft Architecture*, 8-12.

The model for which Price and Brody established a theoretical ground, developed into computerised systems such as HVAC,[208] which is a technology for indoor automated comfort and security systems.[209] Another model that is AI assisted and not based strictly on the functional attributes of a system, as HVAC, took its form in the so-called *smart rooms* developed in Massachusetts Institute of Technology (MIT) or as experiments in ubiquitous computing at XeroxPARC, Georgia Institute of Technology, Fraunhofer Institut in Germany and other renowned organizations.[210] Smart rooms, such as those experimented with at MIT, have properties that enable them to perform like invisible assistants. They have cameras, microphones, motion tracking systems and other sensors that collect the inputs from users of the space. The inputs are collected in an attempt to interpret peoples actions in the space so that the digitized elements of the space can be altered to help people in the space. The smart rooms can provide an unencumbered user-interface to a virtual environment.[211] In this way, smart rooms present a step toward a symbiosis between smart and digital materials. Current research on smart materials, extends from shape memory alloys, actuators and sensors to an extension of digital mechanisms to the fabric of the cybernetic buildings. This new characteristic of a building's transformable materiality is discussed from the perspective of digital façades or the external skin of the building in the fourth chapter.

The possibility to adjust and change parameters in the interaction process that cybernetics brings in can be understood as an abstract element of an architectural design. Interaction can introduce the variability to the disposition of structural elements and in this way establish multiplicity of spatial assemblages that the inhabitant of the space can choose from, as exemplified through the *Generator* project. In this way, spatial dispositions are not fixed by an architect but are selected by an inhabitant: the architect just creates a flexible platform for an interaction process to happen. In this way the inhabitant of the cybernetic space can actively participate in a continuous assemblage of elements that can be in a mode of a dynamic composition. The architect's relationship with an architectural space realised through utilisation of cybernetic concepts, such as the *Law of Requisite Variety* established by Ashby, feedback loops,

[208] Heating, Ventilating and Air-Conditioning.
[209] Isabella M. Amirante and Burattini Ernesto, "Automatic Procedures for Bioclimatic Control" in J. Klercker (ed.), *Education for Practice*, Proceedings of the 14th eCAADe Conference, Lund, Sweden, 12-14 September 1996, 29-40.
[210] Anders and Phillips, "Arch-OS", 25.
[211] Christopher R. Wren et al., "Perceptive Spaces for Performance and Entertainment: Untethered Interaction using Computer Vision and Audition", MIT Media Laboratory, Perceptual Computing Section Technical Report Number 372, 234, Retrieved May 02, 2010, from http://alumni.media.mit.edu/~flavia/Papers/perceptiveSpaces.pdf

circularity, self-organisation, mutualism, communication, learning, etc., can emerge into spaces that will influence the development of a different way for people to interact with their habitats. Another example, besides the *Generator* project, that represents qualities of the cybernetic environments with the range of options for continuous physical re-composition is the *Fun Palace* project by Cedric Price. An interesting addition in relation the *Generator* project is the social quality of interaction that will be discussed further.

2.2 Modes of Social Interaction in the *Fun Palace* Project

In the *Fun Palace* project, which Cedric Price also referred to as a *laboratory of fun*,[212] he envisioned a building that acts like a generator of social activity. The notion that is constantly present in Price's work is a particular kind of intelligence with interaction as a main motivation because he believed that intelligence does not lie in a head or a computer but in interaction.[213] Heinz von Foerster distinguishes the *Fun Palace* as the first cybernetic building because it accepts circularity and creates a base for circular processes to occur. The social and political issues that Price addressed in this project reach beyond formal boundaries typically addressed in architecture. For him, the social concept of the building regards the *Fun Palace* primarily as *people's workshop* or *university of the streets*.[214] The degree in which the control of physical environment is conducted by the users presents the level to which the self-participatory element of social activities must extend. If the time factor is included as an absolute design factor in an architectural design process the inbuilt flexibility or planned obsolescence can be achieved. An interesting premise that illustrates the continuous changeability and the accentuation of the social development process is Price's understanding of time. Time is an element that largely determines the physical form of the building because of the imperative deadlines an architect needs to accomplish when design and construction of a building is concerned, in the traditional terms of the design and construction processes. In case of *Fun Palace*, the notion of time constrains is diminished because of the constant changeability of the building through social involvement. This means that the structure of the building is under constant construction and the social aspect build into the building's programme is the component that influences this change. In a sense

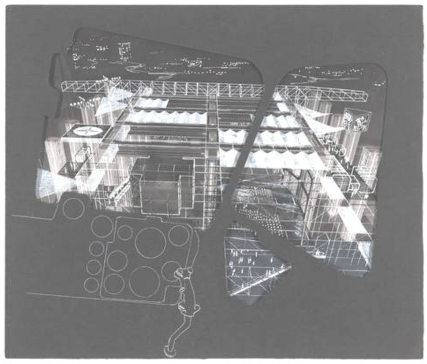
[212] Isozaki, "Erasing Architecture into the System" in *Re:CP*, 28.
[213] Ibid., 69.
[214] Price, "Interview with Cedric Price" in *Re:CP*, 57.

the building is under constant de-construction. An absence of the time constraint can allow the building to be perceived as an architectural process rather than as completed architectural object. In the *Fun Palace* project illustrated in figures 2.4 and 2.5 below, Price and Littlewod's main goals were achieving the continuity of social interaction through an assembly and sharing of knowledge by means of diverse modalities of programmatic activities. Littlewood's orientation was also towards achieving redefinition of leisure in the post-industrial Britain[215] and relates to later theories, such as Von Hippel's of open innovation systems.[216]

The activities that were included into the overall programmatic activity of the building range from leisure-time activities, such as mechanical tests like those commonly conducted by technicians and psychologists, through music and science activities, such as lectures, film-making, TV and theatre performances, etc.[217] Joan Littlewood's idea was to dismantle the formalism of theatre and amusement facilities and to reinvent them in a more creative way by their reincorporation into the everyday life of society. Considering building's purpose and its changeable properties required a non-permanent structure that is easy to dismantle, to transport and reassemble in other locations with the flexibility to adapt to the new conditions of the new locality.[218] This line of thought came out of the idea that was strongly incorporated in the projects of 1960s and that is the idea of uncertainty. The base for this idea was constructively represented in the 1968 exhibition *Cybernetic Serendipity* that suggested a particular approach to interactivity, one that favours unanticipated effects. In her discussion about the meaning of the term *serendipity* Michelle Henning points toward Lorraine Daston, the science historian, who associated the links between the modern and ancient concepts of serendipity with the regard towards distinctive differences between them. In ancient terms serendipity was considered to be an appetite for curiosity, while in modern times serendipitous discoveries can happen to individuals who have the wandering but voracious desire for novelty. These individuals have ability to combine *focused attention and peripheral intellectual vision*.[219]

---

[215] Mathews, *From Agit-Prop to Free Space*, 70.
[216] Collected Papers of Eric von Hippel, Section 3: Open Information / Intellectual Property / Information Trading, 3, Retrieved March 20, 2011, from http://web.mit.edu/evhippel/www/papers/evh-03.htm
[217] Isozaki, “Erasing Architecture into the System” in *Re:CP*, 28-33.
[218] Ibid., 33.
[219] Lorraine Daston, "Curiosity in Early Modern Science" in *Word and Image*, Number 11, 1995, 391-404.

Figures 2.4 and 2.5: Hand perspective drawings for *Fun Palace* project, Cedric Price, 1964.

Besides scientists, like Gordon Pask, architects, like Cedric Price, the artists associated to the Fluxus group, like John Cage, Alison Knowles and Dick Higgins, were part of the exhibition as well. They were interested in the creation of work that is participatory in character and that would motivate the audience to complete it. Price's work was partly influenced by John Cage's music that supported incorporation of uncertain and discontinuous elements in varying combinations according to the circumstances of the performance.[220] The participatory component in Cage and Price's works is the factor that connects them, because both authors do not finalise their work but leave them open for public engagement. In this regard, an important aspect of the *Fun Palace* was that it was not strictly determined by the components related to the time or space, which are traditionally composed and pre-set by an architect. The significance of the *Fun Palace* was in the changing view of architecture not merely composed of static elements but perceived as an assembly of hardware components that were run by the software created out of people's actions. In this way the social interaction that occurs inside the building becomes the running force of its life at the same time initiating self-organisation, as discussed in the next section.

2.2.1 *Fun Palace* as Self-Organised System

The *Fun Palace* can be regarded as an architectural formalisation of a self-organised system in regard to the definition of self-organised systems according to Bonabeau, Dorigo and Theraulaz. This definition concerns four basic functions self-organisation relies on and these are balance of examination and exploitation, multiple interactions

[220] James Pritchett, *The Music of John Cage*, Cambridge University Press, Cambridge, New York and Melbourne, 1996, 57.

and positive and negative feedback.[221] The translation of the first basic function, that is balance of examination and exploitation, into architectural artifacts in Fun Palace's interior, presents a base for open exploration. An open exploration is based on one's curiosities and it involves employment of given options that change each time interaction happens. There is a continuous pattern of change in the system of architectural elements arrangement through collective activity. In the concept of *Fun Palace*, pattern and structure at the global level arises solely from the interactions among the participants in the system because they are enabled to move and change the architectural elements at their disposal. The structural frame(s) of the building, which support the main loads of construction and the façade are non-movable elements however because their structural instability can bring the building to collapse and endanger people inside the building. These construction elements frame the social interaction that happens inside the building and support the continuity of its flux.[222] The interactions are specified by the rules executed using only local information that is provided inside the building through movable physical elements, without reference to the global pattern or non-movable construction elements. This is at the same time a crucial difference with the *Generator* project, discussed previously in the chapter in which it is possible to move all the elements of the building regardless of their construction importance. In this case the combinatorial form may provide the safety constraint, which can be regulated through restriction of certain combinations considered as harmful. *Fun Palace* provides a social platform for examination and exploitation because all the resources and program activities in the building are at the disposal to participants independently of the time period, which means that the building is open for public interaction during the day and night.

Regarding multiple interactions as another of the base functions of self-organising systems, the interaction that occurs within *Fun Palace* has quantitative properties because it is possible for a large number of people to interact in real-time and at the same time. It also has different degrees of freedom because participants can be involved in different modes of interaction depending on the action they choose to participate in. Another instance that implies a self-organisation in the system, such as the *Fun Palace* is the absence of a priori order one needs to follow in order to interact. Therefore, there

[221] Eric Bonabeau et al., *Swarm Intelligence: From Natural to Artificial Systems*, Oxford University Press, New York, 1999, 9-11.
[222] Scott Camazine, “Self-organizing Systems”, Boalsburg, Pennsylvania, USA, 1, Retrieved April 05, 2010, from http://web.mac.com/camazine/Camazine/Self-organization_files/Self-organization.pdf

is an intense focus on non-linear interactivity. In artificial systems non-linearity is often achieved through positive feedback that amplifies the initial change.[223] The result of the first amplification again triggers positive feedback that amplifies the effect of further change. Through this process in time a number of components have aligned themselves with the configuration created by the initial change and the configuration stops growing, which means that the system has exhausted the available resources. This kind of alignment is often the emergent property of the system and in this way an emergent can self-organise.

Applied in the case of the *Fun Palace* this can mean that there is a finite number of elements that one can interact with inside the building's space and in a definite time period all the combinations of elements are reached. After this point, in the case of artificial systems, self-organization can occur because the system has learned all the possible configurations and now can decide which one is the best in the specific conditions. In case of *Fun Palace* the agents involved are humans and it can be considered that after a number of element configurations are exhausted they can decide which one is best suited or to introduce negative feedback. In case of artificial systems, after the non-linear alignment is achieved by utilisation of positive feedback, the only possibility to change this situation and create a new alignment adapted to the new situation is to introduce negative feedback. In case of more complex self-organizing systems there will be several interlocking positive and negative feedback loops, so that changes in some directions are amplified while changes in other directions are suppressed. In this regard, positive and negative feedback, as third and fourth function of self-organizing systems, is obtained by the participants in their direct or indirect interaction. This means, because the structure and the activity that happens inside the *Fun Palace* is under constant change, one can add or reduce from the work previously done by a different participant in order to make a common effort. This means that input or configuration of interior elements created by an individual alone can be regarded as positive feedback but then when another individual changes the alignment first individual achieved, this can be regarded as negative feedback. The presence of negative and positive feedback is important for adaptive behaviour.

[223] Tom De Wolf and Tom Holvoet, "Emergence Versus Self-Organization: Different Concepts but Promising When Combined" in Sven A. Brueckner et al. (eds.), *Engineering Self-Organizing Systems: Methodologies and Applications*, Springer-Verlag, Berlin and Heidelberg, 2005, 12.

In relation to the collaborative social activities that can form around buildings, *Fun Palace* can be regarded as a *transparent building*. An engagement in *Fun Palace* activities can be referred to as a collaborative process because although participants may have different views about how certain procedures should occur, through mutual feedback a common solution can be achieved. A cybernetic architectural environment comprise this important aspect of social interaction as a primary component in the conceptualisation of cybernetic architectural spaces. This can be achieved, as previously noted in the example of the *Fun Palace*, through different modes of interaction with the space or its elements that can create a base for different levels of intuitive learning about people's influence on the environment and their relation with each other. Another interesting concept illustrated by the *Fun Palace* project is interaction through self-organization that will be discussed in the next section.

2.3 Interaction Through Self-Organisation

W. Ross Ashby introduces the term *self-organisation* to contemporary science in 1947 in his text "Principles of the Self-Organizing Dynamic System".[224] Further development of the term was conveyed by cyberneticians Gordon Pask, Heinz von Foerster, Norbert Wiener and others. An important element for development of the term 'self-organization' is Ashby's concept of the *Homeostat,* a central theme for another of his books "Design for a Brain" published in 1952.[225] In this book,[226] Ashby established and developed a complete mathematical apparatus for the analysis of complex systems. His homeostat illustrates a vision of a complex system that contains a number of fluid ever-changing entities engaged in trial-and-error search processes, which are in themselves temporal.[227] These entities evolve through an adaptation to their environment. Such adaptation is a prolonged process that can happen through time, if the conditions for its occurrence are achieved, through the set of trial steps that do or do not work. This means that the homeostat has the ability to organize itself or to learn and adjust to the environment, to a certain degree, through entities that are in a flux or a constant process of adjustment/response to the environmental conditions, which through their behavioural patterns reach an equilibrium. In this sense the homeostat presents an

[224] William R. Ashby, "Principles of the Self-Organizing Dynamic System" in *Journal of General Psychology*, Volume 37, 1947, 125-128.
[225] William R. Ashby, *Design for Brain*, John Wiley & Sons Inc., New York, 1954, 29.
[226] Reprinted in 1960.
[227] Pickering, *The Cybernetic Brain*, 107.

ontology of becoming that cannot be determined in advance but which evolves through environmental factors which through time can determine what will system's entities become in the future. This points towards the necessary constituent of Ashby's science: an interaction with the unknowable.[228] The homeostat illustrates a good model for adaptation to the environment and therefore reflects the relationships that may occur within this environment through relations and connections between dynamic entities within a complex system. The quality of an entity's interaction will determine the level of system's adaptation to an environment. System's adaptation happens through a complex interaction as a continuous feedback loop between a complex system and its environment.

The conclusion that Andrew Pickering draws from Ashby's concept of the homeostat, is that it can be perceived *as a model of dynamic entities evolving in perfomative (rather than representative) interaction with one another.*[229] This means that through observation of an environment the system have the ability to change and adjust to it, because through its performance within an environment and interaction with it, a system learns about it. Through learning, in an active engagement with an environment, system's perception of the environment changes. The system starts to perceive and establish patterns and connections between fluid entities within an environment in a trial and error search processes. As it learns about the environment through these processes the system becomes an integral part of the environment, because of the new connections established through a continuous conversation with an environment. The homeostat, when disturbed from the state of equilibrium, can converge on one of many possible stable states. Ashby's concept of the *Homeostat* and his *Law of Requisite Variety* in which he, among other, describes stable states, created a base for an introduction of a *Regulator* theory that required internal models for self-organized endurance and stability in a system. In terms of an architectural design Ashby's relation was articulated through a cybernetic philosophy of evolutionary design, or of design *in medias res*, which presents a different approach from the blueprint attitude of the modern engineering design. The blueprint attitude concerns a position of a designer as a detached observer who commands physical entities via a deviation through knowledge.

[228] Ibid., 109.
[229] Ibid., 154.

Heinz von Foerster and Gordon Pask collaborated on the self-organization research theme which Pask describes in his text "Heinz von Foerster's Self Organisation, the Progenitor of Conversation and Interaction Theories" written in 1996.[230] In this text he describes self-organization as a process that happens between people as they are gathered together to learn about each other and each other's environment. Pask saw this interaction, which was declared by von Foerster, as paradigmatic of a conversation between two participants. As a consequence of this mode of interaction an observer who comes to know the system must be a participant in the system. The boundaries of the system, which are not prefabricated, are created by the activities of the system.[231] Pask calls this a prescient notion of *autopoiesis* or auto (self)-creation, a term developed by Humberto Maturana and Francisco Varela in 1972, which expresses a fundamental dialectic between structure and function.[232] Pask stated that in regard to the idea developed by himself and von Foerster, self-organization is not adaptation or habituation, nor it is a some special form of learning but a fundamental paradigm that merges and forms a bridge between the old and new cybernetics.[233]

In order to establish a relationship between von Foerster's and Pask's notions of self-organisation and consequentially autopoiesis it is important to define how is self-organisation perceived within architecture and what it can be translated into. One of the most related is the subject of the form-finding process discussed in the next section.

2.3.1 Form-Finding as Self-Organisational Process in Architecture

A pioneer in the application of form-finding process in architecture was Frei Otto.[234] Under his direction during 1964-1991 research was conducted at the University of Stuttgart at the Institute of Lightweight Structures. This research was focused on structural forms, obtained through the *lightweight principle*. In the creation of structures, this principle concerns the use of a minimum amount of material, while through the shape optimization process it maximizes, at the same time, their stability and strength. Explorations involved creation of small-scale models and consisted of the

[230] Pask, "Heinz von Foerster's Self Organisation", 349-362.
[231] Ibid., 353.
[232] Humbert R. Maturana and Francisco J. Varela, *Autpoiesis and Cognition*, D. Reidel Publishing Company, Dordrecht, Holland, 1980, 295.
[233] Pask, "Heinz von Foerster's Self Organisation", 355.
[234] Branko Kolarevic and Ali M. Malkawi (eds.), *Performative Architecture: Beyond Instrumentality*, Spon Press, New York, 2005, 199.

experimental work of interdisciplinary teams of architects, biologists and engineers. These teams were involved in repetitive processes of improvement and selection that, in addition to the optimization criteria and the structure's function, included architectural features such as perspective, symmetry and proportion. Exploratory objects emerged naturally through a *self-optimization* process, as it was considered at the time. In general, the conclusions of these experiments were that the output of the form-finding process can be formalised in optimal structural shapes, which need to fulfil the functional requirements and to accompany strength and durability at minimum cost.[235] A number of architects, biologists and mathematicians have explored the topic of natural structures, such as biologist D' Arcy Thompson in his book "On Growth and Form" published in 1917.[236] In this book Thompson emphasized roles of physical laws and mechanics rather than evolution, as the fundamental determinant of the form and structure of living organisms. He examined a variety of natural objects, such as shells, and discussed principles that influenced their formation accenting correlations between biological forms and mechanical phenomena.[237] Nowadays, the research on biomechanics by Claus Mattheck, described in his 1998 book "Design in Nature: Learning from Trees",[238] which includes the mechanics of the tree growth, also addresses importance of natural laws for the design of man made structures.

The above shows that, in architecture, form-finding is a generative process that explores processes in nature to discover a more spontaneous way in which the organizational structure of a building should occur. It presents a field for exploration in the search for optimum form and its dynamic adaptability, at the same time discovering a set of relationships that were not, through its history, relevant for architecture. The beauty of these objects is in an emergent property of natural forms, which does not have to be prescribed through design. An interesting attribute of these kind of emergent objects is not in their aesthetics but in the modalities in which they become formalised through their physical structure obtained in relation to natural forms, apparently actualised without a plan, in a range of different materials and at a multitude of scales. In obtaining the formal physical attributes these emergent forms go through a natural algorithmic process that determines their form, size, structure, material, consistency, colour, texture,

[235] Wanda J. Lewis, *Tension Structures: Form and Behaviour,* Thomas Telford Ltd., London, 2003, pp. 23-24.
[236] D' Arcy W. Thompson, *On Growth and Form*, Cambridge University Press, Cambridge, New York, Melboune, Madrid and Cape Town, 1961, 94.
[237] Ibid., 188-189.
[238] Claus Mattheck, *Design in Nature: Learning From Trees*, Springer-Verlag, Berlin, Heidelberg and New York, 1998, 42.

etc. One formal approach for the application of these algorithms is through use of patterns, which will be discussed further on in this chapter. The form of a pattern created through the self-organisational process can be unexpected, adaptive and dynamic. The formalisation of an architectural design, similarly to patterning in nature, should be able to exist in a perpetual state of emergence. This was discussed through the Fun Palace project as a cyclical process of the continual construction and de-construction of a building. This implies that the building should be able to process any internal forces, such as social interaction, without relinquishing function.

In the digital age, the form-finding process is enabled through the utilisation of different parametric software applications. In the form-finding process generated by a computer, elements that may assist the designer are geometric (morphology) calculation, physical modelling and equilibrium calculation. One of the early form-finding software applications was Formex. The Formex computational processes configuration was with particular emphasis on the generation of surfaces, curved shapes and pattens, as well as configurations modelled on polyhedra and various geodesic forms.[239] For general or specific form-finding purposes many other methodologies have been developed. Among those, the CORELLI software application for generating polyhedra by rotation of polygons.[240] The new methods integrated in novel software applications, such as CATIA, are designed to deal with arbitrarily chosen forms, while most of the early form-shaping applications, such as ones previously mentioned, were based on some kind of regular geometric properties.[241] The formal complexity of the Gehry's *Guggenheim Museum* in Bilbao was possible because of CATIA's capability of dealing with arbitrarily chosen forms. Complicated curves, such as those used for the *Guggenheim Museum*, Bilbao have been defined as hyperstructures and design with them as hypersurface architecture,[242] as discussed in the fourth chapter of this thesis.

In another aspect of the form-finding process, an architectural building can be regarded as a result of a self-organisation applied through architectural design, which is as such a complex process, because its construction as well concerns activities that can be

[239] H. Nooshin, *Formex: Configuration Processing in Structural Engineering*, Elsevier Applied Science Publishers, London, 1984, 65.
[240] P. Huybers and van der Ende, *Prisms and Antiprisms*, (Proceedings of the International IASS Conference on Spatial, Lattice and Tension Structures, Atlanta, April 24-28, 1994), 142-151.
[241] Gyula Sebestyen and Chris Pollington, *New Architecture and Technology*, Architectural Press, Elsevier Science, Oxford, England and Burlington, MA, USA, 2003, 87.
[242] Stephen Parrella (ed.), “Hypersurface Architecture II” in *Architectural Design*, Volume 69, Issues 9-12, John Wiley & Sons, Academy Editions, London, 1999, 41.

considered as collaborative in their essence. Design's complexity is reflected in a number of different conditions that need to be fulfilled in order for a building to be realised. This comprises collaboration between architects, construction engineers, urban planners, urban designers, traffic engineers, economists, official government bodies, such as boroughs, official design institutions, such as CABE, and inhabitants of the community where the building is to be constructed. Additionally, cities and buildings have cultural, historical and existential dimensions that result in interconnectedness, which cannot be reduced only to building or design components. Every architectural and urban component, from the largest structural unit to the smallest patterned detail are emergent wholes that act like elements of a larger emergent whole, which is then an element of a larger emergent whole. This process is circular and creates a base for other circular processes to occur and therefore has essentially cybernetic character.[243] According to previously stated, architectural components, such as columns, doors, windows, etc., and urban components, such as streets, squares, parks, etc., can be regarded as cybernetic elements in an ongoing real-time process of constant composition, considered as a positive feedback, and re-composition, concerned as a negative feedback. In this regard, Pask sees self-organizing systems of cities and possible predictability of their chaotic or ordered growth as a possible example of cybernetic principles application, which he describes briefly in his text "The Architectural Relevance of Cybernetics".[244] In regard to such self-organizational processes, simulation systems enable visualisation of possible performance capabilities of buildings in architecture and settlements and cities in urbanism, which will be discussed further.

2.3.2 Simulation Systems in Architectural Design

MVRDV from Rotterdam in collaboration with different academic institutions have done research on the subject of generative growth of human settlements from 2001-2006 that resulted in simulation software applications *Optimixer (RegionMaker)* and *Climatizer,*[245] both of which are polemical *toy* systems. The first plans, simulates and then visualises the generic development of human settlements or region scale entities through set up of given parameters. The second simulates possible climate changes in a

[243] Jane Jacobs, *The Death and Life of Great American Cities*, Vintage Books, New York, 1992, 169.
[244] Pask, "The Architectural Relevance of Cybernetics" in *Cyber Reader,* 79.
[245] MDRDV, *KM3: Excursions on Capacities*, Actar, Barcelona, Har/DVD edition, 2005, 38.

similar manner depending on the development of different types of human activities, such as industrial exploitation, construction, etc. Regionmaker employs a simple genetic algorithm that generates a large amounts of proposals, evaluates them according to the user adjusted parameters and criteria and then eliminates the alternatives that have a low score according to the pre-set parameters till the resultant solution is achieved that corresponds the most with the pre-set criteria. Obtained scenarios with a pre-fixed variety of parameters can be compared both quantitatively and aesthetically. Although made as mock-ups these applications also showed that systems like cities or climate have far more complex behaviour than ones simulated by the software. The accumulated knowledge of RegionMaker served as a base for development of *SpaceFighter*, an alternative to scenario-based planning. SpaceFighter is a web-based computer game that facilitates interaction between participants and simulates the effects of their individual decisions over time. This simulation software application was developed at the Berlage Institute in Rotterdam, The Netherlands in 2005-2006 in cooperation with Delft School of Design and the software firm cThrough.[246] An important aspect of these applications is that the result of the interaction can be visualised soon after the process of simulation is finished. This allows for the possibility to make a decision whether a chosen option or a set of parameters for the chosen option can be regarded as adequate or of importance for the design.

Computer simulation is a method for studying complex systems, which concept originates from the late 1940s. John von Neumann, who is recognised as a creator of the modern computer architecture, conceptualised the idea of running multiple repetitions of a theoretical model, while he studied the random behaviour of a complex neuron system. Von Neumann was gathering statistical data from the theoretical model at the same time deriving behaviours of the real system based on that data. This method is called the Monte Carlo method because the model uses randomly generated variables to represent behaviours that could not be modelled exactly but could be characterised statistically.[247] In the text von Neumann wrote between 1948 and 1949, “The General and Logical Theory of Automata” his main preoccupation was the question whether a machine or an *automaton* can self-reproduce.[248] Through an application of mathematical

[246] Batstra Brent et al. (eds.), *Spacefighter: The Evolutionary City (Game)*, Actar, Barcelona, 2007, 67.
[247] William Aspray, *John Von Neumann and the Origins of Modern Computing*, The MIT Press, Cambridge, Massachusetts, 1990, 114.
[248] John von Neumann, “The General and Logical Theory of Automata” in Zenon W. Pylyshyn and Liam Bannon (eds.), *Perspectives on the Computer Revolution*, Ablex Publishing, New York, 1989, 203.

logic he proved that this is possible conditionally if an automaton could have a set of instructions or an algorithmic program for building itself or to be able for self-generation, which in itself implies the possibility of self-organization. For him this was possible in two steps, firstly to make an exact replica of the program and secondly to use the program as a set of instructions for making a replica of a robot.[249] In this way cellular automata became an illustrative example of how an algorithm can be a generative tool.[250] They relate to the the observational principle of cybernetics because they can model complex systems and can assist in understanding the patterned activity of neuronal systems.[251] In these terms cellular automata are a simulation of an automaton's self-generation at the same time showing their potential for self-organization. In regard to architecture and in respect to von Neumann's consideration of how the form is generated, the principle of cellular automata does not have to be simply interpreted as two dimensional decoration of an architectural façade, as in Kostas Terzidis's workshop experiments.[252] It can inform an understanding of how physical structure in its modular configuration can be programmed to have a self-organizational attributes.

These new conditions change the traditional perception of architectural space, as arrangement of static objects in an environment, to a notion of relational situations and flows of information. The simulation is important in architectural terms because it can give some idea of the future influences of the built structure on its surroundings, in terms of its urban density, thermal characteristics or insulation properties, etc. A number of processes that occur in the urban and architectural environments can be modelled and examined through utilisation of computers in case their logic and operational mechanisms have been discovered. According to Manuel De Landa, particular importance of computer tools is in their possibility to rapidly simulate the effects of large chains of non-linear feedback processes. These tools can simulate interaction by bringing virtual elements together with the use of algorithms. This can be of great assistance to the design process because certain combinations can produce emergent and random results.[253] This quality can create results with unanticipated formal aesthetics

[249] Rudy Rucker and John Walker, *Exploring Cellular Automata*, Autodesk, San Rafael, CA, 1989, 54.
[250] John Holland, "Outline for a Logical Theory of Adaptive Systems" in Arthur Walter Burks (ed.), *Essays on Cellular Automata*, University of Illinois Press, Urbana, Illinois, 1970, 287-351.
[251] Ibid., 353-354.
[252] Kostas Terzidis, *Algorithmic Architecture*, Architectural Press, Elsevier, Heidelberg, London, New York, Oxford, Paris, San Diego, San Francisco, Singapore, Sydney, Tokyo, 2006, 162.
[253] Manuel De Landa, "A Thousand Years of Non-Linear History" in Camilo Pinilla, *The Politics of Design* and P. Healy & G. Bruyns (eds.), *De-/signing the Urban*, Delft School of Design Series on Architecture and Urbanism, 010 Publishers,

and provide ground for self-organizational structures to occur, as ones explored by Michael Hensel, Achim Menges and Michael Weinstock,[254] amongst others.

Besides the information based approach there is a more distinctive direction present in the architectural discipline, which is the utilisation of computers that were initially introduced as an alternative means to convey drafting. This new mode of production replaced all previously used design representations in a form of drawing, modelling and visualisation techniques as discussed in more detail in the third chapter of the thesis. This development is very rapid in a sense that some of the architectural offices, such as SOM,[255] will in the near future entirely substitute the current modes of drawing and 3D model production, which employ software such as Microstation, AutoCad and Rhino for example, with parametrically based software, such as Revit developed by Autodesk.[256] This software is built for Building Information Modelling (BIM) that can help with analysis of the early architectural concepts and better maintenance of the design through documentation and construction. This will change the notion and meaning of an architectural drawing because the full shift to parametric software will, beside the possibility to create almost any shape, allow for a chance to produce drawings that contain much more information, such as information about the manufacturing companies that produce certain elements of the construction elements, individual and total cost of the construction, etc. All this information is currently divided into different forms of representation, such as drawings, 3D models, cost information sheets, design presentations, etc. that are more related to the traditional mode of architectural design production. Thus other areas of architectural practice are drawn into interaction.

It can be concluded that mechanisms of self-organization can influence many aspects of architecture, including the processes of simulation. If self-organisation can be regarded as a design principle in the creation of an architectural space, as in the case of *Fun Palace* and *Generator* project, a base can be created for more creative approaches and methodologies that can inform architectural design and turn it into an interactive process at the same time relocating an architect from his/her position of a detached observer to the point of engaged participant. One approach to this is discussed in the following

Rotterdam, 2006, 374-389.

[254] Michael Hensel et al., *Emergent Technologies and Design*, Routledge, New York, 2010, 16.

[255] Skidmore, Owings & Merril

[256] Autodesk, Autodesk Revit Architecture, 1, Retrieved April 05, 2010, from http://www.autodesk.co.uk/adsk/servlet/pc/index?siteID=452932&id=14645193

section.

2.4 Concept of *Mutualism* as Interactive Process

In his vision of human-environment relations, Gordon Pask proposes the concept of *mutualism* as a main bonding element that can be regarded as an interactive moment between humans and their surroundings.[257] According to Douglas H. Boucher the idea of mutualism is defined as assistance that different organisms provide to each other. This idea became important for modern ecology from the early 1970s, although this idea was not entirely absent from previous ecological thought.[258] Therefore, mutualism as a concept can be understood as the mutually beneficial interaction between species. A particular way of representing different positions about mutualism is called the phase-plane model, which represents the population densities of two species in four possible phases relational to the future of the two species involved. Alfred Lotka and Vito Volterra conceived a particular phase-plane model that they applied to competition and predation in the 1920s and 1930s. This model is called Lotka-Volterra model and when applied to mutualism its conclusions were that both examined species attain higher densities when they exist together than if they would exist alone.[259] One of the conclusions that can be drawn from this is that the concept of mutualism have its advantages in relation to the concept of competition in regard to the social development of human beings.

Early ideas of mutualism were closely related to the oldest of the ecological theories and that is the one of the balance of nature, that were proposing mutualism as a part of the adaptation of species to each other.[260] With the scientific revolution in the seventeenth century natural theology perceived natural and human worlds as analogous and in balance. The balance maintenance is achieved by means of each individual's adaptation to the place in a hierarchy.[261] Since the nineteenth century human progress through competition has become the dominant theme in both the natural and social sciences. According to Abour H. Cherif mutualism as a concept in biology and ecology has been

[257] Pask, "The Architectural Relevance of Cybernetics" in *Cyber Reader*, 78.
[258] Douglas H. Boucher (ed.), *The Biology of Mutualism: Ecology and Evolution*, Oxford University Press, New York, 1985, 1.
[259] Ibid., 3.
[260] Ibid., 8.
[261] Ibid., 9.

neglected compared to competition and predator-pray interactions in related research.[262] In his opinion, the idea of competition began to be recognised as an important factor in nature, as an inseparable element of human existence and/or the ultimate source of human progress in research that have been conducted from Thomas Malthus and Adam Smith to Charles Darwin and Herbert Spencer. Until the end of 1970s the conventional wisdom of competition was widely regarded as the major selective biological process in shaping the pattern of natural communities.

The dominant themes of natural and social sciences in the nineteenth century were competition and progress-through struggle. At the same time the political and intellectual opposition was developed as a meaningful reaction to these themes. This reaction was expressed in the growth of working-class organizations in Great Britain, such as trade unions, Chartism and the *Friendly Societies*. These organizations were organized by workers in order to share their resources. These associations functioned as small cooperative insurance companies and were conceived to provide an opportunity for workers to deal with catastrophes, such as illness or funerals. As well, they provided a useful cover for trade unions allowing for ways of accumulating strike funds. In the 1830s these ideas and processes developed into large cooperative federations inspired by Robert Owen's ideas.[263] In this regard the concept of mutualism is important as a social and political instrument that can create a variety of platforms for development of ideas and accumulation of knowledge within a society.

In regard to architecture, which represents an assemblage of cultural artifacts and reflects society's historical development through its built elements that form the background for social events, the concept of mutualism is important as an aspect of building's relation to its environment and the culture that forms around it. An understanding of mutualism through an approach that is considered as progressive and qualitative for further analysis, is the cybernetic one. Cybernetics in its principles and characteristics, discussed previously in the text, can in the best way create a base for development of mechanisms for such relationships to occur. Cybernetic environments stipulate potentiality for democratization of architectural space that can evolve and advance through digitization processes. In the relation between architecture and

[262] Abour H. Cherif, "Mutualism: The Forgoten Concept in Teaching Science" in *The American Biology Teacher*, Volume 52, Number 4, April 1990, 206, Retrieved April 11, 2010, from http://www.jstor.org/pss/4449085
[263] Boucher, *The Biology of Mutualism*, 11.

cybernetics and their potential fusion, this thesis proposes interaction through the *cybernetic mutualism*, discussed in the next section.

2.4.1 Cybernetic Mutualism – Embedded Computer Systems

In Ashby's opinion the relation of the cybernetics and the computational machine is similar to the one between geometry and ordinary space. Cybernetics's subject-matter is the domain of *all possible machines* and for its operational state it is not important that some of the machines are not yet invented. Cybernetics can offer a framework in which all individual machines can be arranged, related and understood.[264] One of the machines that Ashby refers to are Turing machines, first conceptualised by Alan Turing in 1936 as *automatic machines*.[265] These machines do not present physical objects but mathematical ones. They are simple abstract computational devices the purpose of which is to assist in an investigation of computation's extent and limitations. Intuitively a task is computable if one can specify a series of operational instructions which will result in the completion of the task by following these instructions. This set of operational instructions is called an *effective procedure*, or algorithm, for the task. The intuition needs to be formed with precision by defining the capabilities of the device to carry out the pre-set instructions. There can be different classes of computable tasks that are resultants of a number of devices with different capabilities that may be able to complete different instruction sets.[266] This concept was the base for creation of today's computers.

In 1940s and 1950s when their technological development was in its early stage, computers occupied whole rooms and were commonly dedicated to a single task. With the development of computer technology the size of the computer components became reduced and this resulted in their wider utilisation through integration in the physical structure. One of such transformations of architectural space became formalised through embedded computer systems. An embedded system is a combination of computer hardware, software and additional mechanical and/or electronic elements, which are

[264] Ashby, *An Introduction to Cybernetics*, 2.
[265] Alan M. Turing, "On Computable Numbers, With an Application to the Entscheidungsproblem", Proceedings of the London Mathematical Society, 1936, 2, Retrieved April 12, 2010, from http://www.thocp.net/biographies/papers/turing_oncomputablenumbers_1936.pdf
[266] Stanford Encyclopedia of Philosophy, "Turing Machines", First published September 14, 1995; substantive revision November 5, 2004, 2, Retrieved April 12, 2010, from http://plato.stanford.edu/entries/turing-machine/#Definition

designed to perform a dedicated function.[267] Examples of embedded computer systems can be found in everyday electrical devices, such as washing machines or microwave ovens. The design of an embedded system to perform a dedicated function is directly contrasted to the design of a personal computer, which is created to perform many different tasks or functions and not only a specific one, as in case of embedded systems. A similarity between the two, resulting from the reduction in computer component size, is in the possibility to create a more physically compact assemblage of hardware and mechanical components of the system. The personal computer can also be regarded as an embedded system because it has a mouse and the keyboard, both of which contain a hardware and a software that is designed to perform a specific function.[268] According to Barr and Massa the first embedded systems appeared at the beginning of 1970s with Intel's introduction of the first single-chip microprocessor. This was a general-purpose processor designed to read and execute set of instructions with the software written to operate its hardware, which was stored in an external memory chip. This software can be designed to provide each digital device with a unique set of features. Examples of early embedded applications included space probes, aircraft control systems and traffic control systems. In the 1980s and 1990s microprocessors became inseparable parts of every day life through their use in food processors, bread machines, cash registers, pagers, fax machines, credit card readers, GPS navigational devices, etc.

An interesting variety of embedded systems are real-time systems. These systems have the same characteristics as previously discussed with an addition of a time-constraint. This means that the function of a real-time system is partly specified in terms of its ability to make certain calculations or decisions in a timely manner. These systems can be *hard* and *soft real-time systems* and this distinction depends on the system's performance regarding the time-constraint or the deadline in which the system needs to perform a dedicated function.[269] The system is required to be *hard* if the consequences of the uncompleted dedicated function are dangerous and it is *soft* if the consequences are normal. Examples of hard real-time systems are electronic engine, flight control, telecommunications, etc. and examples of soft real-time systems are cruise control, Internet video, user interface, etc. The main point in the design of real-time systems is not in their performance speed but in the systems predictability, which is a guarantee

[267] Michael Barr and Anthony J. Massa, *Programming Embedded Systems: with C and GNU Development Tools*, O'Reilly Media Inc., Sebastopol, CA, USA, 2006, 1.
[268] Ibid., 2.
[269] Ibid., 3.

that the *hard* dead line will be accomplished. This means that the system needs to be predictable in a very precise measure in order not to have a delay in the sequence between the set of instructions the system have to perform. A dedicated function needs to be performed precisely following the predefined set of steps in a precise timely manner, which means that the system has satisfied specified execution behaviour in an operational environment that is constantly changing.

In this regard, if an architectural space can be conceived as a cybernetic environment augmented with a diversity of sensors and a variety of actuators programmed to perform a number of dedicated functions, all of which can execute a specific task in a real-time manner, the purpose of these functions will determine whether an architectural space is in this case a hard or a soft real-time system. Factors that determine whether the soft or hard real-time embedded system is applied within an architectural space, in terms of the technical functionality of the system, are hardware and software systems used for the purpose and their appropriate interfaces, the system execution behaviour and its quality attributes. A potentially significant qualitative factor can be the level of a mutualistic interaction, which means that the system can learn about the habits of inhabitant and adjust accordingly, while at the same time an inhabitant can input new information necessary for the system to adapt. This new information can include non-functional attributes, such as randomly chosen ambience qualities of the space during evening hours that could be related to the music one was listening during the day. For example, if inhabitants of a space have a tendency towards leisure activities, a system performing this kind of actions can be regarded as a soft system. If, alternatively, an inhabitant of a space has health issues and is in need of constant attention because his/her life can depend upon system's possibility to detect behavioural changes or bodily positions in order to react in time to save a life, then this should be hard real time system.

An interesting aspect of such cases is regarding a system's functionality. Architects of Modernism imagined a house that functions as perfectly as a machine.[270] Nevertheless, the machine aesthetics that was present in the architectural conception of buildings in Modernism, resulted only in their representational qualities. By the introduction of real-time embedded systems as natural constituents of an every-day house, the house becomes a machine that can, with great precision, perform and execute pre-programmed

[270] Le Corbusier, *Towards a New Architecture*, Dover Publications, UK, 1986, 48.

set of dedicated functions according to its inhabitant's needs. This is not the only development of Pask's vision in regard to the relationship between cybernetics and architecture. In its application in architecture both systems, embedded computers and personal computers, are used for different stages of architectural design. While personal computers are used throughout the design stage, embedded computers, with an accent on soft real-time based systems, can be implemented in the construction phase and in the phase of a building's finalisation through their application on façades, as discussed in the fourth chapter of the thesis. One of the most important points that can guarantee that real-time systems will perform a dedicated function is the interaction between a system's hardware and the architecture of embedded software. Important software design issues are in making decisions regarding the utilisation of different software operations, such as whether *polling* or *interrupts* should be used for a specific purpose, and the distribution of different priorities to the various tasks and interrupts,[271] or events of other kinds. Both concepts, polling and interrupt, are communication techniques. In the early days of computing the process used was *batch processing*. This was a process that would execute a single program at a time from start to finish.[272] Batch processes are not very flexible and cannot provide an open computing system for spontaneous interaction to happen.

In case of architectural spaces augmented with computer controllable devices there is a question of the complexity of the tasks a system needs to perform, like whether the system needs to measure the humidity in the rooms, as in museums and galleries, or whether it needs to react to changes in the temperature or the heart beat rate, as in hospitals. Considering different typology of buildings and therefore different types of activities performed inside them, there is an overall tendency of inhabitants to interact with the space and its elements and in this way interrupt the on-going computer processes that are preprogrammed to perform a dedicated function. For example, one enters a room and triggers a motion sensor that detects movement, as a result the lights

[271] Barr and Massa, *Programming Embedded Systems*, 4.
[272] In the late 1950s the paradigm of *interactive computing* emerged that changed the approach towards computing. Interactive computing concerns a possibility for a computer operator to stop and start programs or edit them on the computer while a certain process operates. This requires that the computer processor receives external signals while it runs. Previously mentioned software operations, polling and interrupts, are two methods that can help realisation of interactive computing. Polling is a process in which computer periodically checks if there are any external signals that arrived and the processor retains control over them in the time period of their processing. These kinds of processes are used for devices with more simple processors. Interrupt is a process in which external signals are handled as they arrive by interrupting the processor in its procedural operations. In this process there is a possibility for an external agent to influence the control over the processor's activities.(See, Simon Yuill, “Interrupt” in Matthew Fuller (ed.), *Software Studies: A Lexicon*, The MIT Press, Cambridge, Massachusetts, London, England, 2008, 161.)

are switched on and room temperature is adjusted to 19 degrees, but if an inhabitant wants to have only third or half of the lights on and a higher temperature, s/he will interrupt the system's performance by inputting new instructions, if such a mechanism exists. The architectural application of embedded real-time computer systems is analysed in the next section through analysis of Intelligent environments and Smart rooms.

2.5 Intelligent Environments and Smart Rooms

All the previously discussed concepts and visionary theorists influenced a formulation of the notion of intelligence in the context of interactive environments that revolved around the central control system applied generally in a wider context. With an expansion of microprocessor application and usage during the 1980s and 1990s onto everyday objects, development of fields, such as *intelligent environments* (IE), started. Intelligent environments were formed in order to study usability of spaces with embedded computation and communication technologies through behaviour of people inhabiting those spaces. These developments influenced a rapid integration of computation into the physical world. Intelligent environments are defined as spaces in which computation is seamlessly used to enhance ordinary activity.[273] In the late 1990s Michael Mozer led the development of the *Adaptive House*.[274] Mozer's view of the 'intelligent' home was one that relied on a home's ability to predict the behaviour and needs of the inhabitants by having observed them over a certain time period.[275] The *Adaptive House* had a property of self programming instead of being programmed to perform certain actions. The performative actions of the house were monitoring the environment and sensing inhabitant's actions in which the system was observing the occupancy and behaviour patterns of the inhabitants at the same time learning in order to predict future states of the house.[276]

Another project in this line of thought from the late 1990s is the *Intelligent Room project* created at MIT and lead by Michael Coen. This project was created as an experimentation with different modes of interaction, such as human-computer

[273] Michael Fox and Miles Kemp, *Interactive Architecture*, Princeton Architectural Press, New York, 2009, 16.
[274] The Adaptive House, 1, Retrieved April 24, 2010, from http://www.cs.colorado.edu/~mozer/house/
[275] Michael Mozer, "Lessons From an Adaptive House" in Diane J. Cook and Sajal K. Das (eds.), *Smart Environments: Technologies, Protocols and Applications*, John Wiley & Sons Inc., Hoboken, New Jersey, USA, 2005, 273–294.
[276] Michael Mozer, *An Intelligent Environment Must Be Adaptive*, IEE Intelligent Systems and their Applications 14, no. 2, 1999, 11–13.

interaction (HCI), as discussed in the first chapter, different forms of natural interaction, etc., by the means of embedding sensors and actuators into everyday objects with which one can interact. The main aim of the project was to enable different modes of human-computer interaction in this way creating a possibility for computational devices to augment spaces and participate in activities that previously did not involve computation.[277] In the *Intelligent Room*, on the lowest system level, there are perceptual systems that generate descriptions of occurrences in the room, real-time. Among systems that are monitoring the room's activity levels there are also systems that can determine location and position relational to the elements in space, like walls, tables, chairs, etc. and to detect the distinctive activity of the occupant, like whether one is pointing towards the wall, then tracking systems that can determine the type of interaction happening, such as sitting, talking, shaking hands, etc., multiple systems that can track what is being said, systems for lighting control, etc. All mentioned interactions have a time-constraint in order for a temporal sequencing to be determined by a higher level systems. This means that there are three layers of different software applications created for operation of the Intelligent Room.[278] The key fact, in the case of previous two projects, seems to be in determining what the room will observe as significant in relation to inhabitant's behaviour. This can vary from the movement's tracking, pointing, voice and gesture recognition to understanding people's actions that can involve one or a combination of a number of previous factors. The point of this research is to develop the human-computer interaction to be as natural as interaction with another human is.

The main difference between the *Adaptive House* and the *Intelligent Room* is in the starting premise regarding self-regulation, the first contains self-programming capabilities, while the second is preprogrammed to monitor and detect changes. According to Charles Hannon and Lisa Burnell the smart home agents need to have a general knowledge about the type of behaviour that is required by the inhabitants and how it is possible to do it. Further, the agents need to be able to make decisions based on the implemented knowledge in a certain context or environment and to make a distinction regarding making an initiative to perform a task or to ask for assistance. Finally, they must have the ability to learn the goals, needs and preferences of the

[277] Michael Coen, “Design Principles for Intelligent Environments”, Proceedings of the Fifteenth National Conference on Artificial Intelligence, Madison, WI, 1998, 136.
[278] Rodney A. Brooks, “The Intelligent Room Project”, MIT Artificial Intelligence Lab, 1, Retrieved April 24, 2010, from http://people.csail.mit.edu/brooks/papers/aizu.pdf

inhabitants in order to adapt their efforts based on the collected knowledge.[279] Hannon and Burnell propose application of biologically inspired models (BIM) that are complex models for organization and communication based on biological systems, which are considered as heterogeneous and dynamic in nature to which entities have to adapt. Because of this quality they consider them as suitable for design and implementation to smart homes systems, as discussed further.

2.5.1 Mutuality of Discrete Interaction

Further investigation in the field of the *Intelligent Environments* was promoted by the concept of *ubiquitous computing*,[280] a term coined by Mark Weiser in 1988 at the Computer Science Lab at Xerox PARC which describes a mode of human-computer interaction that does not involve a desktop model of a computer. Ubiquitous computing can be defined as fully integrated computation into everyday objects and activities, which is often regarded as the connection point of computer science, behavioural sciences and design. This kind of computing promotes simultaneous engagement with multiple computational devices and systems during the everyday activities not necessarily with the attention of the participant or in other words participant may not necessarily be aware that the interaction with some computational device happens. Weiser considers ubiquitous computing to be a third wave in computing. For him, a first wave were mainframe computers, which were shared by a large number of people. The part of nowadays second wave, are personal computers with which interaction happens one computer to one human. A third wave presents an evolution in relation to previous two, in which sharing of a number of computational devices embedded into an environment presents the beginning of the age of calm technology.[281] This presents an evolution in terms to human-computer interaction as well, because interaction is not limited by the number of participants or the number of digital devices.

Today the realisation of the concept of ubiquitous computing is part of everyday life. There are several conditions that are being developed in order for us to have such a frequent interaction with our environment. Firstly, the technological development of

[279] Charles Hannon and Lisa Burnell, "A Distributed Multi-Agent Framework for Intelligent Environments" in *Journal of Systemics, Cybernetics and Informatics*, Volume 3, Issue Number 1, 2005, 1, Retrieved May 08, 2010, from http://www.iiisci.org/journal/CV$/sci/pdfs/P446593.pdf
[280] Also regarded as Pervasive Computing and Intelligent Environment.
[281] Mark Weiser and John Seely Brown, "Designing Calm Technology", Xerox PARC, December 21, 1995, 1, Retrieved April 24, 2010, from http://nano.xerox.com/weiser/calmtech/calmtech.htm

radio frequency identification (RFID). An example of a practical application of this technology can be found in different modalities created to spontaneously control different actions, like at entrance and exit points in shops and shopping centres, or in a more radical manner in the *Calypso* night club in Rotterdam[282] in which guests have an option to augment themselves with the RFID chips by injecting them into the body. In this way one *does not have to worry* about paying for a drink because this is done automatically through the RFID chip which is there to assist in transferring the money directly from guest's account to the account of the club. According to Jason Weiss and Philip Caiger the physical boundaries of ubiquitous computing will become more blurred due to current developments in nanotechnology and wireless computing.[283] The trend in the miniaturisation of computer components, as one characteristic of nanotechnology, that involves building highly miniaturised computers from individual atoms or molecules, which act like transistors in a chip, can allow for an impressive levels of computing power in a tiny packages that can operate without people's knowledge or awareness of the nano-computers being present. Wireless computing technology can be utilised to connect those miniaturised particles of nano-computers into a network, in order to create the possibility that they can be programmed to perform specific actions.[284] These developments are still prospects of practical possibilities or in other words the practical implementation in architecture is still a futuristic prognosis.

Microscopically small computers that have wireless connection present an infrastructure for ubiquitous computing to emerge. Weiss and Caiger note that there are two concepts that need to be considered regarding this kind of ubiquitous computing and these are *context-aware computing* and *natural interaction*. Computational context awareness requires that computers can understand the conditions of the relevant context and offer services in respect to these conditions.[285] Example of this can be a context-aware map that has stored information about its user, such as that s/he is absent from home, that it is 18:00 hours, that there are no appointments in their schedule and that s/he might be interested in a dinner soon so the map can prepare a list of the possible choices of restaurants in the neighbourhood with the guidance to offer if the user asks for it. Natural interaction concerns that the computer can supply the information without the

[282] *Calypso* Night Club, Mauritsweg 5, 3012 JR Rotterdam, The Netherlands.
[283] Jason Weiss and Philip Caiger, “Ubiquitous Computing” in *The Industrial-Organizational Psychologist* (TIP), Volume 39, Number 4, April 2002, 45.
[284] Ibid., 45.
[285] Ibid., 46.

user making the cognitive effort to retrieve the information. These context-aware systems are based on mechanisms for movement detection and different kind of measurements, such of factors including temperature, humidity, air and power flow, etc., conducted within an environment that can determine the conditions inside it.[286]

Reasoning in context aware systems is necessary in order to deal with the constitutional imperfection and uncertainty of context data. There are several main tasks of reasoning: to detect if there are possible errors, then to make computations about missing values, to determine the validity and quality of the context data, to translate context collected information into meaningful content and consequentially to infer new context information with implicit content that may be relevant for applications. Reasoning is a fundamental condition for context-oriented decision-making that concerns system's adaptations according to learned or user-provided decision rules.[287] Previously noted processes and parameters present a base for creation of Ambient Interactivity, which development depends on the integration of several different context providers, which may be dedicated sensors, users applications, database monitors, etc. The inclusion of new types of context providers requires the implementation of new Context Monitor Agents with specific interfaces and functionalities.[288] This means that if an embedded system has a large number of functional or other attributes, more complex it becomes and therefore requires additional computational power. In designing architectural spaces with real-time embedded systems it is necessary to evaluate real necessity for a certain attribute to be included into the system and the quality of interaction this attribute will channel. It is also important to decide early on the project what is the concept of the space to be designed, so that through the design process it is possible to establish evaluation parameters of the attributes that are likely to be included in the design of the interaction with the space. At the same time, the awareness of the technical and computational requirements for the system are compulsory to be determined early in the design stage in order not to create improbably complex systems which operation will become difficult.

[286] Yoosoo Oh et al., *Designing, Developing and Evaluating Context-Aware Systems*, Proceedings of the 2007 International Conference on Multimedia and Ubiquitous Engineering, IEEE Computer Society, Washington DC, USA, 2007, 173.
[287] Dargie Waltenegus, *Context-Aware Computing and Self-Managing Systems*, CRC Press, Taylor & Francis Group, A Chapman & Hall Book, Boca Raton, London, New York, 2009, 85-86.
[288] Ibid., 120.

The cybernetic mutualism is the mode of interaction proposed in this thesis and it presents an evolutionary step further in the human-computer interaction in regard to the relationship between a participant and an cybernetic architectural environment. So far, the limiting factors of the basic mode of human-computer interaction are reflected through the restricted opportunities determined by the pre-set range of rules and values that are observed by the system and to which system reacts in a certain way. This kind of action-reaction relationship cannot be regarded as interactive because interaction is considered to be a mutuaistic relationship with an environment in which spontaneity of participant's action is followed by the system's unexpected response through a feedback loop of continuous conversation. In this way interaction frames the possibility for a conversation between a participant and an environment. The novelty of this approach provides a multiplicity of possibilities for democratisation of an architectural space through evolution of cybernetic principles. Interactive environments created by these principles can change our perception of an architectural space and through different spontaneous relationships can provoke a more immanent and playful relation with our habitats. Consequentially, ubiquitous computing can make a base for changeable taxonomy of spaces and re-invention of space typology. Alterations in this regard can concern change in physical form in term of its size, colour, texture, etc. One of the examples in terms of qualitative occurrences inside of architectural spaces through implementation of thematic interaction, such as application of water as an inspiration for the different modes of interaction, is the *Water Pavilion* in the Netherlands.

2.6 Modes of Thematic Interaction in the *Water Pavilion* Project

The *Water Pavilion* project is important for analysis because it presents a continuation and actualisation of some of the ideas about interaction that began with Price's *Fun Palace* project. The *Water Pavilion* illustrates the cybernetic environment that was built and operational for a period of time and that had diverse modes of interaction. It is an example of liquid and flexible architecture with a dynamic system that provides a constant interaction between participants and the cybernetic environment. One of the underlying characteristics of the pavilion was the unpredictability of interaction, which means that the participant can spontaneously and intuitively discover the space without prescribed actions. Another reason for selection of this building is because it has the *theme* of interaction, which is water. As discussed previously, the theme is a condition within the process of communication that can be open to a variety of possible actions. Through the theme participants within interactive social systems, such as *Water Pavilion*, can establish a meaningful relation with their environment. Theme presents the point of departure of a message sent by a participant or a system and initial constituent of the concept. This message contains an information. Concept is a signifier of interaction, which can shape it and give interaction its order. Information contained within the theme correlates the method of interaction's development. Concept is a mechanism that allows for the information to find its way through a system and influence the development of interaction depending on the theme.

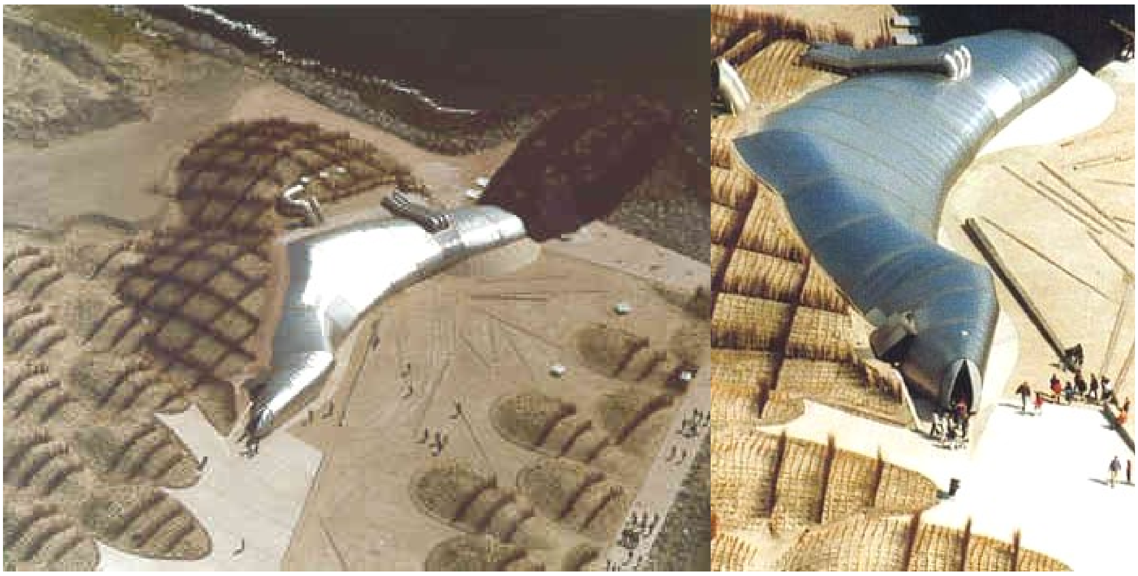


Figure 2.6 and 2.7: *Water Pavilion* by Lars Spuybroek and Kas Oosterhuis, island Neeltje Jans, the Netherlands, 1993-1997.

The *Water Pavilion* was located at the small island Neeltje Jans in the Netherlands. It consisted of two distinct structures, *Fresh Water Pavilion* by Lars Spuybroek from NOX and *Salt Water Pavilion* by Kas Oosterhuis from Oosterhuis Associates. The Pavilion was designed, constructed and opened in the period from 1993-1997. The building was around 100 metres long and had two interlocking parts that were connected in a joint, so the movements through both structures were continuous, which emphasised different experiences one had inside the pavilions. Both parts, *Fresh* and *Salt Water*, were designed to have distinctive characters. *Fresh Water Pavilion* had a wavy, elongated flowing form of approximately 61 metres in length, coated with stainless steel, as can be seen in figures 2.6 and 2.7 above. While *Salt Water Pavilion* had a very tapering and angular form in the remaining 42 metres of length, with a dark grey colour finish.[289]

The concepts of liquid and flexible architecture interpolated in this pavilion, originate from Merleau-Ponty's ideas of the body and the point of overlapping in which fusion and exchange take place.[290] As well as the intertwining of subject and object in perception with Deleuze's ideas about smooth space and becoming.[291] In this regard, Spuybroek and Oosterhuis saw the building as a dynamic system that has continuous interaction between people, building and its environment and they managed to realize this idea in this pavilion. The pavilion was conceived as a digitized architectural environment with thematic conversation between agents involved in the interactive process. Its formal representational attributes as well as the thematic content are reflecting the fluid and flexible media artwork accomplished by means of architectural and computer languages. This means that inside the *Fresh Water Pavilion* there was a network of sensors that reacted to bodily movement and triggered different actions in relation to where one is in the pavilion. The interactive character of the pavilion consisted of an installation of projections of light and sound. The sensors that were specially designed for this interior were connected to three interactive systems, which operated simultaneously. The first system contained animations generated real-time and connected to LCD projectors. The second one controlled a light movement on a 60 metres long central curve with approximately 200 blue lamps arranged on the cable duct, as shown in figures 2.8 and 2.9 below. The third system controlled a sound system that could be manipulated and adjusted by the movements of the participants.[292]

The aim of the project was to create a collective interactive experience so that a number of people can actively participate in triggering different actions. The system was entirely intuitive because there were no electrical switches or controls one needed to physically touch or switch on in order to get feedback. Different actions that could happen inside were routed through a matrix of sensors that were controlled by the software. Distinct actions operated on various levels so the feedback could be performed real-time and immediately. This happened, for example, in the form of deformation of a virtual water droplet or *delayed* in form of distortion of lights and

[289] John Kevin Waters, "Biological Thinking" in *Blobitecture: Waveform Architecture and Digital Design*, Rockport Publishers Inc. Gloucester, Massachusetts, USA, 2007, 79.
[290] Maurice Merleau-Ponty, *Phenomenology of Perception*, Routledge, London and New York, 2003, 182.
[291] Kari Jormakka, "Liquid Architecture" in *Flying Dutchmen: Motion in Architecture*, IT Revolution in Architecture, Birkhauser – Publishers for Architecture, Basel, Switzerland, 2002, 65.
[292] Lars Spuybroek, "Water Pavillion" in *NOX: Machining Architecture*, Thames & Hudson, London, 2004, 20.

sounds, as shown in figure 2.9 below. In one of the mentioned embedded computer systems, interaction happened through participant's body positions and movements that were detected by the camera. The camera was connected to the computer, in which the pattern projected from the ceiling was created. In the moment the camera detected difference between the participant's body position in relation to the pattern projected from the ceiling, the wave effects would appear that simulated the virtual water, as shown in figure 2.8 below.

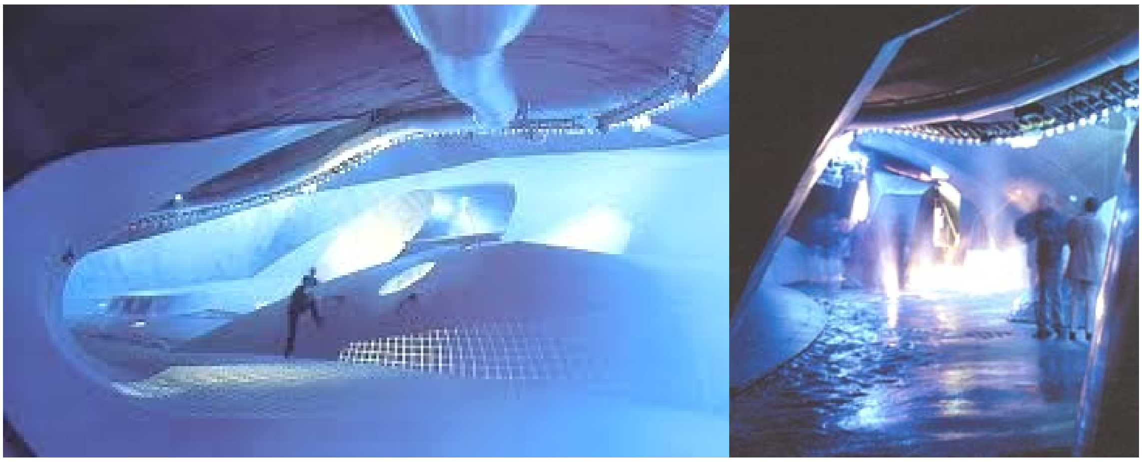


Figure 2.8 and 2.9: Interior of the *Fresh Water Pavilion* by Lars Spuybroek, island Neeltje Jans, the Netherlands, 1993-1997.

As explained by Spuybroek, the idea behind this interactive system was for it to have two modes of interaction, one that would operate locally and the other that would operate as a whole. The system was designed to respond to different levels of intensity of action. Another of the systems mentioned above, consisted of six wire-frame projections of which four were ripples, one was blob and one was a wave. The wave projection was activated by motion sensors that visitors could trigger by simply passing the invisible infra-red sensors. The ripples were activated through groups of touch sensors and the blob was activated by four actuators that were part of a game, which consisted of four players of which each had one actuator. Manual operations produced in the interaction with the sensors had an immediate real-time effect on the wire-frames and the waves in line or circle patterns were transferred through a mesh. This means that the ripples were waves calculated in real-time, dependent on the forces participants used to manipulate the sensors and not filmed effects played back in the moment of interaction.[293]

[293] Ibid., 26.

In the case of *Fresh Water Pavilion*, the interior of the building was created with interactivity as a main constituent that embraces its visitors on multiple scales. The media and architecture are fused into an interactive physical object.[294] People are able to interact with the structure and systems both consciously and unconsciously. In the pavilion's interior there are multiple layers of digital materiality obtained through augmentation of physical structure with sensors and actuators. These include projected patterns on the floor and walls that represent digitized water surface and that have an interactive quality. Interactivity is instantaneous as soon as disturbance to the surface is accomplished by a body movement or a touch. It can be said that this project employs three kinds of materials: natural – utilised in construction of the physical structure; virtual – incurred through different pattern projections on architectural elements in space; and digital – obtained by augmentation of natural materials with hardware and software. One of the problematic issues in the case of this project is Spuybroek's description of it. His accent in not so much on the aesthetics of it but rather on the functional view, which can be understood through his explanations of the technical specifications of how the system performs, rather than descriptions of what kind of ambience or experience Spuybroek wanted to create.

Inside the *Salt Water Pavilion* a visitor was able to experience a simulation of the movements of the sea because the environment contained walls and floors covered in water and from which the water dropped on visitors.[295] This was a building that had an orthogonal flat form, which represented a box with the content inside it. The light in the *Salt Water Pavilion* was positioned in such manner to reflect on the wet wall surfaces. On to the walls the images of different perceptions of water and fluidity were projected. For Giannachi, through these projections the building becomes a hypersurface.[296] Inside this building, unlike in the *Fresh Water Pavilion*, there was no explosion of experience through the augmented sense of vision and hearing. There was an interactive part of the interior which concerned manipulation of light and sound, but it was not instantaneous and it was less intuitive than in the *Fresh Water Pavilion*. Forms of interactivity that

[294] Ineke Schwartz (1997), "Testing Ground for Interactivity: The Water Pavilions by Lars Spuybroek and Kas Oosterhuis" in Gabriella Giannachi, *Virtual Theatres: An Introduction*, Routledge, Taylor & Francis Group, London and New York, 2004, 100.
[295] Gabriella Giannachi, "Performing Through Hypersurface" in *Virtual Theatres: An Introduction*, Routledge, Taylor & Francis Group, London and New York, 2004, 100-101.
[296] A hypersurface is a threshold whereby the density of difference in an interface becomes vital, self-configuring and autopoietic. See, Stephen Perella, "Hypersurface Architecture and the Question of Interface", Interfacing Realities, 1997, 2, Retrieved December 06, 2010, from http://www.v2.nl/archive/articles/hypersurface-architecture.

were particular to *Salt Water Pavilion* include navigation through a 3D model that was projected on the wall. This mode of interaction was based on human-computer interaction rather than interaction with a real-time embedded computer system, as in case of *Fresh Water Pavilion*. Another mode, which was not present in the *Fresh Water Pavilion*, is the building's potential interaction with its surroundings. This was accomplished through acquisition of the data from the outside of the building. The data was received from the meteorological station situated close to pavilion that is registering tide, salinity, speed of the wind, etc. When the data was received, a computer with a help of software written specifically for this purpose translated the data into commands, which were then translated into a meaningful information and feed back into the system inside the interior. The meteorological data were represented through slowing down or speeding up the light, its intensity and colour, and appropriate sounds.[297] Designers wanted to develop the software that was running the pavilion further so that people could interact with the building via Internet. Unfortunately this development was stopped with the dismantling of the pavilion in 1997. The *Water Pavilion* presents a serious attempt in the search for the harmonious and playful interaction between a cybernetic architectural environment and its participants.

2.7 Conclusions

From the discussion in the second chapter three modes of interaction can be generated: Interaction as participatory process, Interaction as cybernetic mutualism and Thematic interaction. These will be described and discussed further.

2.7.1 Interaction as Participatory Process

This mode of interaction was observed through spontaneous processes that emerged within cybernetic environments between people and architectural space, as in the case of Price, Pask and Littlewood's collaborative *Fun Palace* project. This mode of interaction involves a process that emerges through how people participate in the activities occurring inside the space. An important prerequisite for the space is that it should be flexible enough to generate social activities with a meaningful content. The activities are organized through the building's program. This means that the conceptual

[297] Giannachi, "Performing Through Hypersurface" in *Virtual Theatres*, 101.

structure of this interaction modality lies in the way the content of different activities is organised within the space. The content of the activity is at the same time educational and entertaining and so it stimulates learning about the environment. Through an engagement with various activities participants establish spontaneous connections between themselves and the space they inhabit. The connection is established by means of conversation with the other participants and through learning about the environment. This means that the conceptual quality of the interaction lies in the meaningful involvement of the participants, and the interaction emerges from the spontaneous relationships established during participation. Part of a person's motivation for participation may be that the learning process is goal-driven. The activities generated in the space are chosen by the participants according to subjective criteria, which may depend on a particular participant's interests and/or skill set, such as their participation in a theatre piece or playing an instrument.

In this case interaction becomes a moment in which a participant is encouraged to make decisions about his/her level of participation in the different activities. This creates a focus not on the final product but rather on the process itself as a means of creation. Therefore, the digitization quality of this interactive modality lies in the fact that the process should be flexible and adaptable and be fully open to participation and engagement in order to create an environment in which thoughts and ideas are freely expressed. In this case, possibilities are given for collective decision making to become an end goal in itself, because participation brings legitimacy to the decision. In this regard, idea generation, conceptualisation and creative problem-solving can facilitate the best decisions possible from a consensus between the participants. This may be possible to achieve if the requisite number and variety of entry points and methods is offered by the cybernetic architectural environment. The number of methods and entry points can be determined by the different levels of participants' interests and skills. This does not mean that the space determines behaviour, but that interaction within these kinds of spaces allows behaviour to be spontaneous and collaborative.

Because of the state of continual real-time interaction, this kind of space can incorporate cyclical feed-back loops of programmed activity with algorithmically changeable content. When this is done interaction directly depends on the essence of the action or the meaningful connections established through the relationships between the elements and the participants in the process. Interaction presents different ways of framing the relationships that participants have between themselves and the elements of the architectural space that surrounds them. Ideas and concepts generated through collective interaction can provide a base for novel approaches in an environment's formalisation and in this regard, an important aspect of collective interaction is a self-organizational attribute conditioned through an engagement with the environment. Self-organization depends on multiple real-time interactions with an accent on those that are non-linear. Non-linearity is important because it does not prescribe the ways in which interaction should be accomplished but offers a multiplicity of choices with flexible and changeable outcomes. This points towards cybernetic architectural environments that are perceived through a model of dynamic entities which can evolve through performative rather than representative interactions with one another. These kinds of buildings or systems can be regarded as *transparent buildings*, as in the case of the *Fun Palace* project. The material quality of transparent buildings lies not only in the physical characteristics of the materials employed in their construction but also in the openness of their content and the possibility they offer for unconstrained communication.

This mode of interaction is based on the prototypical structure, which is the feedback loop. The interaction happens between the spatial system and participant within it in the previously described manner. In the case of this mode of interaction, it presents more complex self-correcting system or the second-order cybernetic system. Interaction happens with the building acting as a feedback system. The structural composition changes in real time with each participant's input but without delay in the information processing. This creates a closed feedback loop system in which, after having compared the result of the interaction with the previous composition, the participant can decide whether to make more changes. The novel interpretation involved in this mode of interaction lies in the strong focus it gives to the aspects of participation and self-organization. The self-organizational attribute is also connected to the learning component, which relates only to people and occurs when all of the spatial combinations in the system are exhausted. This means that participants learn how to use the system and adapt to it, while the system retains its function. In the case of this mode of interaction the accent is placed on the self-organizational activity that emerges within the space.

The evolution of the interaction within the cybernetic architectural environment leads to interaction as Cybernetic Mutualism, which will now be described in more detail.

2.7.2 Interaction as Cybernetic Mutualism

This is the mode of interaction proposed by my research. It has the same functional basis as the participatory second-order interaction previously described, which means that the technical basis for the interaction is a multiple feedback loop mechanism. The difference with the participatory mode lies in the conceptual quality of the procedures that coordinate the interaction occurring between the participant and the space, the digitization quality of the processes involved in its realisation and the material quality of the architectural/cybernetic artefacts that are integrated into the composition of the space. In cybernetic mutualism, interaction implies the relationship that a participant has with the environment when using a computer as a mediator. This means that the interaction frames the possibility of a conversation between a participant and an environment. This provides for a multitude of possibilities for participation in the architectural space's performance through direct conversation with the environment. A cybernetic architectural environment can contain a number of dynamic digital objects able to react to the changes in the environment and create a meaningful relationship with it, one that can be autonomous in comparison with the participant's relation with the environment. This means that the digitization quality implies the augmentation of the architectural space with digital objects. In this regard it can be said that digital objects are discrete physical entities that have been coordinated by a computer and are defined by their mutual relations and by the processes they create within the environment. The multi-layered nature of the digital object involves the combination of hardware, such as processor units and data storage, and software entry points, such as operating systems and software applications, coupled with the object's functional and aesthetic attributes. A mutualistic cybernetic environment can contain a network of such digital objects.

This is another difference with the previous mode of interaction. While the process of participatory interaction is mediated through programmatic activity that is not dependant on digital objects and can operate in an algorithmic manner, in a cybernetically mutualistic interaction architectural environment it is augmented with digital objects, which mediate the interaction. The digital objects observe the action that happens within the environment and are able to react to the quantitative attributes of the participant's activity. These quantitative attributes may comprise measurable factors of the action performed within the space, like the intensity and/or speed of a movement, the participant's weight and/or height, different gestures, sounds, etc. This means that the system's performance depends upon measurable factors that can be detected and computed in real-time. The system can detect and compare the difference in the participant's intervention in relation to the optimal performance and can *decide* how to react to different inputs. This means that a dynamic system needs to be designed in a way that it is able to distinguish between the input of various participants and *decide* to change its state by adapting to the new conditions in the environment. An important factor in this regard is the possibility of creating a mutualistic relationship between the participant and the dynamic system by means of multiple feedback loops.

Mutualism is the conceptual quality of this interactive modality, referring to the possibility that both systems, natural and artificial, have to learn from each other. The conceptual quality of the participatory interaction required that the final decision should be made by the participants, and so the learning component was related only to self-organization of natural systems. In the case of cybernetic mutual interaction, the learning component is related to the artificial systems as well. This can be achieved by the creation of a number of systems contained within the complex system that frame the action of the systems contained. In this case, the complex system can measure the effects on the environment, compare the level of achievement of these systems' goals to their own and adjust the goals of the systems according to the fulfilment of its own goal. In what follows, the complex systems can set the goal of the constituted system based on the external actions of the participants. This kind of adjustment of goals based on the result of actions can be regarded as learning.[298] At the same time the human participants learn about the system they use though interaction with it. This means that learning is the possibility that a natural or artificial system has to adapt to the dynamic conditions in the environment.

The interaction with the system is determined by the complexity of the system. Complexity means that the system is diverse and contains multiple, multiply

[298] Pask, "A Comment, a Case History and a Plan" in *Cybernetics, Art and Ideas*, 55.

interconnected, elements. The complex system can be adaptive in that it can have a capacity to learn from experience. This implies that complex systems can self-organize over time. The system's collective behaviour can emerge from the interaction that takes place between a number of simple elements within the system. The complexity results from the heterogeneous structure of the system, which consists of many different parts with multiple connections between them. These different parts are not independent although they can behave differently between each other. These systems should also be flexible enough to handle the appending of new systems, operating procedures and protocols for information transfer, coordination and communication. This means that more complex systems, which contain multiple levels of other systems, can provide more intricate interaction, which may involve a diversity of performed actions. An important issue in this case is determining the appropriate level of complexity because, if the system is overly complex, a participant may not be able to use its full potential.[299] Therefore, cybernetically mutualistic interaction has to be spontaneous and intuitive, with the right level of complexity to arouse curiosity and encourage playfulness. This means that intuitive learning takes place through discovery of the system's characteristics by means of use and feedback. An important issue is the predetermined decision of what will be significant to the system in this mode of interaction.

The difference between cybernetically mutualistic interaction and other modes of interaction lies in its conceptual quality which means that the right balance of intuitively comprehensive features need to be able to communicate meaningful content in the conversation taking place between the participant and the environment. In this mode of interaction the accent is placed on the way in which participants establish a relationship with the environment. Consequentially, it creates a foundation for the creation of a changeable taxonomy of spaces and the re-invention of space typology. Alterations in this regard can involve a dynamic modification of the architectural elements in relation to their material qualities, such as physical form, colour, texture, etc. This implies that the material quality of mutualistic interaction is a cultural perception in which the duality of physical objects lies in their fusion of physical form and information patterns. In this regard, these kinds of architectural elements can be considered to be virtual.[300] It can be said that cybernetic environments that have mutualism as their mode of

[299] Ashby, "The Law of Requisite Variety" in *An Introduction to Cybernetics*., 18.
[300] Hayles, *How We Became Posthuman*, 43.

interaction can be perceived as dynamic interactive assemblages of mutually interconnected components that establish performative rather than representational interactions both between themselves and with the participants.

2.7.3 Thematic Interaction

In this mode of interaction the theme is the starting point in the conversation with the environment, while the concept is the main operator of the interaction. The *thematic* in this case is concerned with the grouping and assembling of the common attributes and characteristics of the digital objects used for the augmentation of cybernetic architectural environments with the aim of creating a characteristic and consistent conversation with the environment. Their common properties mean the aesthetic and functional attributes of digital objects. This means that the theme determines the ambiance of the cybernetic architectural environment. The social aspect of this interaction modality is also part of the theme because it directly relates to the conversation between two people and the significance of the language through which conversation can take direction relative to the theme. Considering that the theme of the conversation can inspire further communication, this can determine the direction and quality of the interaction. This means that a participant and a system can establish a relationship through feedback loops that is framed by the ways in which the interaction with environment functions in relation to the theme. Later on, the participants in the interaction, as autonomous observers, can presuppose their relationship with reality by means of a common understanding that is achieved through communication and conscious comprehension of the physical reality that surrounds them. The common understanding they establish about an environment may be achieved through a set of associations relative to the theme, which can be standardised for better incorporation into the system. These associations can be based on the way the aesthetic attributes of a space are designed, which is connected to the theme of interaction.

The *thematic* may also be understood as the way in which the computer translates the message in relation to the theme of interaction. Such a message contains information about the measurable instances in the conversation, such as the tone or volume of the voice or the proximity of the participant with whom the dialogue is taking place. The information contained within the theme correlates with the method of the interaction's development. In this regard, the conceptual quality is a signifier of this interaction modality, which can shape it and give order to an interaction. The concept can be algorithmically conceived and represented. This means that it gives the theme its structural flux. The interesting characteristics of thematic interaction, within an architectural framework, are the various modalities by which the theme can be translated into digital forms that can be understood by the participants. The thematic interaction should, through a concept, influence the way a sense of the space is created. Interaction in this case presents an additional aesthetic quality that accentuates the space's fluidity and adaptability. The theme of interaction may also influence the activity performed inside the space. The possibility of creating different entry points in which interaction happens in different ways, such as through touch, voice recognition or movement, can result in different interpretations and formalisations of the same theme. The dynamics in this mode of interaction can be the result of different interpretations of the theme of conversation.

The accent in this mode of interaction is on the thematic content or the thematic conversation taking place between the participant and the cybernetic architectural environment. The modes of interaction discussed presented different modes and forms of interactions that occur within cybernetic architectural environments in relation to diverse human-computer interactions that happen during the architectural design process, something we will now discuss further.

Chapter 3: Digitization of the Design Process – Incorporating Digital into Physical

The previous chapter discussed the conceptualization and historical background of cybernetics as groundwork for the emergence of contemporary cybernetic environments in form of interactive architectural spaces, as well as, the results digitization has on the physical structure, the materiality introduced in realization of such spaces, their interactive character and what kind of impact they have on the participant and environment. Through incorporation of software based processes in different aspects and phases of an architectural design another quality emerged in this relationship between architecture and interactive systems, namely in the software used in its design. This form of software's influence on architectural design is not instantly visible and the relationship between the two has been developed through years of adaptation to the new means of production. This chapter concerns exploration of human-computer mode of interaction and its possible developments through software used in architectural design production, digital fabrication processes and parametric design software.

Digitization of the design process within architecture strongly influenced the speed of design production. With the increase of means for information storage, which became almost infinite, the possibility to produce larger amounts of work became standard within the practices. Therefore with acceleration of the production process the amount of produced information also increased. The question that can be formulated is whether the quality of architectural design production changed. Some architectural practices, such as Frank Gehry, Peter Cook, Nox, Greg Lynn, etc. embraced the new possibilities that were introduced by software and started exploring numerous options provided by, for instance, parametric software, which relies on the large amount of calculations made possible by computers. Parametric software, as well as digital fabrication, are digital processes which involve new relationships between the architect, the idea, the drawing/model, building elements and the fabrication material. Various relationships in these different process can result in an interaction with qualities of cybernetic mutualism in the architectural design production stage and the fabrication of the building's physical model. New modes of interaction that involve certain aspects and qualities of cybernetic mutualism are Parametric Interaction and Interaction During Digital Fabrication. These qualities will be analysed further on in the chapter. These two modes of interaction cannot be fully regarded as cybernetic mutualism because they reflect this concept only in some stages.

In a number of architectural practices, which have kept the traditional approach to architectural design production, software is used merely as an advanced pen. Meaning by this that the stages of the design process did not change from the traditional ones and therefore the thinking process during the design stages did not evolve, something which will be discussed further in the chapter. In order to keep the quality of expression contained in the *line* drawn by the hand of a particular individual, hand drawn sketches are scanned, imported into a computer, redrawn and/or attuned in the appropriate software application. Attuning includes quality acquisition in the sense of upgrading from a sketch into an illustrative drawing. An upgrade involves supplement of a number of layers which contain different qualities of information. After adjustments hand drawings are used in the presentations with addition of the colouring. This is known as *task automation*[301] where the computers are used to perform known processes more efficiently, rather than to replace existing processes with a higher-level ones. It can be concluded that the thinking process that is followed by creation of the design is still more attached to the pen then to the mouse.[302] The question that remains from the era of handmade architectural drawings to the age of digital possibilities is the one of finding a suitable visual register.

According to Peter Cook a visual concurrence, which develops in parallel with the statemental notion of a drawing, is difficult to grasp, even more so because of the present period in which political and philosophical reviews have the high intellectual ground for architectural commentators. Statemental notion of a drawing means that an architect can make a statement, relative to the project's concept, through the content of a drawing in relation to the visual imagery an architect creates. For Cook, the difficulty of finding an appropriate visual register was present even in times of hand-drawn imagery, when even the most visionary concepts and drawings were expected to refer to built or crafted form. In this regard, the statemental notion of a drawing would gain power through the likelihood of the drawn image.[303] The point that Cook makes here is in regard to the specific rhetoric of the constructable in an architectural image. He refers to

[301] McCullough, *Abstracting Craft*, 79.
[302] Cecil Balmond (with Jannuzzi Smith), *Informal*, Prestel Verlag, Munich, 2002, 34.
[303] Peter Cook, *Drawing: The Motive Force of Architecture*, John Wiley & Sons, Chichester, England, 2008, 12.

the notion that the content of architectural image has to resemble known forms in order to be comprehended and accepted. In Cook's statement architectural drawing, besides its obvious technical lineament, can as well communicate project's concept and explain the work being done on the development of the idea through the urban, structural, social, economical, political, etc. conditions. These conditions serve as filters in the formalisation and materialisation of an idea. Depending on the project's idea and its conceptualisation through different kinds of drawings or images an architect can make a statement that can address political, social or cultural issues. This will greatly influence the aesthetic expression an architect chooses for the project. This concerns that though interaction with available materials, such as pen, paper or a computer software, an architect can reach his/her aesthetic style. In this chapter it will be argued that, as hand made drawings, computer produced drawings can also have a distinguishable character, which depends on architect's aesthetic expression discussed in the next section.

3.0.1 Aesthetic Expression

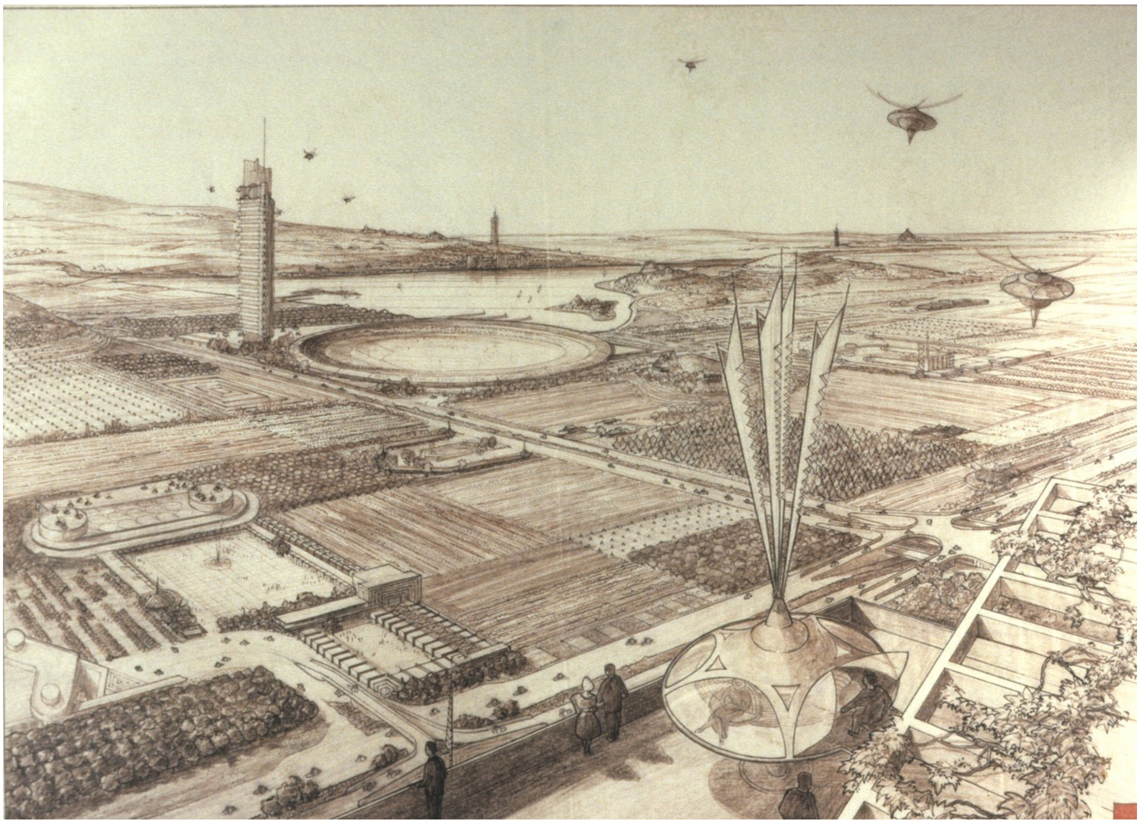


Figure 3.0: Frank Lloyd Wright, *Living City*, 1932, aerial view, freehand drawing.

According to Cook a drawing can represent a motive, strategy, vision, image, composition, expression and atmosphere, technics or surface of one's intentionality.[304] The question of choice between these is that responsible for the aesthetic quality of a particular drawing. For example, Frank Lloyd Wright's drawings of *Broadacre City* and *Living City* reflect *endless Midwestern plants and soft, crafted materials and gruffly polite Midwestern conversation and values,*[305] as illustrated in figure 3.0 above. Drawings like this, besides the architect's character, intentionality and attitude, reflect the time in which they were created. In the times of hand-made drawings, architect did not have the means to create the hyper-realistic 3D models that sometimes explain the project even too clearly in the conceptual sense, but they had imagination, talent and the knowledge for craftsmanship.[306] Considering that building construction presents a long and complex process, talent and craftsmanship are only initial parameters in its condition. During the design process these parameters can distinguish aesthetic quality of an architectural drawing and consequentially building's form and differentiate architectural approaches and expressions.

An aesthetic expression of an architectural drawing can be achieved, among other means, through an abstraction of the quantitative information a drawing contains. With the digitization of the design process an interesting aesthetic transition occurred from drawings which were once created directly on a piece of paper, to those produced by means of a computer. This transition concerns the translation of an architectural drawing's explanatory plane surfaces, such as plans, cross-sections and elevations through digital X, Y and Z axes relative to the real geographical coordinates. The state of these plane surfaces changed from static two-dimensional pictures to dynamical and interactive multiplicity of transparent layers with the diversity of overlaid information and within almost infinite drawing space. Such layering of information created the possibility for a two-dimensional drawing to be translated into a three-dimensions within the same drawing space, something impossible in the hand-drawn mode of production. The differentiation between groups of lines with a distinct meaning and purpose are represented through the utilisation of different layers that can have distinct parameters, such as colour, line thickness, line type, etc. One implication of this is that besides the utilisation of advanced tools the need for the craftsmanship still remains

[304] Ibid., 12.
[305] Ibid., 10.
[306] George Barnett Johnston, *Drafting Culture: A Social History of Architectural Graphic Standards*, The MIT Press, Cambridge, Massachusetts and London, England, 2008, 42.

with the difference in the quality of the attained set of skills.[307]

An aesthetic transition to computer drawings by means of digitization can be investigated through usage of various CAD software applications such as AutoCAD or Microstation, and the concepts developed for their specific functions that enable this transition in the drawing production, such as introduction of *layers* or *reference files*, discussed further in the chapter. Nowadays, the process of computer-aided drawing production includes utilisation of previous software applications and their combination with other graphic editing software, such as Adobe Illustrator and/or Photoshop. The mastery of systematising the right set of parameters in few or several used software applications through the process of production renders the drawing with a distinctive character. In comparison with hand-made drawings, this results in an aesthetic quality peculiar to computer-aided drawings. The level of quantitative information and an aesthetic quality of a computer drawing can differentiate drawings to technical and illustrative drawings, similarly to the differentiation of free hand-made drawings and technical hand-made drawings. This means that computer-aided drawings can have a multitude of different approaches in their aesthetic configuration because the software processes concerned allow for this. For example, there are the drawings or plans produced for a building's construction used on a construction site, which contain technical information about construction execution. On the other side, there are computer drawings that have a more descriptive and illustrative character, which can explain the architect's idea and a building's concept in different way that through the quantitative information. This concerns constitution of additional layers of sophistication to a drawing through combination of different software applications.

In order to explain distinct characters of different types of architectural drawings it is necessary to conduct a more detailed analysis about the variable character of architecture.

3.0.2 Architectural Dichotomy

Architecture is considered to be an alliance of art and technology[308] which is as well

[307] McCullough, *Abstracting Craft*, 59.
[308] R. L. Rutsky, *High Techne: Art and Technology from the Machine Aesthetic to the Posthuman*, University of Minnesota Press, Minneapolis, 1999, 41.

reflected through a relationship between an architect and an engineer and indicated through the types of drawings that are created through different stages of architectural design. According to Peter Eisenman, the various theories of architecture that can be called humanist are characterized by a dialectical opposition, which is an oscillation between the concern about an internal accommodation or the program of the building and the way it is materialized, and the concern for articulation of ideal themes in form, like ones apparent when the configuration of the plan is concerned.[309] Eisenman distinguishes modernism as outmoded functionalism which proclaimed that architecture can be generated only if comprehended as an autonomous and pure discipline, while for him post-modernism perceives modern architecture as an obsessional formalism. Therefore, the statement that post-modernism implicitly proclaimed is that the future lies inexplicably in the past, within the peculiar response to function that characterized the nineteenth century eclectic command of historical styles.[310] The balance between the form and function which existed in the nineteenth century architecture was disrupted with the rise of industrialisation because of the problems of a more complex functional nature that concerned accommodation of a large number of people. This resulted in re-orientation of architecture to progressively become a social or programmatic art. This social and programmatic aspect of architecture links it to interaction because of the ways in which the activity is conducted within the space and therefore manners in which interaction frames the dynamics of space.

In the nineteenth century and continuing into the twentieth, as the program grew in complexity, the type-form became diminished as a realisable concern. The expression *type-form* derives from the theory of Aldo Rossi, as explained by Peter Eisenman in the book “The Architecture of the City”. Rossi's comprehension of time as a collective memory lead him to a special transformation of the idea of *type*.[311] He introduces memory into the object and in this way the object embodies an idea of itself and a memory of a former self. This means that type becomes analytical and experimental structure utilised as an operand in history, instead of being a neutral structure found in history. Through introduction of memory, type becomes an apparatus, an instrument for analysis and measure. This apparatus, as understood by Rossi, is not reductive although it is supposedly scientific and logical. Instead, it allows for a meaningful content to be

[309] Peter Eisenman, “Post-Functionalism” in Kate Nesbitt (ed.), *Theorizing a New Agenda for Architecture: Anthology of Architectural Theory, 1965-95*, Princeton Architectural Press, New York, 1996, 80.
[310] Ibid., 80.
[311] Aldo Rossi, *The Architecture of the City*, The MIT Press, Cambridge, Massachusetts and London, England, 1984, 39.

introduced into urban elements. This meaningful content, although it is typologically predetermined, is always original and authentic and often unanticipated.

According to Rossi, innovation in architecture did not generally occur through the object during architectural history. This means that the architectural form occurs as a consequence of many factors, like the programme of the building. On the other hand, building typology was never considered to be latent to become the animating force of a design process. This means that explorations with formal attributes of the building are considered to reflect architect's aesthetic expression and therefore can be perceived as more inspiring for an architect. The possibility of invention became possible with the type-form, because type is now both, process and object.[312] This is important because of the potential multi-layering of meaning with an introduction of digital processes in architectural design. The type-form is important for interaction because it emphasise the importance of an event. In this thesis, event is perceived as a moment in which form, programme and the work of building's materials come together, as discussed in the first chapter. An event inscribed into a building becomes a memory. Meaning constructed through memories, as proposed by Rossi, gives a strong poetic character to objects and buildings. In this thesis, the multi-layering is introduced in two aspect of its formalisation. The first one is through cultural artifacts in different digital architectural forms, such as digital façades and cybernetic environments, which interactive attributes enabled a new type-form to appear in an urban and architectural landscape. The second one is through interaction during architectural design process and parametric software based processes that enabled, among other things, the possibility to store information in different parts of a drawing and interact with the data in a new way that was not possible in the hand-made mode of production, as will be discussed further in the chapter. The sphere of type-form procedure gets to be extended to the virtual world of a computer that can be combined and interpolated with the architectural physical structure. It is, as well, related to the poetic meaning of an object which through memory can obtain the subjective attributes.

After World War II architectural design was understood in the oversimplified form-follows-function formula as a result of the shift in balance in favour of function. During the late 1960s, in the theories and polemics it was thought that the ideas that were

[312] Eisenman, “The Houses of Memory: The Texts of Analogy” in Rosi, *The Architecture and the City*, 7-8.

represented in the early Modern Movement could sustain architecture. For Eisenman, the main premise of this attitude was articulated in what he called “English Revisionist Functionalism” represented in the work of Reyner Banham, Cedric Price and Archigram. The neo-functionalist attitude, reflected in their work that idealized technology, was endowed with the same ethical positivism and aesthetic neutrality of the pre-war polemic.[313] Their projects clearly stressed an attitude towards the insignificance of form in comparison to function. They considered the programme of the building as essential for any commencement of social activity, as discussed through Price's Fun Palace project in the previous chapter. This is partly because the programme of the building is perceived as a dynamic process that alters as the social activity changes, while form remains static and insensitive to people's interaction.

The importance of discussion about the relationship between the form and function and the consequences when this balance is disrupted is introduced in order to understand the difference between the concepts of form-giving and form-finding processes. Form-finding is interesting for analysis because of its self-organizational aspect, which was discussed in the previous chapter. A form-giving process can help in explanation of the transition between the two processes in the construction of an architectural drawing. This can be related to the modes of interaction relative to the hand-made and computer-aided drawing production and how this changed in the digitization of the architectural design process, as discussed in the next section.

3.0.3 Construction of the Architectural Drawing – Form-Giving Process in the Hand-Made Mode of Production

In respect to previously discussed duality of architecture and its dialectical relation between form and function it is necessary to make a distinction between free hand-made drawings, which are artistic in character, and hand-made technical drawings created with rulers and rapidographs, which have an engineering character. There are a few important questions in this regard, the first one considers the difference between modes of interaction in the process of hand-drawing and computer-aided drawing. Interaction is important because it presents a constituent which determines the prospect for an artistic expression. The second question is whether an architect's artistic expression

[313] Eisenman, “Post-Functionalism” in Nesbitt, *Theorizing a New Agenda for Architecture*, 81.

changes through the utilisation of new means of digitized production and how this may influence the artistic character of a drawing and whether the aesthetic expression can be conveyed through computer-aided drawing.

An artistic character of a drawing is referred to what Henry Focillion addresses as the dynamics of creativity that the art needs to perceive and express.[314] The flux of forms that occurs in space, in matter and in the mind is one way to record the object-form. According to Focillion, understanding and giving form is a dynamic process, rather than a static code. Works obtain meaning through the giving form process. Focillion argues that the quality of a tone or of a value depends not only on the way in which it is made, but also in the way in which it is set down. Malcolm McCullough's understanding of the 'set down' points to the idea of *focused action.* [315] Focused action involves the act of creation performed by an architect/artist, who have obtained a specialised set of skills that is put into action in the moment of creation and this can evolve through learning. The result of the focused action has a certain distinctiveness. McCullough suggests here that the moment of creation is also in flux, so as the one who creates learns, his/her skills to produce a creative work of art or architecture develop as well. McCullough also notes that the essential significance of Focillion's argument about the form-giving process is in its portrayal of it as a two-way action. This two-way action can be referred to as an interaction between the hand and the object that has a phenomenological character and attributes experienced through touch. In case of hand-drawings this means an interaction between the paper and the hand though a pen as a mediator of the transmitted thought. The moment in which the act of drawing occurs is a subjective event in which a personal expression can be the motive for a drawing's manifestation. As the drawing process continues, the interaction between objective and subjective becomes essential for the translation of meaning through a drawing. The sensual qualities of a hand-drawing directly express its materiality as an important characteristic in the interaction process because one can touch paper, rotate it around, erase lines, feel the texture of the paper, etc.

Richard Sennett notices that touch presents different qualities of the intelligent hand.[316] This relates to the question of how different individuals use their hands in interaction

[314] Henry Focillion, *The Life of Forms in Art*, Zone Books, New York, 1996, 33-34. A revived classic on the phenomenology of creativity.
[315] McCullough, *Abstracting Craft*, 8.
[316] Richard Sennett, *The Craftsman*, Pinguin Books, London, 2008, 152.

with the object of work. Sennett notices that specific professions, such as surgeons, cellists or pianists, do not need a particularly shaped hand to begin with their education. The possible limitations in terms of hand shape or proportion of fingers and palm can be exceeded with training. Concerning architects, the conclusion is the same. Another issue is how touch can supply the brain with different kind of sensate information than the eye, which has been a long standing debate within philosophy and the history of medicine. Before Charles Sherrington re-examined it, the argument was that the eye supplies images that are contained in a frame, while touch delivers almost infinite data.[317]

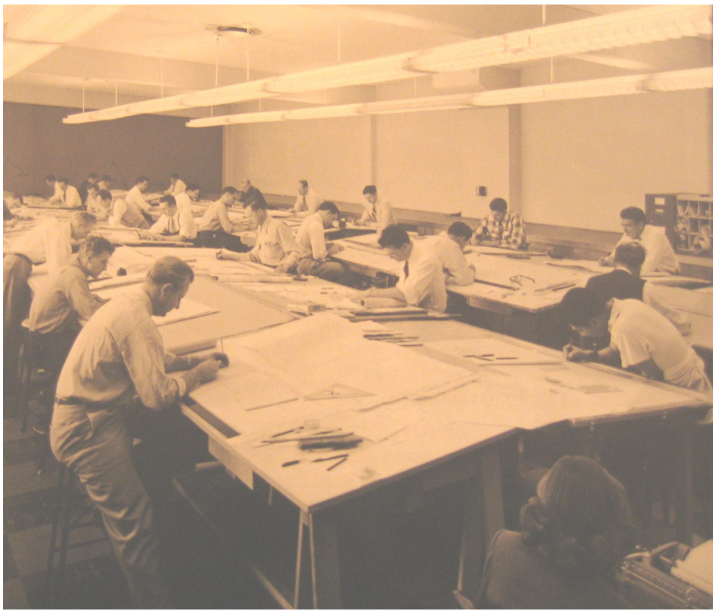


Figure 3.1: Traditional drafting in an architectural office.

In discussion about touch, Senett refers to research by Sherrington and the conception of *active touch*[318] that is the cognisant intent that directs the fingertip, which makes the touch proactive as well as reactive. The development of Sherrington's research was with emergence of *localised touch,*[319] a proactive engagement of fingers without direct cognisant intent that occurs when brain is stimulated to start thinking in the moment the fingers find a particular place on an object. As an example, Sennet writes of a medieval goldsmith whose perceptions of the material arose through his fingers, interacting with the material until the ostensibly adulterate spot was found. With the help of this localized conscious indication, the goldsmith could cogitate backward to the nature of

[317] Ibid., 152.
[318] Charles Sherrington, *The Integrative Action of the Nervous System*, CUP Archive, 1947, 107.
[319] Sennett, *The Craftsman*, 153.

the material. For Howard Risatti, hand presents a reflection of the entire human organism and a direct extension of the mind.[320] In combination with an appropriate technique and suitable material, the hand establishes physical relationship between itself as extension of mind, body and craft object. In this regard, it can be said that the hand informs the craft object through applied technique, which means that it gives the object its physical form and formal meaning.

The traditional process of architectural drawing production considers direct hand manipulation and immediate interaction with the *object of production*, like pen, paper, rulers, colour pencils, etc. in which the output of the thinking process can be immediately perceived, as illustrated on the figure 3.1 above. This means that the delay time between the thinking process and its description through a drawing is minimal. Drawing a line with a pen or pencil incorporates a kinaesthetic sense of direction and length. As it is a tactile act, it feeds back into the mind in a way that reinforces the structure of the resulting graphical image.[321] Therefore, these tactile qualities of a hand drawing are directly conditioned to provide a fluid and smooth interaction during the design process. In this regard, a drawing presents a relationship between the way an architect imagine a space and the way the architectural ideas are drawn. Architectural drawing can have a dialogic character and create a base for communication between an architect and other parties involved in the design process or it can be used as a monologue in form of personal and autonomous cultural production. This is specific for a conceptual phase of design in which an architect communicates his/her idea.

From the previous it can be concluded that hand-made drawings have an advantage during interaction in the fluency of thought in terms of the immediacy of meaningful descriptive result in the form of a line(s). However, the performance in terms of diverse computer functions use, such as copy, paste, undo or erase, that enable faster speed of production is advantage in computer drawing. Computer-aided drawings can be created with a higher speed of execution but interaction time between the thought and its description is delayed. It can be said that the the reason why a large number of architects still use pen and paper in the design's conception stage is because of the greater naturalness and spontaneity of interaction with the pen.[322] Following this, its

[320] Howard Risatti and Kenneth R. Trapp (foreword), *A Theory of Craft: Function and Aesthetic Expression*, The University of North Carolina Press, Chapel Hill, USA, 2007, 109-110.
[321] Francis D.K. Ching, *Architectural Graphics*, John Wiley & Sons, Hoboken, New Jersey, 2009, 15.
[322] Claude Faure, "Pen-Based Human-Computer Interaction" in M. I. Simner, C. G. Leedham and A. J. W. M.

important to describe in more detail the process of interaction with the computer and consequentially with software, as discussed in the next section. This will inform an exploration of the digitization of the design process.

3.0.4 Modes of Interaction in the Digitized Architectural Design Process

In the creation of a computer drawing, interaction occurs between the hand and the mouse and/or, depending on the software, the keyboard. The experience of touch is shifted from the fingertips to a whole arm. The directness of interaction with the paper is shifted to the interaction with a screen though a mediator, which is usually a mouse. Representing more than a digital interpretation of a paper surface,[323] the screen gave more possibilities because the outcome of the interaction is animated and the results of interaction anticipated. Anticipation of a user is connected to the unpredictability of the outcome, for example if we activate a link or an icon there is a moment of anticipation while the operation is executed by the computer. In terms of human-computer interaction development an important breakthrough was the invention of the computer mouse. Its inventor, Douglas C. Engelbart[324] describes it as a pointing device with which one interacts with a screen to select objects on a screen and in this way tells the computer that a certain action with these objects is about to happen,[325] as it is demonstrated on a video for a 1968 demo created by Engelbart for explanation of how the mouse operates.[326]

While with pen and paper the interaction is immediate, with mouse and screen it happens through a series of mouse clicks. The moment of expectation between different moments of action or between mouse clicks is crucial for this mode of interaction. For example, if one is to draw a line in AutoCAD one can either choose an appropriate icon or type an appropriate command in the command line (*l* for *line*) and click on a screen to position the first point and then click again to position the second point of a line. The line is drawn through a series of actions, the resultant sum of which leads toward the

---

Thomassen (eds.), *Handwriting and Drawing Research: Basic and Applied Issues*, IOS Press, Amsterdam, The Netherlands, 1996, 373.

[323] Ivan Sutherland, "Sketchpad: A Man-Machine Graphical Communication System" in Noah Wardrip-Fruin and Nick Montfort (eds.), *The New Media Reader*, MIT Press, Cambridge, Massachusetts and London, England, 2003, 109.

[324] Bill Moggridge, "The Mouse and The Desktop" in *Designing Interactions*, The MIT Press, Cambridge, Massachusetts and London, England, 2007, 27.

[325] Ibid., 28.

[326] "The Demo", MouseSite, Stanford University, Retrieved July 30, 2010, from http://sloan.stanford.edu/MouseSite/1968Demo.html

desired outcome. A further level of interaction was achieved with combined use of the keyboard and the mouse (as illustrated in figure 3.2 below) for which Engelbart's initial thinking started in 1951.[327] For this mode of interaction he introduced another device with which he could control the action on the screen. Engelbart asserts that the chording key set he built for himself was adopted by a number of users. An advantage of this set was that it was possible to type any of the characters in the alphabet with one hand, while giving commands with the three button mouse with the other and to point at the same time. According to Engelbart, this mode of interaction provided a much richer vocabulary and more compact way to initiate interaction than the Graphical User Interface (GUI).[328]

Figure 3.2: Douglas Engelbart's combined use of the keyboard and the mouse.

In regard to human-computer interaction, another of Engelbart's concerns was to create a systematic approach to the increase of human intellectual capacity, which he discussed in his 1962 text "Augmenting Human Intellect".[329] The development of the concept for a computer-based system for augmentation of human intellect was carried out at Stanford Research Institute in Menlo Park, California between 1957 and 1977.[330] An early insight of Engelbart's was related to organizational changes to the ways of working and the ways in which work flow is handled, as a result of the transition from manual tools, such as pen and paper, to computer-based tools. Therefore, Engelbart's objective was to develop principles and techniques for designing an *augmentation system* that will, besides its interactive potentials, provide for changes both in ways of conceptualizing,

[327] Moggridge, "The Mouse and The Desktop", 30.
[328] Douglas Engelbart, "The Demo that Changed the World" in Moggridge, *Designing Interactions*, 36.
[329] Douglas Engelbart, "Augmenting Human Intellect: A Conceptual Framework" in Fruin and Montfort, *The New Media Reader*, 95-108.
[330] Michael Friedewald, "The Continuous Construction of the Computer User Models in the History of Human-Computer Interaction" in Gerhard M. Buurman (ed.), *Total Interaction: Theory and Practice of a New Paradigm for the Design Disciplines*, Birkhauser – Publishers for Architecture, Basel, Switzerland, 2005, 30.

visualising and organising working material and in procedures and methods for working individually and cooperatively. This approach evolved into the kind of working environment in which all the parties to a project or company are able to work online with the possibility to store all their data (such as plans, programs, designs, reports, documentation, specifications, reference notes, memos, etc.) in one place on a computer. The exchange of data and intercommunication between the parties was enabled via consoles.[331] This conceptual framework envisioned by Engelbart is by and large the standard modality of workflow organization within architectural offices today.[332]

The development of Engelbart's concepts as actualised in the devices discussed previously, such as the mouse and its potential combination with a keyboard, has led to the modes of Human-Computer Interaction most widespread today. This mode actually implies an action-reaction kind of relationship. Typing a command on a keyboard or selecting an icon with a mouse is an action performed by human user, this action activates the appropriate program flow of the computer generating appropriate output, which is computer's reaction to user's input. Consequentially, the place at which the interaction between activity of the human and the digital processes of a computer takes place is the human-computer interface.[333] Discussion of computer interface will be developed further on in this chapter. The previously discussed form of two hand interaction provides an engaged approach with the means available for drawing creation. Typing command abbreviations with one hand and using the mouse to control the action on the screen with the other, confers considerable advantage to the speed and smoothness of drawing construction. This kind of interaction resembles the activity during hand-drawing mode of production in regard to engagement of one hand with a pen and the other with a ruler. In this mode, while one hand controls the movement of a ruler the other one creates the line. If translated into a computer operations, the ruler and pen control are enabled by the mouse, while the other hand can have new operational

[331] Douglas Engelbart and William K. English, “A Research Centre for Augmenting Human Intellect” in Irene Greif (ed.), *Computer-Supported Cooperative Work: A Book of Readings*, Morgan Kaufman Publishers Inc., San Mateo, CA, 1988, 83.

[332] Some general differences to Engelbart's workflow organization is in the nature of the conducted work, explicit for the production of architectural design: all the files are stored on a server and an architect access the files via his/her computer. A file can be used and amended by one architect at the time, which means that there is no multiple users option for the real-time processing of the file. This mode of production influences design process to a great extent because as an essentially collaborative process, architectural design depends on good information interchange and possibility to communicate fast and efficiently.

[333] Friedewald, “The Continuous Construction of the Computer User Models in the History of Human-Computer Interaction” in Buurman, *Total Interaction*, 30.

attribute which depends of the respective software and that is to quicken the process of command execution. This acceleration is expressed in the number of clicks leading to the execution of the command. Regarding previous modes of human-computer interaction it is interesting to analyse different modalities of materiality involved in the process of interaction, as discussed in the next section.

3.0.5 The Condition of Materiality

In relation to heterogeneous modes of interaction which occur during the production of architectural drawings it is interesting to address the issue of materiality regarding the comprehensive understanding of the digitization of the architectural design process. As previously discussed, digital processes can initiate different modes of interaction with the object of production. The *object of production*, also noted in the description of a hand-drawing process, is considered to be an apparatus used to produce an output of a thinking process. In the digitized mode of production hardware and software are the objects of production, both with different levels of perceptive materiality. In case of interaction with the software the materiality of the process cannot be fully comprehended because of its speed and the microscopic size of the electrons controlled by the software. According to Matthew Fuller, the materiality of software can be operative at many scales, from the particular characteristics of a language, used for writing code for example, or other modes of interaction with hardware to the events that can occur at the level of models of user subjectivity or forms of computational power.[334] This extends the reach of software into social and cultural instances, such as during the architectural design production, that can in return inform the ways in which software is used. For Matthew Kirschenbaum, software also leaves the material trace in form of printed work,[335] as is the case of architectural drawings. In his opinion, when working with software, as digital objects move between different information states, formal materialities are routinely established and dissolved. This can be seen as an object is transformed through a succession of different formats. Different computational structure is imposed by each new format.[336] In case of architectural design, drawn lines and geometrical shapes that determine resultant representational qualities of a building and correspond to actual physical forms get to be translated into a set of computational

[334] Fuller, *Software Studies*, 4.
[335] Matthew Kirschenbaum, “The Word as Image in an Age of Digital Reproduction” in Mary E. Hocks and Michelle R. Kendricks (eds.) *Eloquent Images: Word and Image in the Age of New Media*, MIT Press, Cambridge, 2003, 137-156.
[336] Ibid., 146.

formats that change architect's relation with the building's materiality as it is translated from the digital formats to the actual physical building.

In relation to Hayles's understanding of materiality of a digital text,[337] and concerning materiality of software and digitization of architectural design process, it can be said that the crucial matter for understanding a design is in terms of how its form creates possibilities for meaning by mobilising certain aspects of its physicality. The materiality of an architectural design is the interaction of its physical characteristics with its signifying strategies. The notion of architectural design's materiality that is centred in the artifact extends beyond the individual object because of the social, cultural and technological processes that supplied its physical characteristics with formal attributes. Such processes that are part of a design's materiality lead to the conclusion that it is impossible to draw a firm distinction between its representational and interpretative concerns. In this line of thought, materiality is closely related with the building's content that is closely bound with building's conceptual postulate(s), so it can be observed as an emergent property. As the concept of the building develops, which is related and depends on the prevailing purpose the building is to perform, the material properties change accordingly. This concerns that the choice of materials for the building construction and finalisation emerge from the conceptual modalities conditioned by the contextual elements. This concerns that the constitutional elements of architectural design's materiality will always be a matter of interpretation and critical debate. In order to create more comprehensive impression about the complexity of the architectural design process and its transformation from manual to digitized modes of production it is necessary to describe, in the next section, its stages through these different modalities.

3.1 The Process of Traditional Fabrication: Technical Hand-Drawings

Previously in the text, a distinction was made between freehand drawings and hand drawn technical architectural drawings. The difference is expressed in the contents a drawing communicates and the way a drawing is interpreted. While a freehand drawing can reflect a multiplicity of purposes and meanings, a technical hand drawing is created with the intention to clearly and concisely communicate all specifications needed for a

[337] Katherine Hayles, *My Mother was a Computer: Digital Subjects and Literary Texts*, University of Chicago Press, Chicago and London, 2005, 103-104.

building to be transformed from an idea to a physical form.[338] Further on in this chapter, the traditional method for making technical architectural drawings will be explained, as well as the means by which this kind of drawing was produced in order for this process to be compared with digitized modes of design production. Before an explanation of the process, it is necessary to determine what drafting is.

In 1912 an English architect and author Reginald Blomfield[339] determined that in the most general terms the object of an architectural drawing is the representation of architecture.[340] In his book “Architectural Drawing and Draughtsmen”, Blomfield explains that the basis for this objective is the study of form and its mastery, the final expression of which is the drawing that is inspired by personal temperament. In Blomfield's opinion the point of making beautiful drawings is not in the technical brilliancy of a draughtsman but in the difficult task of designing an elegant architecture. In this book he tries to establish the connection that architecture had with art through his study of sixteenth, seventeenth and eighteenth century draughtsmen. This study regards the broad modalities of draughtsmanship and diverse characters of architectural drawings, which range from the most simple and practical ones created for the purpose of building construction to the fantastic visions of architecture such as Piranesi's fictitious drawings of Rome.[341] In his understanding of the meaning of a drawing, G.B. Johnston states that there is an etymological link through terms of work between the words *drafting* and *drawing.* These are considered to be the human activities of dragging or pulling tools across surfaces or inscribing marks upon the earth. He considers both modalities of body labour important, moving heavy loads in the building of walls and the manipulation of precise instruments during the projection of lines.[342] Therefore, it can be said that in historical terms the act of drawing a line involves a movement of a hand, in case a line is drawn on paper, or the whole body, in case it is inscribed on the earth..

In these terms, the production of line, at its most basic level, initiated by movement and

338 David L. Goetsch et all, *Technical Drawing*, Thomson Delmar Learning, Clifton Park, New York, 1999, 3.
339 Reginald Blomfield, “Architectural Drawing and Draughtsmen”, Cassell & Co., London, New York, Toronto, Melbourne, 1912, 68, Retrieved July 31, 2010, from http://www.archive.org/stream/rsarchitecturald00blomuoft/rsarchitecturald00blomuoft_djvu.txt
340 The respective authors chosen for the discussion about the historical development of drafting/drawing production are chosen because of their individual positions about architectural drawing, which should demonstrate how the notion of what drawing is, or should be, developed through history with the introduction of new technological means.
341 Blomfield, *Architectural Drawing and Draughtsmen*, 124.
342 Johnston, *Drafting Culture*, 2.

force represents manufacturing codified symbols with a pointed tool, such as pen, pencil or rapidograph. While drawing a line, the eyes follow its direction and with that action the potential of the line to suggest motion is basic.[343] It is basic in a sense that it represents the motion of a point inscribed on different materials, such as paper, canvas or earth. This refers to the Paul Klee's idea that *the line is a point set in motion*.[344] Through this cognition, as the line suggests new forms, an associative thoughts are exhorted.[345] The physical action of the hand transfers the motion to a drawing. As noted by Rissati, technique is a direct expression of a human hand, which involves the hand's ability to carry out certain operations based on technical knowledge of material and mastery of manual motor skills.[346] As an extension of human hand, a pen guided by an architect's hand, makes a mark on the paper reflecting the motion of the hand and creating a drawing. According to James Gibson, who writes about human perception in relation to the contact with a drawing, making marks is both viewed and felt.[347] In one's encounter with a drawing, it obtains meaning and individuality.

Previous discussion about the nature and quality of a technical architectural hand drawing provides a brief introduction in the means and methods in which and architectural hand drawing was constructed. Understanding of the concept and the meaning of drafting or drawing is essential for comprehension of the modalities in which CAD software, with the Sketchpad program as its origin, operates in the production of computer-aided drawings, something to be discussed further in this chapter. In order to compare it with the computer-aided production, it is necessary to understand the interactive modalities that occur during the hand-drawing production, as discussed in the next section.

3.1.1 Drawing Production in the Concept Stage

The process of architectural drawing production has transformed through history during a social and technological changes, through which *drafting culture*[348] and its tools have

[343] David A. Lauer and Stephen Pentak (eds.), *Design Basics*, Thomson Wadsworth, Boston, MA, USA, 2008, 134.
[344] Paul Klee, Des Moines Art Center, “Paul Klee: Paintings and Watercolours from the Bauhaus Years, 1921-1931”, Catalogue of an Exhibition Des Moines Art Centre, September 18 – October 28, Des Moines Art Centre, 2.
[345] Lauer and Pentak, *Design Basics*, 128.
[346] Howard Risatti and Kenneth R. Trapp (foreword), *A Theory of Craft: Function and Aesthetic Expression*, The University of North Carolina Press, Chapel Hill, 2007, 108.
[347] James Jerome Gibson, *The Ecological Approach to Visual Perception*, Lawrence Erlbaum Associates Inc., New edition, Hillsdale, New Jersey, 1986, 267-291.
[348] Johnston, *Drafting Culture*, 4.

changed as well. Further description therefore relates only to one cross-section in time and is connected to the end of 20th century architectural practices localised within a specific context, those of Belgrade in Serbia. It presents affiliation of an architectural community of people with a common aesthetic preference and relationship to training. The choice of this particular group and discussed process of production is because it is related to my architectural education and professional experience. It is important to say that this process of production presents an intermediate stage in the evolution towards computer drawing because it utilizes photocopy machines as introduced by Xerox in 1949.[349] The process of a manually produced architectural technical drawing, explained further in the section, illustrates only one phase of the architectural design. This stage is concerned with processing of an idea through the development of a concept in several distinctive phases.

This means that in the first or the initial stage after refining and formalising the project's concept through a series of freehand drawn sketches, the architect draws plans, cross-sections, elevations, perspective and axonometric views by hand on the white non-transparent paper with the graphic pencils and rulers. These drawings represent the projections of the architect's imagination developed in the drawing, which is not simply a means for registering an already complete idea. The idea is developed and refined through further drawing. In this phase we have an architect's imagination elaborated through lines that have an exclusively material end and physical formalisation. The precise and accurate character of drawings is reflected through practical rather than emotional response to the final product in a form of a building and it presents one aspect that can differentiate it from art. The aesthetic quality of a drawing is not significant here but the substantive quality of the drawn object certainly is.[350] This means clear definition and representation of a drawn object, among other things, through set of predetermined standardised symbols, such as those for doors or windows.[351] This considers creation of plans, sections and elevations as plain line drawings.

In the second stage, when the explanatory level of the design has reached a satisfactory point, which means that accessibility, functionality and structure are clear and well formed, this piece of paper was overlaid with another, transparent type of paper called

[349] Neil Schlager and Josh Lauer (eds.), *Science and Its Times: 1950 – Present*, Gale Group, Farmington Hills, Michigan, 2000, p. 498.
[350] Johnston, *Drafting Culture*, 17.
[351] Ernst and Peter Neufert, “Neufert: Architect's Data”, Blackwell Science Publishers, Malden, MA, 2000, 175-189.

tracing paper. This paper was used for making an ink-print of the design with ruling pens and rapidographs instead of graphic pencils. Titles of pages, text, appropriate symbols, hatching and different mark-ups were also added to this paper. Technical letter writing, hatching, shading and different symbols were appended either with stencils and/or templates, such as Letraset, applied to the paper as dry transfer lettering. This phase prepared the design for copying. At this point it was necessary to add everything that should be *printed* in black and white. This phase is mechanical in character because the architect traces over the existing drawing to make a long-wearing copy which will have more endurance to physical damage. The architect repeats the process of drawing done in the initial stage with a different tool and without much cogitative engagement with the design because this procedure does not require it. This can be considered as the first layer of the explicitly aesthetic quality of the drawing because the creation of the template for the *printed* copy provides space for creativity reflected in the choice of letters, disposition of letters and symbols on the paper, disposition of the drawing related to the paper format, etc.

In the third stage, the prepared ink-print, with all the necessary information, was copied onto plain white paper. Copying in this traditional way of production, was equal to what in today's computer terms is described as printing, with a difference in the finishing level of the drawing. A computer print results in the output of a completed drawing with added text, colour and graphics representing people, cars, trees, etc. and the ink-print is outputs a black and white line drawing. The original ink print remained intact for making more copies in case a mistake is made when colouring.

The fourth stage comprised colouring with markers, colour-pencils or other colouring instruments, according to the architect's choice. The choice of colouring utensil determined the aesthetic quality and character of a drawing. In this case, as McCullough notices, the tool is not only performing some action it is also representing that action.[352] As he further observes, the choice of a particular tool may represent not only an action but also an approach. In this stage of an architectural design the creativity of the designer reached a level of an artistic performance because in this phase of finalisation there was a transition from strictly architectural, clear continuous line drawing, to a more emancipated mode of presentation, as illustrated on the figure 3.3 and 3.4 below.

[352] McCullough, *Abstracting Craft*, 61.

This is a stage in which a personal drawing style and approach is most obvious.

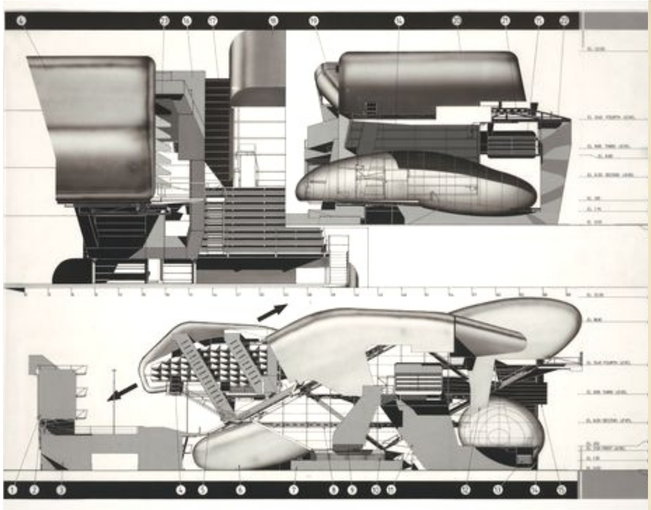


Figure 3.3: Ink, airbrush and cut-and-pasted printed self-adhesive polymer sheet on frosted polymer sheet, Neil M. Denari, Elevations, Prototype Architecture School No. 5, Los Angeles, California, 1957.

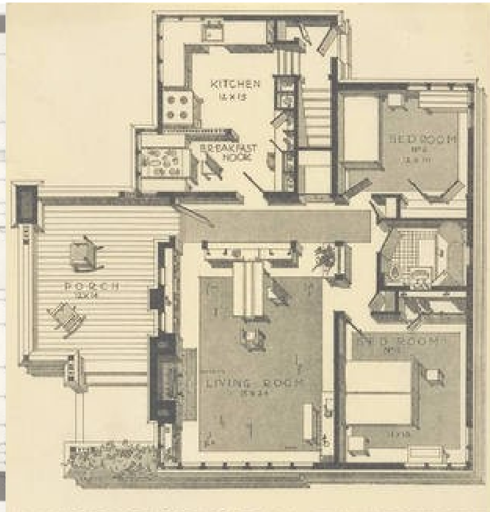


Figure 3.4: Lithograph, Frank Lloyd Wright, Plan for American System-Built Houses for the Company project, 1912-1916.

In the fifth stage, after colouring, the drawing with the distinctive aesthetic quality was glued onto a sheet of cardboard. The content of the project's presentation remains the same in the digitized mode of production with minor differences in the stage performance plan. An architectural project in the initial stage described previously, should explain itself through set of plans, cross-sections, elevations, isonometric and/or perspective views. If the design is approved and to be constructed, a project acquires a different level of complexity.

Previous stages present an initial phase in what used to be hand-drawn architectural design production in Belgrade, Serbia. In the United Kingdom, for example, these stages are defined and regulated by Royal Institute of British Architects (RIBA).[353] As architectural design reaches more advanced stages it arrives at a point in which the creativity of the discipline transforms and is substituted with the administrative processes in which segmentation of the design results in procedures equivalent to the *assembly line*[354] manufacturing processes. This transformation is a point in which a design enters the realm of business, political trends, financial conditions and becomes a service. In this regard, G. B. Johnston states that in the present cultural milieu an

[353] See RIBA, Minimum Design Standards, 14, Retrieved March 12, 2009, from http://www.architecture.com/NewsAndPress/News/PolicyNews/Press/2009/RIBAWelcomesMinimumDesignStandardsPolicy.aspx
[354] Term and process introduced by Henry Ford. For reference see Ray Batchelor, *Henry Ford, Modernism and Design: A Twentieth Century Cultural Phenomenon*, Manchester University Press, USA, 1994, 89.

architect aspires towards an image of a champion of individual expression who is opposed to the equalizing forces of bureaucratic rationalisation.[355] This concerns that an image an architect aspires to is that of a hero in a struggle against sameness and the oppression of the everyday. The truth disguised within this construct of professional ethics and political agency is that in order to achieve any work, an architect must serve very close to power and wealth.

The design conceptualisation proposed by this thesis entails a particular engagement with ideas and concepts from outside of the discourse of architecture, such as cybernetics and media, in order to explore different modalities and influence that may introduce new ideas and approaches in dealing with architectural space. The results of this process can be essentially different than those created through traditional approaches, such as those mentioned above, which regard an architect more as a draughtsman that creates beautiful drawings. The conceptualisation suggested in this thesis regards the introduction of meaning in the creation of architectural forms and consequentially in its drawings. Meaning in these terms does not include only the functional aspects of design. Further, the digitization of the architectural design process relates to the transition from the traditional hand-crafted to computer-aided drawing production, as discussed in the next section.

3.2 The Process of Architectural Design Digitization: Computer Drawings

Concerning computer drawings, some architects will argue that the final hand-drawn presentation has more character, reflecting an architect's temperament than one produced by a machine, which is usually considered as synthetic and superficial. Hand drawing is seen to nurture ambiguity which implies multi-layered expression and response and also fosters imagination and creativity.[356] According to George Stiny, ambiguity is prominently missing in computer-aided architectural design. It is also absent in the case of designs drawn in the most basic mode, such as line drawings. Ivan Sutherland suggest that the reason for this is in the structured nature of computer drawings.[357] For him, an ordinary designer is unconcerned with the structure of his

[355] Johnston, *Drafting Culture*, 2.
[356] George Stiny, "What Designers Do That Computers Should" in Malcolm McCullough, William J. Mitchell and Patrick Purcell (eds.), *The Electronic Design Studio: Architectural Knowledge and Media in the Computer Era*, MIT Press, Cambridge, Massachusetts, 1990, 19.
[357] Ivan Sutherland, *Structure in Drawings and the Hidden Surface Problem*, Petrocelli, New York, 1975, 5.

drawing material. In case of drawings produced with pen and ink or pencil and paper, as discussed previously in the chapter, there is no inherent structure or there is a very simple one based on emergent sets of affordances.[358] In Sutherland's opinion, these tools only make dirty marks on paper whereas the principal concern of the designer is with drawings as a representation of the evolving design. For him, the behaviour of the computer-produced drawing is indispensably dependant upon the topological and geometric structure built up in the computer memory as a result of drawing operations. The properties of the computer drawing are independent of the properties of the object it describes.[359] In this regard, the concept of CAD software used for manufacturing computer-aided drawings is closely related with the concept of drafting, described previously in the text. In order to be able to compare the structural approach of hand-made and computer-aided drawing it is necessary to analyse important concepts in computer-aided drawing production.

3.2.1 Important Concepts in Computer-Aided Drawing Production

In the traditional mode of production, floor plans were drawn with all the necessary information on one sheet of paper, in one layer. The distinction between walls and furniture, for example, was made with differentiation of line thickness between such elements in a drawing. Computer-Aided Design (CAD) brought in several new possibilities and advantages, such as the speed of computers, nearly inexhaustible storage space and rapid recall capabilities. Further on, the drawings can be stored in the database for future use by different designers in a variety of software applications. Through the interaction with a computer it is easy to correct drawing errors and immediately visualize a revised picture on a screen, to create 3D models of any object or engineering element, use colour graphics that can display more distinct information on the screen so that certain important features can be highlighted and information easily differentiated,[360] generate file-to-factory production that allows for the fluidity of the object's construction, to use parametric design, etc. Besides these technical advantages, it can be argued if there is still an absence of ambiguity and distinctiveness in the computer-drawing, regarding the historical development of software applications

[358]Affordance is here regarded as a quality of an object, or an environment, that allows an individual to perform an action. See James Jerome Gibson, *The Ecological Approach to Visual Perception*, Lawrence Erlbaum Associates Inc., Hillsdale, New Jersey, 1986, 127-143.
[359] Ibid., 131.
[360] Dhananjay M. Kulkarni, A. P. Rastogi and Ashoke K. Sarkar, *Engineering Graphics with AutoCAD*, PHI Learning Private Limited, New Delhi, 2009, 8.

and the potential for a more profound graphical expression this allowed for, a factor which will be discussed further on in this chapter.

One point in having coloured graphics that can display more distinct information on the screen is closely related to the existence of *layers* and *levels*, features named differently in specific software applications but common to many. The different parameters of layers and levels, such as the selection of colour, line type, line thickness or global view, enable the grouping of lines with the same properties, which enables segmentation of the computer drawing into distinct elements that can be easily rearranged and handled graphically. The main conceptual premise of layers and levels is to allow for information differentiation. They present units of software whose scope makes them the appropriate handlers of the information.[361] When a layer or level is exported to a different application or environment, such as Adobe Illustrator for example, the functionality of the layer and the ability to handle any errors that might be effected by that functionality transfers as well.[362] In terms of layering information, there is another feature of software applications, such as Microstation, and this is a *reference file*. The function of a reference file is that it presents a sum of layers or a *live* drawing that can be referenced in to other drawings or design files, but cannot be manipulated while referenced inside them. Similar to an object in object oriented software, a reference file is the expression of a hierarchy.

In the sense of traditional modes of drawing production, *references* would be regarded as different sheets of paper with drawings on them. The drawings contain sets of lines that would be regarded as *layers* or *levels*, which would be created by different pencil colours for the differentiation of elements, although this was not the case because in the traditional mode of production layers did not exist. If drawn on a piece of paper, the presence of layers is constant and could not be changed. In the computer drawing one has the possibility to interact with them by switching them on or off, changing their colour, line thickness or line type, freezing or locking them for easier drawing manipulation, among other changes. In this way one drawing file can contain more reference files and therefore more information which can be used relative to what the drawing should represent. In different software applications references and layers have

[361] Paul Clements et all, *Documenting Software Architectures: Views and Beyond*, Addison-Wesley, Pearson Education Inc., Boston, MA, First edition, 2002, 94.
[362] Ibid., 94.

different attributes but the main logic remains. Reference files can be overlaid on top of each other and can be switched on or off when necessary. In the reference files different levels of information can be drawn on the distinct layers relative to the desired drawing content and level of detail, by switching layers on or off one can get a number of prints from one drawing file. This was not possible with the traditional modes of architectural drawing production. For example, in a computer drawing one can draw façade/exterior walls on one layer, interior walls on the second, furniture on the third, doors and windows on the fourth and so on. When necessary a designer can switch on a layer and when printed this would become a completely different, incrementally increased, set of information. In order to have a fuller understanding of the previously discussed concepts it is necessary to address the mode of interaction when appropriate software is used.

3.2.2 The Mode of Interaction with Software

Another interesting aspect of human interaction is with the software component and the different condition in which this mode of interaction influences the design process. According to Michael Murtaugh, this kind of interaction is linked with a tradition of engineers, software hackers and mathematicians who were looking for ways to break out of the rigidity and the strictness of their systems and also the speed at which one could get results from the running of a program.[363] For Murtaugh, in the 1960s, interaction represented liberation from and reaction against the mainframe batch-processing computer centre. During this time a radical use of computers involved the provision of an untrained groups of users with direct and real-time interaction with the machine. Interaction with the software means that the user makes choices through text typing, or utilisation of GUI.[364] Most of the software applications explained and analysed in the following section have GUI as the principal mode of interaction, while some also have a text typing or *command line* option.

[363] Michael Murtaugh, "Interaction" in Fuller, *Software Studies*, 143.

[364]An initial conceptualisation of GUI can be traced back to Vannevar Bush who in 1945 published an article "As We May Think" in which he proposed an information administration tool that he calls the *Memex*. (See "GUI Definition: Brief History", Retrieved November 09, 2009, from at http://www.linfo.org/gui.html The Memex is a system that would allow storage of data on a microfilm, which would be easily accessible, programmable and linkable with hyperlinks.(Ibid.) In 1963 Ivan Sutherland developed Sketchpad. The predecessor of the first computer with a GUI was a point-and-click text editor for the oNLine System or NLS and it was developed during 1950s by Stanford Research Institute team lead by Douglas Engelbart. (Moggridge, *Designing Interactions*, 20.) This first GUI had a text based hyperlinks that were manipulated with a mouse. The concept of hyperlinks was further refined and converted into graphics by researchers at Xerox Palo Alto Research Centre (PARC) and the name of the new interface was PARC User Interface (PUI). It consisted of graphical elements such as menus, windows, icons, check boxes and radio buttons. The first computer with GUI was PARC's Alto computer built in 1974.(See "GUI Definition: Brief History")

According to John M. Carroll and Judith R. Olson, there are several approaches in designing software interfaces.[365] One approach is to preconceive a model while starting the design process, during which development it is necessary to build a prototype, test it, and through this process to refine the design until an acceptable usability is accomplished. This is the classic empirical approach. The second design approach is to simplify the system and its interface in order to reduce the problem of communicating an appropriate conceptual model to the user. This entails that the system consists of only a small number of components and interactions. An implementation of this approach, called the *training wheels* approach,[366] was carried out by Carroll and Carrithers, who provided new users with only a small but significant subset of commands to learn. This small set fits a relatively simple conceptual model. The user was gradually acquainted to more rarely used or more complicated commands once one subset of commands was learned. Faster and more successful learning was enabled by this approach.[367] Another approach to training is the minimal manual or the *minimalist design*,[368] which include some main points, such as the less reading with only basic topics included, encouraging learner's initiative, modularisation of topics into smaller chunks of 1 to 5 pages, more error recovery information and the possibility to use manuals as references after training.[369] The problem with *training wheels* and *minimal manuals* is exclusion of all the learning and help needs, such as that users of complex applications often use unique subset of available functions.[370] Like architects who use complex applications, such as 3D modelling software, that has large number of options for different functions, like modelling or rendering. Another difficulty is that people have different learning styles for which it is necessary to have multiple training approaches and document types, such as training tutorials. Companies that create complex software, like AutoCAD, Microstation or 3ds Max, often make one software for more than one user group, like architects, mechanical engineers, civil engineers, etc., not necessarily making the subtle distinctions for different needs of various professionals. This results in software

[365] John M. Carroll and Judith Reitman Olson (eds.), *Mental Models in Human-Computer Interaction: Research Issues About What the User of Software Knows*, National Academy Press, Washington D. C., 1987, 24-25.
[366] J. M. Carroll and C. Carrithers, “Blocking Learning Error States in a Training Wheels System” in *Human Factors*, Number 26, 1984a, 377-391.
[367] J. M. Carroll and C. Carrithers, “Training Wheels in a User Interface”, *Communications of the ACM*, Number 27, 1984b, 800-806.
[368] J. M. Carroll, “Minimalist Design for Active Users” in B. Shackle (ed.), *Proceedings of First IFIP Conference on Human-Computer Interaction: Interact '84*, 1985, London, September 4-7, Amsterdam: North-Holland, 39-44.
[369] J. M. Carroll, P. Smith-Kerker et all, “The Minimal Manual” in *Human-Computer Interaction 3*, 1987-1988, 123-153.
[370] Ronald M. Baecker et all, *Readings in Human-Computer Interaction: Toward the Year 2000*, Morgan Kaufmann Publishers Inc., San Francisco, CA, 1995, 671.

applications that not necessarily have fluency in the demanding working conditions and can collapse when a more complex drawing operation is required.

Following the previous discussion, it is interesting to observe how much architects have adapted to the way software applications are written, usually by people who are not architects and are therefore not familiar with the process of architectural design and how this influences the design process. Firstly, in order to use such software, architects need additional training. By the end of basic training there is a period of adaptation in which it is necessary to apply the newly gained knowledge in a real project. Because of the abundant number of commands and options, it is difficult to memorize them all at once. The number of commands that is subsequently used in common daily work is usually much less than the number of existing ones. Secondly, because of the rational way in which a computer drawing is created, by clicking and dragging on the screen through a mouse as a mediator, there is a certain detachment from the thinking process. The creative processes involved in the creation of a design, such as making a composition, are more naturally performed with a pen because of the previously stated reason in regard to interaction during the hand-drawing process. Thirdly, the commands made for creation and manipulation of a computer drawing are not necessarily created to resemble processes used in the traditional mode of production. For example, copy and paste commands in the hand-made drawings were possible only by manual re-drawing of elements. Trimming or clipping the line or part of a whole drawing did not exist in the hand-drawing mode of production, the line was drawn from point to point. If the lines crossed, this was considered as the architect's style and an aesthetic quality of a drawing which could intensify the poetry of visual experience. It can be said that there are traces of similarity between drawing a line by hand and by a computer. The action of drawing a line by hand concerns marking the starting and ending point of a line by drawing two dots that will when connected form a line. The same set of actions is necessary when drawing a line on a computer, as discussed previously in the chapter.

The interactivity of the software also concerns the level of software's flexibility and openness to accompany possibility for expansion of its use so an architect can employ it in a more creative manner and not merely as a tool for drawing construction. The creative usage of software also involves its exploration through different modalities that can open new architectural design approaches, something discussed in the next section.

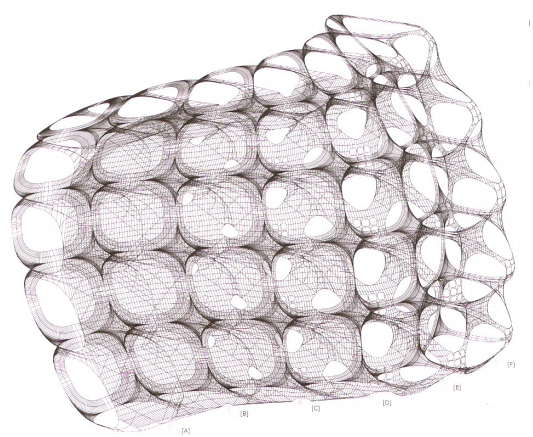
3.2.3 Creative Approaches in Software Use

In terms of software's interactive possibilities, the question that develops is whether the use of software is proportional to its potential. This does not concern the amount of software applications architects use for the creation of drawings or models but how they deal with the materiality of the software and what kind of new significance for architectural design this implies. In this regard, an algorithmic procedure can be observed as a new means of creation, a different approach to the perception of software use than of it being simply a tool, as most architects consider it. Some of the examples that involve more creative application of software principles were discussed in the second chapter, such as Price's *Fun Palace* and *Generator* project, as well as Spuybroek and Oosterhuis's *Water Pavilion*. Architects who use software more abstractly, in a way that encourages creative activity and exploration, recognize software as a material that has its own generative force. These are architects and designers, like Daan Roosengaarde[371], Mark Goulthrope from dECOi Architects and others who are engaged with software's and hardware's practical application in the construction of elements in architectural space, such as creation of digitized interactive walls, which will be discussed in more detail in the fourth chapter of this thesis. Then there are architects, like Greg Lynn[372], who work with the software in an unorthodox manner, dealing with a code in such a way that it can interpolate the shape but whose work is based mostly on theoretical explorations.

Others, like Bernard Cache, develop software applications, like *Top Solid*,[373] that are based on associative parametric attributes. The latter connects practice and theory in a direct way that allows for the conceived design to be manufactured almost immediately according to the *file to factory production*[374] principle, as explained further on in this chapter. An interesting aspect of Cache's work is his focus on the process rather than the form, as in case of Greg Lynn[375] or Michael Hensel and Achim Menges.[376] His explorations with composition are unravelled in his book “Earth Moves” in which he

[371] Studio Roosegaarde, Retrieved August 15, 2008, from http://www.studioroosegaarde.net/
[372] Greg Lynn “Form”, Retrieved August 15, 2008, from http://www.glform.com/
[373] Top Solid, Retrieved August 15, 2008, from http://www.topsolid.com/products/plm/
[374] Kas Oosterhuis, “A New Kind of Building”, in Arie Graafland and Leslie Jaye Kavanagh (eds.), *Crossover, architecture, urbanism, technology*, 010 Publishers, Rotterdam, 2006, 240-269.
[375] Greg Lynn, *Animate Form*, Princeton Architectural Press, New York, 1999., 136.
[376] Michael Hensel and Achim Menges (eds.), *Morpho-Ecologies*, Architectural Association, London, 2006, 88.

provides a classification system of architectural images he differentiates as vector, frame and inflection.[377] The system he creates can be perceived as a theory of composition in a sense that the images he distinguishes can function as abstract principles for architectural operations. In Cache's case however, there is a danger in focusing strictly on the mathematical essence of geometry which could restrict certain kinds of creative expression. The most essential characteristic of these processes are their interactive qualities and potentials. In this thesis, interaction is regarded as more important for computational architecture than form because interaction can initiate the processing of form, as explained in the second chapter through form-finding as self-organisational process in architecture.



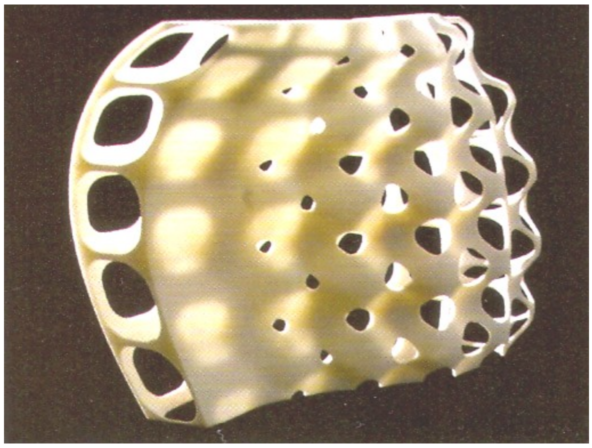


Figure 3.5: Parametric 3D model and 3.6: Rapid prototype morphological test of digital system definition based on manipulation components constituted by interaction of various pneumatic bodies within a cast system. Gabriel Sanchiz Garin, Diploma project, AA Diploma Unit, Unit Masters: Michael Hensel and Achim Menges, 2006.

In terms of processes by which new and coherent structures, patterns and properties emerge from within complex systems, the work of Michael Hensel and Achim Menges offers an interesting approach, as illustrated in figures 3.5 and 3.6 above.[378] Their approach emphasises the key concepts of emergence in relation to design. For them, a significant change in the culture of architecture was initiated with this new area of research. The engagement with this field requires more than a mere catalogue of new materials coupled to innovative production technologies. An apprehension of the behaviour of complex systems and the mathematics of their processes is requisite, as well as, the systematic transference of that knowledge to design and production. Emergence has the potential to change the way in which the architecture is thought

[377] Cache, *Earth Moves*, 57.
[378] Michael Hensel et all, *Emergent Technologies and Design: Towards a Biological Paradigm for Architecture*, Routledge, New York, 2010, 11.

about and the way in which it is produced. It provides an explanation of how natural systems have evolved and maintain themselves.[379] The concept of emergence can be regarded as a self-organisational process, following the discussion about the form-finding process. The forms developed through these processes do not acquire a distinct aesthetics but are apparently actualised without a plan, in a range of different materials and at a multitude of scales.

In regard to the architectural imagery and formal compositions that can be created through different digital processes, cybernetic mutualism can offer a set of principles that can establish new relations between the architectural elements in a drawing. These principles do not necessarily depend on those drawn from nature, as in case of Hensel and Menges, because forces that shape natural forms and structures do not always allow for implementation of another species' needs (i.e. architectural structures formed according to the principles of ant's nests do not necessarily satisfy the requirements for human habitats). Cybernetic mutualism proposes a harmonious relation between form and function without segregation of their significance in the architectural design. The form and function of a building are both equally important. Form in cybernetic mutualism can be created by the architect in a way that is not prescriptive but coincidental and spontaneous. The principles of a form-finding process can be based on self-organisational and self-optimization processes based on architectural features such as proportion and perspective, as well as fluidity, dynamics and changeability. The physical attributes of forms can be generated through algorithmic processes and the capacities of materials. They determine their form, size, structure, material, consistency, colour, texture, etc. Interactivity can be integrated in the architectural design in the concept stage so the design can become a platform that contains collaborative and performative features that reflect cybernetic mutualism. In this way, an architect - instead of being an objective observer - becomes an engaged participant.

3.3 From Digital to Physical: Software for Technical Drawing Production

In the first phase of drawing creation, Auto-CAD and Microstation are the two most common software applications in use for the production of technical drawings within architectural practices that use Windows operating systems. In both software

[379] Ibid., 11.

applications it is possible to create 2D drawings, in the case of surface modelling, and 3D models, in the case of solid modelling. This is useful because the 2D and 3D file types are compatible with each other within a specific application and there is no information loss or misinterpretation in transferring the file from one application to another. Interestingly, neither Microstation or Auto-CAD were initially created for architectural use but for employment in mechanical engineering. This resulted in the enhancement of precision which is an attribute more connected with engineering than architectural design practice. Architects started using these software applications by adapting the way a design evolves in relation to the conditions of the software. This means that the great deal of the software's performance determines the development and outcome of the design. The following section explores the modalities of the software's influence on the design production and the potential changes that may occur in the process.

3.3.1 An Early CAD Concept

An interesting comparison with the development of concepts and conditions that directly influenced development of Auto-CAD, as we know it today, can be found in the composition of Ivan Sutherland's *Sketchpad program.* This program was developed in 1963 to provide swift *conversation* between man and computer through the medium of a line drawing.[380] Sketchpad was the first system developed to use drawing as a medium for communication with a computer and the first one to use a complete Graphical User Interface, as shown in figure 3.7 below. Unusually, the main idea was that there is no state of the system that can be called *drawing*, as characterized in its traditional terms. According to Sutherland, hand drawing presents an active process which creates a trail of ink or carbon that is fixed on a paper. Equivalently, in computer-aided drawing any line segment is straight and a line can be relocated by moving one or both of its end points. Specifically in the case of Sketchpad, a new line segment and two new end points are set up in storage when the *draw* button is pressed. Consequently, one of the line's end points is left attached to the light pen so that subsequent pen motions will move the point. As a result, the state of the system is no different from its state whenever a point is moved.[381] This principle of the line drawing act is similar to that

[380] Sutherland, *Sketchpad*, 17.
[381] Ibid., 87.

today when using Auto-CAD or Microstation. The components of a drawing are conceived as objects that can be manipulated, constrained, copied, instantiated, represented iconically and recursively operated upon by the designer,[382] so the interaction implies direct manipulation of the drawing elements.


Figure 3.7: Sketchpad in use, 1963.

After a period of testing the system, Sutherland came to an interesting conclusion about the difference between the properties of computer and of paper drawing. He concluded that the difference is not only in the accuracy, ease of drawing and speed of erasure where computer drawing is concerned, but also the ability to interact with a drawing's elements by moving them around on a computer without the need to erase them.[383] This is particularly important in cases when a designer is not sure if s/he will need a certain element in the further drawing. The designer can drag an object and leave it outside of a drawing and use it later if necessary. Further interactive advantages are in the possibility to copy the object almost an infinite number of times, rotate it, scale it (or change its dimensions proportionally), skew it, realign it, etc. It can be concluded that the main difference between paper and computer drawing are in the modes of interaction between the designer and the object of production.

In order to explore the impacts of digitization on architectural design and what kind of

[382] Sutherland, “Sketchpad” in Fruin and Montfort, *The New Media Reader*, 109.
[383] Ibid., 17.

implications this has in the case of interaction, the next section is dedicated to an analysis of CAD software.

3.3.2 Impact of CAD Software on Architectural Design

In the traditional mode of production, the scale of a drawing determined the size and the level of detail in the drawing concerned. In comparison to the size of a real building, a drawing was relatively small. In this regard, architectural drawings were estimates and the designer determined the degree of a drawing's precision and detail. CAD software operates regardless of such limitations of scale, because it is the indefinite extension which differentiates it – all technical drawings are based on the Cartesian coordinate system,[384] as illustrated on the figure 3.8 below. This provides for a drawing to be created at a real scale, that is, the scale of a drawing corresponds to the scale of a building 1:1. Only when printed might drawings acquire an appropriate architectural scale, such as 1:500, 1:200 or 1:100. In the traditional mode of production the scale of a drawing had to be determined before the drawing process started and when drawn at a certain scale a drawing could not be adjusted to a different one. Different scales assume different levels of detail, therefore the utilization of layers in a computer drawing provides the possibility to manipulate the level of detail and in this way avoid confusion between the level of detail in a computer drawing and the printed one. In this regard, the utilisation of CAD software for creative design thinking or problem solving is a question of designer's choice rather than software's inappropriateness. In the early stages of an architectural design, as discussed previously in the chapter, the designer can choose other media for design thinking which do not require the same levels of precision as CAD software.

Another interesting difference between Auto-Cad and Microstation is in terms of interaction. The commands for the production of a drawing's elements and their manipulation in both applications are the same: *line*, *polyline*, *rectangle*, *circle*, *arc*, *trim, offset*, *extend*, *rotate*, *fillet* and *hatch*. These are main commands for drawing creation. In the software abstraction of the architectural design these commands become symbolic expressions for spatial arrangements, rectangle for a room, a bed, a table;

[384] Marshall Brown, "For_getting Drawing: Toward an Architectural Pedagogy for Digital Media" in Jamal Al-Qawasmi and Guillermo Vasquez de Velasco (eds.), *Changing Trends in Architectural Design Education*, CSAAR Publications, Amman, Morocco, 2006, 66.

circle for a tree, a lamp, etc. Through a drawing process these graphical elements obtain meaning. Through the history of architecture, the harmony and proportion of geometric models used for shaping the form of a building had an important role in the representation of architectural design.[385] In terms of architectural drawing's aesthetic, technical drawings produced with Microstation or Auto-Cad have different aesthetic attributes than those that are illustrative in character, which may additionally be processed with Illustrator or Photoshop, as shown on the figure 3.9 below. The difference is in the information a drawing should communicate and kind of presentation it is used for. In terms of technical drawings, which are usually black and white line drawings with the occasional addition of hatch and/or patterns, aesthetics is not a prevailing criteria because these drawings are used for building construction and therefore should be clear, precise and explanatory in terms of technical detailing. This distinction of a drawing's aesthetics is because different kinds of architectural drawings communicate architect's idea to different parties involved in the design process, such as other members of the team, other parties involved in the project, client, different official institutions, etc.

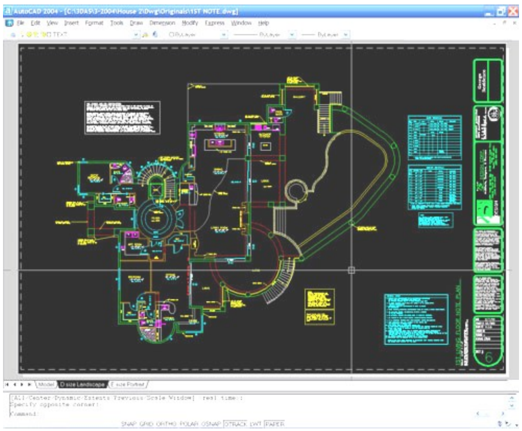


Figure 3.8: Technical architectural Auto-CAD drawing, 2001.

Figure 3.9: Illustrative architectural computer drawing 2009.

AutoCAD offers two options for implementation of previously mentioned commands, first through GUI icons that one can click on and execute the command without pressing Enter and second through the command line where one can enter abbreviation of the command through keyboard and by pressing Enter execute the command. The second one is the most preferred option among architects and most find it very difficult to switch to icon usage when learning Microstation. At the first glance this does not

[385] Jay Kappraff, "A Secret of Ancient Geometry" in Catherine A. Gorini (ed.), *Geometry at Work*, The Mathematical Association of America (Inc.), US, 2000, 26.

sound as a major difficulty but in practice it is a question of a whole bodily relation towards the computer and also the difference in mode of interaction, whether it is through a computer icon or a command line. The habit of typing the commands in the command line is very difficult to overcome when usage of keyboard becomes completely restricted or very limited. In terms of interaction with a computer drawing, it is important to compare the ways in which a drawing is structured in the traditional and computer production in order to determine differences in the respective modes of interaction.

The development of the area of storage and manipulation of large files[386] resulted in a possibility of using such files in a specific new manner.[387] An interesting attribute of a reference file is that it can be imported into a design file for viewing and construction without a need for additional memory. A drawing can also contain more than one reference file. Drawing elements inside a reference file cannot be altered but can be copied into a design file. This means that one of the main attributes of the reference file is that this file is used to create a drawing larger than the memory capacity of the system.[388] Architectural drawings very often include the same information repeated throughout several drawings. These drawings can be regarded as operands in terms of a quantity or function upon which a logical operation is performed. In the traditional mode of drawing production this would require the redrawing of the same information over and over again on different pieces of paper. In the case of computer drawings this process is shortened and compressed because of the clearly organized structure and larger flexibility of computer drawing manipulation. In the computer drawings production, the process of production is separated into two distinctive components that can be treated separately. First, a production of a virtual drawing and second, a production of a physical representation of a drawing. These processes were simultaneous in the hand drawing production, because the physical result of a drawing was immediately visible.

From the previous discussion it can be concluded that in comparison to the hand drawing, computer drawing offers a significant advantage in relation to the flexibility and organization of a drawing. In terms of interaction, particular properties of software

[386] Ibid., 28.
[387] In Auto CAD they are called *X-ref files* and in Microstation *Reference files*.
[388] Richard C. Dorf and Andrew Kusiak (eds.), *Handbook of Design, Manufacturing and Automation*, John Wiley and Sons, New York, 1994, 109.

applications, discussed previously, provide a range of interactive modalities with the drawing that were not present in the hand-made mode of production. These include the exploration of the properties of the software's materiality to the extent which allows finding characteristic visual register and architect's individual aesthetic expression. A drawing sometimes needs to go through a several computer calculations and operations so that it can reach a desired aesthetic expression. In the transition between these different interactive modalities a drawing obtains its distinct character. In this regard, it can be said that through interaction and by consequentially learning, an architect expands expertise and develops his/her creative style.

In order to better understand the advantages attained through the use of CAD software and how the digitized modes of production developed novel modes of interaction that occur in digital fabrication of physical objects further discussion is about Computer Numerically Controlled (CNC) and Rapid Prototyping technologies.

3.4 Digital Fabrication of Physical Objects

The connection between architectural design and digital fabrication tools presents more than competence to manipulate sophisticated production tools and can be observed as an apparatus that can stimulate innovation within architectural design. In this regard, Branko Kolarevic argues that the relationship between conception and production in architecture has been radically reconfigured in the digital age. This reconfiguration created a direct link between architectural design concepts and the processes of building construction utilised through file-to-factory processes of CNC fabrication. Kolarevic distinguishes three types of digital fabrication: two-dimensional fabrication, subtractive fabrication and additive fabrication,[389] each of which relate to the process that enables the material to be structured in a particular way into the final result. While for Timothy Hemsath, digital fabrication has three areas: ornamental tooling, tectonic jointing and surface/structure integration,[390] which concerns the design issues regarding aesthetic expression a designer wants to achieve. In further discussion of both of these considerations, the processes involved in the digital fabrication and the aesthetic

[389] Branko Kolarevic (ed.), *Architecture in the Digital Age*, Spon Press, Taylor and Francis, New York and London, 2003, 31.
[390] Timothy L. Hemsath, "Searching for Innovation Through Teaching Digital Fabrication" in Gerhard Schmitt et all (eds.), *ECAADe 2010 Conference: Future Cities*, Verlag der Fachvereine Hochschulverlag AG an der ETH Zurich, Switzerland, 2010, 23.

expression they produce will be explored, as well as the different modes of interaction concerned. Besides the interaction with the software required for these processes to occur, it also concerns the utilization of materials characterised as solid and soft in the discussion about materiality the first chapter, the interaction with which can create any imaginable shape, as it can be seen on the figure 3.11 below.

Figure 3.11: Example of a physical wall produced with CNC technology, 2007.

Kolarevic considers that the reason why architects started to devote more attention to the production of buildings is the complexity of *blobby* forms, which emerged with so called *blob* architecture,[391] which will be discussed further on in this chapter. The question of the modality that can support the spatial and tectonic arrangements of such complex forms, which feature blob architecture, were introduced by an ever-increasing use of continuous, highly curvilinear surfaces, such as those constructed by NURBS (Non-uniform rational B-spline) curves and Bezier splines. The complex forms introduced through usage of intricate curves that are easy to construct within the appropriate software applications, such as Rhino, 3ds Max, Maya or CATIA, were initially questioned in terms of their credibility and mostly constructibility. But with the digitization of the design process, constructibility became a direct function of computability. With the utilisation of NURBS curves and Bezier splines it was

[391] Kolarevic, *Architecture in the Digital Age*, 31.

necessary to find new instruments of practice that will enable construction of such complex forms and that will explore the opportunities opened by the digital modes of production.[392] This was enabled with CNC and Rapid prototyping. An interesting question that emerged from previous chapters is how to distinguish different interactive modalities that occur in distinct digital fabrication processes and how this influences the formal and aesthetic attributes of the produced object. The first to be explored in these terms is the CNC process, discussed in the next section.

3.4.1 CNC Process – Aesthetics of Cutting, Milling and Drilling

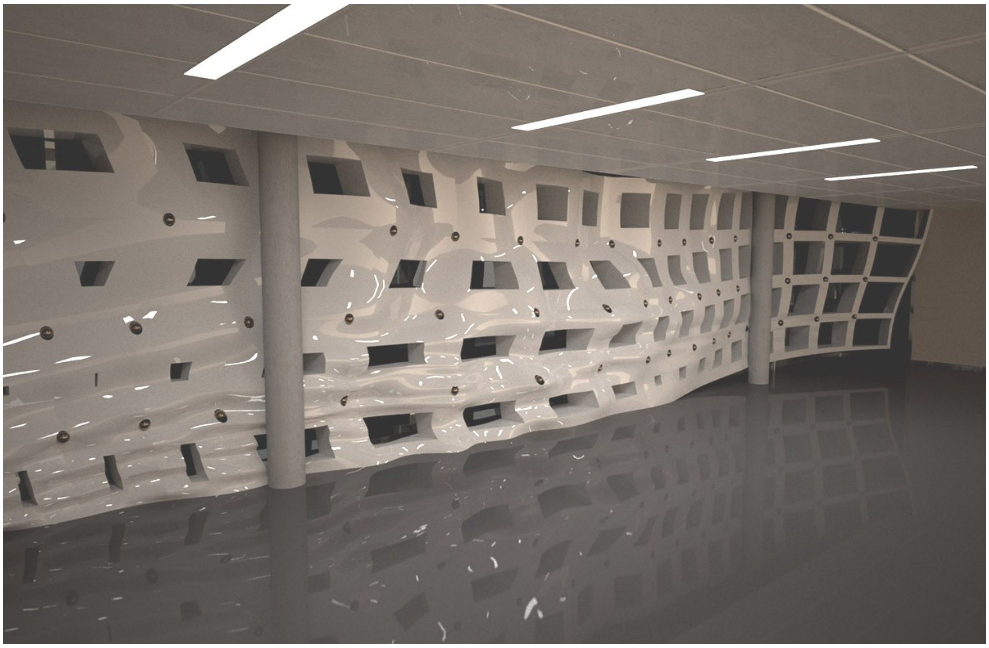


Figure 3.12: Example of a physical wall produced with CNC technology, 2008.

In the process of file-to-factory production, an engineer firstly prepares a 2D drawing or 3D model in CAD, then this computer file is processed through another kind of software called Computer Aided Manufacturing (CAM) which creates real-life versions of components designed within the CAD models. This formulation is based on the 3D model which helps generating a CNC code which will drive appropriate machine tools. CAM produces a preparatory CNC code text files written as G-code, M-code, T-code, S-code and F-code,[393] which present functions chosen in relation to the operational

[392] Architectural Research Centres Consortium, *ARCC Conference Proceedings*, The School of Architecture and Applied Arts, University of Oregon, Eugene 16-18 April 2007, 160.
[393] *G-code* is a preparatory code in the Numerical control programming language. These are functions that are in charge for aligning the tool in the right position, performing the work of milling, drilling or cutting, etc. *M-codes* control the whole machine causing it to start or stop working, to switch a coolant on or off, to rotate the tools, etc. *T-code* determines

purpose needed.[394] An important issue is choosing an adequate material which will when processed produce effects that comply with the overall aesthetics. The produced object's quality depends on the quality of interaction between the appropriate tool and the material and it implies a level of refinement of the processed material and sophistication of the finishing, as shown in figure 3.12 above. In order to take a physical shape the file needs to go through four stages of interaction with the machine and these are roughing, semi-finishing, finishing and contour-milling.

The CNC process is based on three underlying mechanical operations: cutting, milling and drilling. Cutting operation is usually two-dimensional while milling and drilling are used for three-dimensional fabrication of physical objects. All these distinctive mechanical processes through the interaction produce different kinds of aesthetics of the material they handle. These processes refer to *subtractive fabrication*.[395] This mode of fabrication involves interaction with the solid material which volume is reduced by a software controlled operations. This happens through utilisation of chemical, electrical or mechanical processes, such during the multi-axes milling processes.[396] After the interaction with material through machining manipulation, the digital computer file acquires its physicality. Physical elements produced by means of CNC digital fabrication are not necessarily considered as beautiful in terms of the traditional approach to craft, but the process of fabrication became beautiful. As Herbert Read noticed in 1936, *the real problem is not to adapt machine production to the aesthetics of handicraft, but to think out new aesthetic standards for the new methods of production.*[397] These new aesthetic standards may also consider the speed of production, prefabrication, efficiency of assemblage, the quality of material in terms of its strength, resistance and lightness, etc. In architecture, some of these present an inherent aspects of traditional craft but new operational mechanisms are needed to be applied to new materials and processes.

which tool is selected. *S-codes* control the spindle speed of the tools. *F-codes* control the tool feed that means if the machine is in motion then the feed is in length units per minute, if it rotates then in degrees per minute, etc. See National Institute of Standards and Technology (NIST), Engineering Laboratory, 3-8, Retrieved May 13, 2009, from http://www.isd.mel.nist.gov/personnel/kramer/pubs/RS274NGC_3.web/RS274NGC_33a.html#1002165

[394] Thomas R. Kramer et all., “The NIST RS274NGC Interpreter - Version 3”, Intelligent Systems Division, National Institute of Standards and Technology, Gaithersburg, Maryland, August 17, 2000, 11-12, Retrieved May 13, 2009, from http://www.isd.mel.nist.gov/personnel/kramer/pubs/RS274NGC_3.web/RS274NGC_33a.html#1002165

[395] Kolarevic, *Architecture in the Digital Age*, 34.

[396] Ibid., 34.

[397] Nicholas Negroponte, *Being Digital*, Alfred A. Knopf Inc., New York, 1995, 204.


Figures 3.13 and 3.14: Stealth.unlimited, *Cut for Purpose*, Rotterdam, 2006 (before and after cutting)

Cutting, milling and drilling, as automatised operations, present digital processes of the tool's interaction with the material. In the traditional way of production, a craftsman's interaction with a material was direct and tactile, while today it is mediated through the usage of software, such as Auto-CAD, and performed by machines such as CNC drills. If we would think about the precesses of milling, drilling and cutting in terms of their spatial vocabulary it is possible to imagine a kind of spaces they can give rise to with possible engagement of different participants in the process. An example can be found in the project *Cut for Purpose*,[398] by Stealth Group from Rotterdam, in which the space was created by collaborative action between a number of agents (people) by means of cutting the cardboard for the intended purpose, which can be seen in figures 3.13 and 3.14 above. A series of spatial interactions were established by people's activities. Activities included creation of spaces for writing, meeting, a video room, a sound room, residency space for an art collective, etc. This interaction was based on a set of guidelines for the creation of space given to the participants. The main goal of this project was not to show the automated processes of mechanistic nature, like those in CNC machines, but to imply new spatial relationships that can be formed through different modes of interaction with the material established by software-based processes, such as algorithms, which can enable a different perspective on the digital processes. In this re-conceptualised CNC process, the characteristics of cybernetic mutualism are implied in the way in which the material was processed through the constitution of the flexible guidelines used for cutting the cardboard. The rules influenced the activity that is performed through the use of space. Here, guidelines determine the nature of people's mutualistic relationship with the space thus created

[398] See STEALTH.unlimited, Retrieved May 13, 2009, from http://www.stealth.ultd.net/stealth/12_cutforpurpose.html.

determining its shape, size, character and use.

In the further identification of different interactive modalities during digital fabrication processes analysis in the next section regards Rapid Prototyping process.

3.4.2 Rapid Prototyping Process – Materiality Refinement

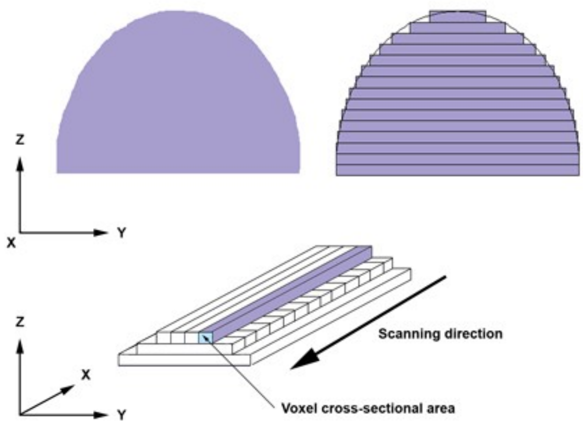


Figure 3.15: Rapid prototyping process

Another mode of the automatic construction of physical objects by means of their virtual representation is *Rapid Prototyping*, which is a recently developed technology[399] invented for the production of models and prototype parts within motor vehicle industry, consumer product industry, medical and aerospace industry, etc. The original meaning of the rapid prototyping is firstly coined with the commercial release of the first stereolithography system.[400] In 1986 Charles Hull receives a patent for *Apparatus for Production of Three-Dimensional Objects by StereoLitography* and this moment represents the beginning of the rapid prototyping industry development.[401] According to Todd Grimm, rapid prototyping devices are an assemblage of technologies driven by CAD data in order to produce, through an additive process, physical models and parts of objects. In other words, it is a digital tool that without machining, casting or moulding produces parts on a layer-by-layer basis,[402] as shown in figure 3.15 above. This

[399] This technology was developed for mass manufacture by the end of 80's while CNC was developed during 40's and 50's.
[400] Todd Grimm, *User's Guide to Rapid Prototyping*, Society of Manufacturing Engineers, Dearborn, Michigan, USA, 2004, 12.
[401] Ibid., 15.
[402] Ibid., 13.

technology is sometimes described as the Solid Free-form Fabrication (SFF) that presents an assemblage of techniques used for production of homogeneous physical objects by means of a sequential delivery of energy and material to points in space specified by a computer.[403] All these technologies include a base material, commonly natural materials, such as thermoplastic or metal powders, acrylics, photopolymers, titanium alloys, eutectic metals, paper, plaster composites and various others. Because of the different mode of production to that of the CNC, it is interesting to distinguish the mode of interaction that happens during this digital fabrication.

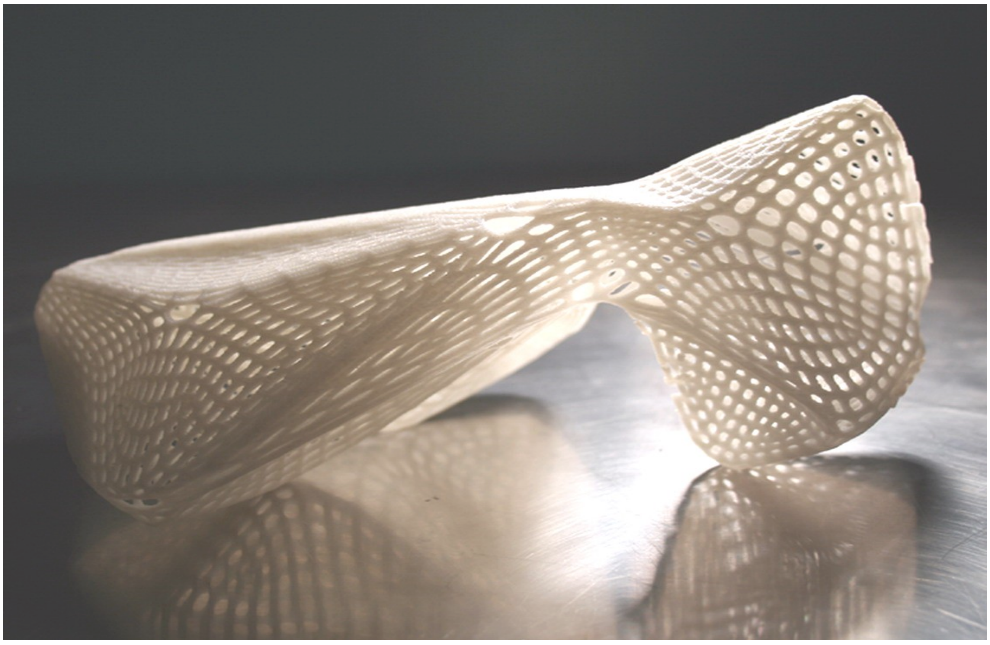


Figure 3.16: Example of a physical model produced with Sintering Rapid prototyping technology, 2007.

The first level of interaction happens by means of an appropriate software. As well as CNC, rapid prototyping processes also use CAD data sources for formulating complex physical shapes and objects in their virtual representation. This happens through creation of the 3D model in CAD, which is then transferred to another file format, the stereolithography (STL) file format that serves as the data interface that communicates between CAD and the machine and which transforms the shape or its specific parts with approximation of the shape through mash of triangular surfaces.[404] The number of triangular surfaces will define the smoothness of the physical layer once it is created by the machine. The STL file, when exported through either binary or ASCII format,

[403] The Rapid prototyping technologies include: Stereolithography, Electron beam melting (EBM), Fused deposition modelling (FDM), Laminated object manufacturing (LOM), 3D printing and Selective laser sintering (SLS).
See Ian Gibson et all., *Additive Manufacturing Technologies*, Springer, New York, Heidelberg, Dodrecht, London, 2009, 17-37.
[404] Grimm, *User's Guide to Rapid Prototyping*, 54.

presents a listing of each vertex coordinates that forms triangles in the mesh. The listing of all of triangular elements, combined with a surface normal, which is a vector indicating the outward direction of the building's material, provides a complete description of the three-dimensional CAD data to be constructed.[405] When the machine reads the data from a CAD drawing or a model through an appropriate software application it creates a number of very thin virtual horizontal cross-sections, that is plans, which are then build up in the physical space by laying a sequential number of material layers in form of a liquid or a powder, on top of each other until the model is finished and the layers are fused. This kind of fabrication is obtained through the second level of interaction, because the transition of the calculative processes and the fusion of material particles, which are arranged according to the predetermined set of computer actions, produce an object that has a distinctive aesthetics, as shown on the figure 3.16 above. The accent in this mode of interaction is on the act of moving of material particles that cumulatively create digital artifacts. This concerns creation of physical elements by means of software-guided processes that interact with material. The development of interactivity may imply explorations in diverse ways in which particles can move and relate to each other.

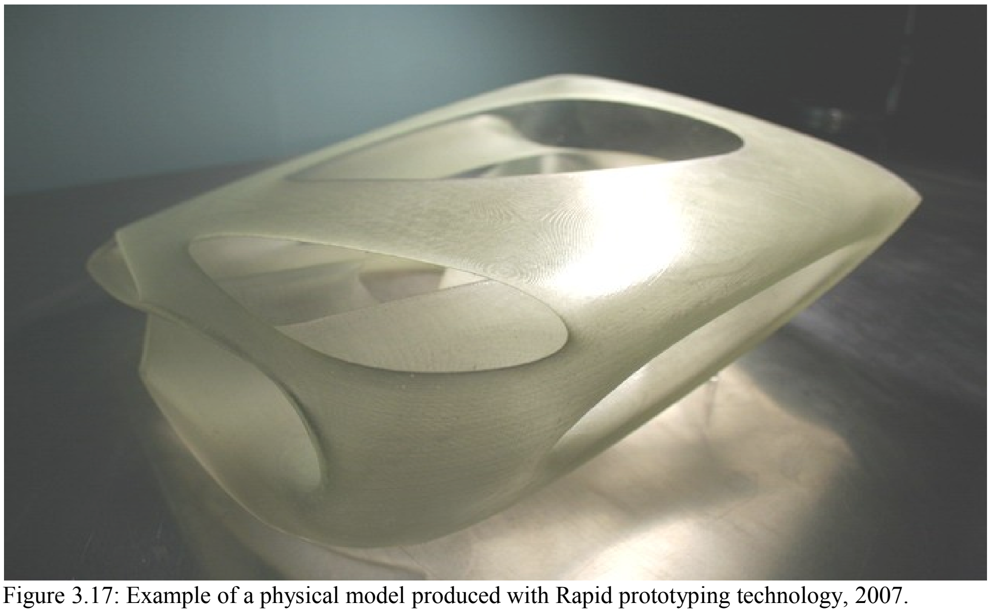
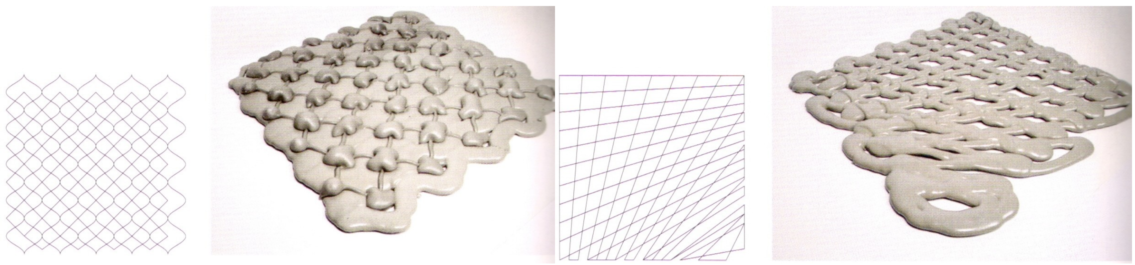


Figure 3.17: Example of a physical model produced with Rapid prototyping technology, 2007.

While CNC technology is more economic at present and widely employed because it offers a range of advantages in terms of high level accuracy, a much wider selection of materials that can be used, and perhaps an easier understanding of its application, Rapid

[405] Ibid., 56.

prototyping offers the possibility to build up any complex geometrical shape. It cannot offer, however, the same accuracy as CNC technology and the sophistication level of material finalisation because in the process of building up the material the selection path is blurry – it moves all the time. Nevertheless, this technology can be employed for a wide range of applications depending on the purpose, for example in design education, the production of architectural physical models, smaller industrial elements, etc. The aesthetic quality of these objects is in their fluid forms with a dynamic character and the texture derived from, for example, the sintering process have a special aesthetic property, as shown on the figure 3.17 above. This special property is expressed through the elegance of obtained structures and fine parallel linear patterns that are the result of object's segmentation into small individual sections, which is a quality the object obtains in the process of translation from three-dimensional model to its physical equivalent.



Figures 3.18 and 3.19: FOAM projects, ETH, Zurich, lead by Fabio Gramazio and Matthias Kohler, 2007.

An interesting example of rapid prototyping creative applications are student's projects, such as Foam 2007 and Foam Monster 2008, done at ETH in Zurich by a team lead by Fabio Gramazio and Matthias Kohler. Student projects are most notable because they are experimental in a sense that they are not constrained by the usual architectural norms and standards of an architectural practice. In these experiments, illustrated in figures 3.18, 3.19 above and 3.20 below, additive fabrication employs a material that is liquid, foams up and then solidifies over a period of time. Experiments reflect the process of mutual dependency between the paths of movement that control the robot, the constitutional material properties and the final shape of the structure obtained in the process.[406] Acquired forms can be considered as outcomes of the mode of interaction between a designer, software-base processes and the material employed. This complex mode of interaction is enabled through several software applications, one that creates

[406] Gramazio and Kohler, *Digital Materiality in Architecture*, 66.

the graphical composition according to which the shape will be created, such as Auto-CAD, and another that controls the robotic arm that performs the movement which creates the structure. The accent in this mode is on the interaction between the materials formalised through the digital processes.

Figure 3.20: FOAM MONSTER, ETH, Zurich, lead by Fabio Gramazio and Matthias Kohler, 2008.

The various levels of interaction in this additive fabrication process are a basic mode of human-computer interaction between the designer and the computer, another one between the robotic arm and the material it shapes and between material with itself in the different stages of its solidification. According to Gramazio and Kohler, only a small fraction of information necessary for production of these forms is constituted in the geometrical description of the foam layout. The layers of foam permeate one another instead of, as it appears, being woven together like textiles. Structures that are formally more complex and disregarding to their apparently chaotic expression can be technically reproducible. These structures are possible to be produced by introduction of more complex input geometries,[407] which can imply more complex interactions of materials. Besides the geometrical composition, the relevant parameter in formalisation of physical elements in this case are interactive processes involved while the foam solidifies. Interaction of the material with itself will frame the outcome of the fabrication process. These experiments reflect different transitions between materiality, interaction and digitization parameters established in the first chapter. Interestingly, the characteristics of cybernetic mutualism in the previously discussed stages in additive fabrication are reflected in the way digital and physical materials merge. As it is not

[407] Ibid., 66.

fully possible to control all the different interactive modalities, either because the period between two stages is too short or because it is very hard to exactly predict the reaction of materials with each other, results are spontaneous and changeable. These characteristics imply that cybernetic mutualism is contained in particular stages of the digital fabrication process.

Gramazio and Kohler's explorations working with natural materials through the utilisation of digital processes can be seen as a step forward in regard to Gottfried Semper's theory about materiality in architecture and its connection with textiles and processes involved in their production. The interactive process of weaving the foam material together and the performativity of this material which permeate itself through the procedure performed by the robotic hand results in a form that has a new aesthetic quality obtained through algorithmic expression. Aesthetic expression obtained in this way is both spontaneous and prescribed. Prescribed, through a set of steps that lead to its finalisation, and spontaneous, in the operational interactive qualities of the foam material which performance has the moment of anticipation that terminates when the material is finally solidified and the shape formed. These are some of the characteristics of cybernetic mutualism. In respect to Semper's suggestion that procedures and materials should be combined freely through the many and mutual relations that can connect them together, rapid prototyping or additive fabrication can be regarded as the fifth procedure compared to his division of procedures discussed in the first chapter and as that which can be regarded as cybernetic mutualism. These mutual relations can be described as interactive modalities that can initiate and direct form's spatial composition. In this regard interaction presents an apparatus for arranging material particles of object's formal state. Interaction becomes the adhesive digital material fused with natural materials in a formalisation of a physical element. It can be concluded that this mode of interaction realize complementary relations between elements in architectural composition and opens up possibilities for new aesthetic expressions.

In relation to the discussion about the change that occurred with the digitization of architectural design production in terms of two-dimensional drawings and how this influenced occurrence of digital fabrication as a further development of interactive modalities, it is necessary to address the importance of the transformation occurred in the process in relation to the software for three-dimensional modelling discussed in the next section.

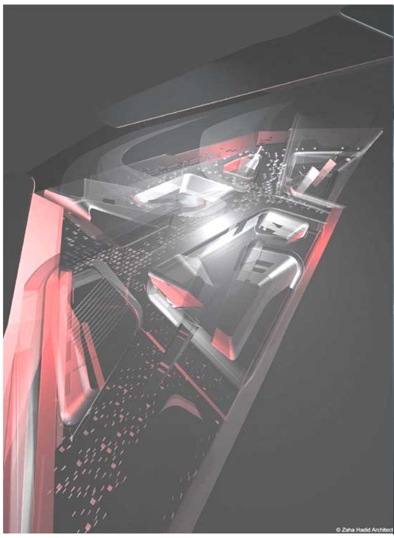
3.5 Virtual Physicality: Software for Three-Dimensional Geometric Modelling

Virtual physicality refers to the misinterpretation of three-dimensional modelling as a physical modality in the process of architectural design creation. Marshall Brown differentiates between *projection* and *model*, in which the misunderstanding arises because 3D software simulates the manipulation and movement of graphic projections.[408] For McCullough, a three-dimensional geometric modelling can be understood as form processing. For him, digital form processing is disparate from the traditional drawing and the traditional model making, neither of which it automates or replaces so much as complements and transforms.[409] The definition of form processing is helpful in understanding software applications, such as Rhino and 3dsMax, commonly employed in computer-aided architectural design production and used in majority of architectural practices. (Because they are highly compatible with Auto-Cad (2D and 3D) and because they offer a sufficient set of tools for creation of simple three-dimensional architectural models. They can support complex geometry as well, since they were originally produced for use in the marine, automotive and product design industries.) Maya and CATIA[410] software applications are also in use, but only in a restricted number of offices because their full engagement is required mostly for the production and rendering of very complex shapes, demanding animations, simulations and high definition visual effects, such as the creation of cartoon animations in the film industry. In regard to interaction these software applications offer different modalities than the previously discussed software for two-dimensional drawing construction. These are discussed in the next sections.

From the architectural point of view, the possibility to iterate designs quickly and generate reports automatically while the design production process is being updated as the design develops are the most adventitious aspects of the Building Information Modelling (BIM) based software. Regarding these aspects, parametric algorithms enable software features that allow the coordinates of attributes to be maintained in relation to each other while designs recur. An advantage in this regard is that three-

408 Brown, "For_getting Drawing" in Al-Qawasmi and de Velasco, *Changing Trends*, 67.
409 McCullough, *Abstracting Craft*, 164.
410 Computer Aided Three-Dimensional Interactive Application

dimensional geometric model of the building does not have to be re-designed to accommodate design changes because attributes effectively reposition themselves automatically.[411] This new relationship with software implies a new mode of interaction that considers another level of complexity, which implies an intensified engagement with the formal properties of the modelled building. The difference between this mode of interaction and the one achieved through script writing is that the outcome of interaction process is real-time and immediately visualised.



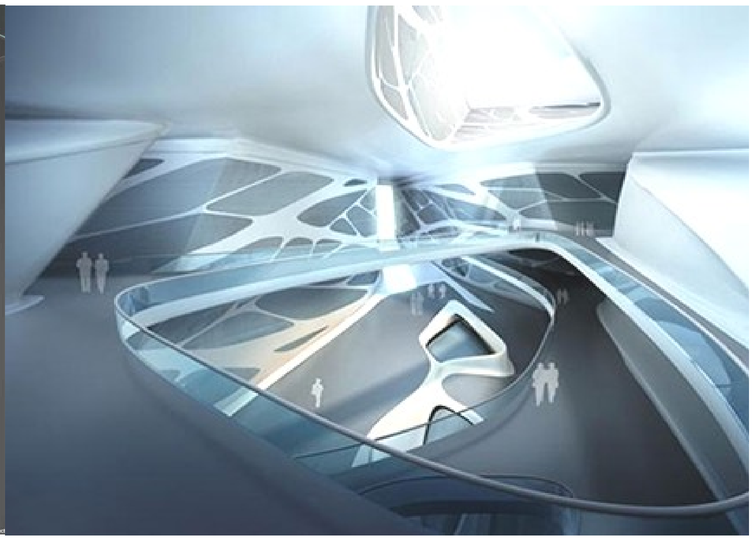


Figure 3.21: Zaha Hadid, Phaeno Science Centre, Wolfsburg, Germany, 2007 computer rendering.

Figure 3.22: Zaha Hadid, Performing Arts Centre, proposal, Abu Dhabi, 2007, computer rendering.

3D modelling tools enable an effective and quick development of the design in relation to a building's volume at the same time observing its harmonious integration in the virtually created environment. Such software provides an illustrative but also accurate instrument that can communicate the concept to all the parties involved in the development of the design. In this way, 3D modelling tools become more than mere instruments for clarification of thought, they become the material for individual aesthetic expressions. An aesthetic expression that has the base in subjective intentions and personal temperaments as shown in figures 3.21 and 3.22 above. These figures are chosen because of the particular aesthetics they express through which it is possible to recognize the work of specific architect, in this case Zaha Hadid. In the next section a further analysis of 3D software involves a discussion about what McCullough describes

[411] Hannu Penttilä, "Early Architectural Design and BIM" in Andy Dong et all. (eds.), *Computer-Aided Architectural Design Futures (CAAD Futures) 2007*, Springer, Dodrecht, 2007, 291-303.

as form processing.

3.5.1 Form Processing

During the architectural design process 3D modelling software is used for the creation of a three-dimensional representation of the building through the simulation of the object's physical properties. 3D modelling is a geometrical process of developing a wire-framed, ghosted or rendered representation[412] of any object with physical attributes linked to numerical values. An image derived from the process is called 3D rendering. Rendering, as a fundamental component of computer graphics, involves converting a description of a three-dimensional scene into an image. The renderers are carefully engineered programs, which operation is based on a variety of disciplines such as mathematics, light physics, software development and visual perception.[413] They have an important role in shaping of an architectural 3D model because they provide simulation of environmental conditions in which the building will reside. In this regard, interaction during construction of the 3D model presents a complex process in terms of the options that an architect establishes before rendering the 3D scene. These choices regard an array of environmental parameters that need to be adjusted, such as disposition of the Sun, type and position of light sources, quality of the light, disposition of the camera views, etc.

The development of an architectural design is accompanied by a continuous production of, so called, *massing models* for verification, clarification and revision of the design's latest contextual state and formal expression. Changes that occur on plans, cross-sections and elevations are not automatic, as in case of parametric software, and have to be separately applied to the 3D model. In this regard, the human-computer interaction implies synchronous use of several software applications, Microstation/Auto-CAD for 2D drawing and Rhino/3ds Max for 3D models. Considering that formal representation is essential for architectural expression many architects consider the possibility to create 3D models as the foremost outcome of the digitalization of the design process. Considering that 3D geometrical model creation can be a long and intricate process, a number of architects focus their attention on the exploration of 3D modelling software

[412] Kunwoo Lee, *Principles of CAD/CAM/CAE Systems*, Addison-Wesley, Reading, MA, 1999, 178.
[413] Matt Pharr and Greg Humphreys, *Physically Based Rendering: From Theory to Implementation*, Morgan Kaufmann Publishers, Elsevier, San Francisco, CA, 2004, XXV.

and become highly qualified experts for a specific software application, such as Rhino or 3ds Max. A number of architects, like Zaha Hadid, perceive interaction with 3D modelling software in more liberated manner, which results in renderings with artistic character, as in the case of Hadid. The aesthetics of this kind of architectural imagery is in its possibility to communicate substance and atmosphere of the building.

For Marco Frascari, aesthetics can be in any element of a drawing that is perceived by the senses.[414] Frascari points out that the characteristics of a drawing that are being perceived by the senses can influence the inner world of an architect in a positive or a negative way, by causing pleasant or unpleasant feelings. These intricate characteristics are refereed as aesthetics. A fundamental role in the conceiving of a building is in regard to what an architect might like or dislike about the drawing that they are drafting. For Frascari, the variety of interfering influences, their interaction and the complexity of these interactive outcomes render the way individuals perceive and process drawings as a set of idiosyncratic stimuli.[415] Although Frascari refers to hand drawn architectural imagery, the same could be applied in case of computer generated architectural drawings and images because through the interaction with software architects learned to express their aesthetic preferences and develop expressions that can initiate, what Frascari calls, a set of idiosyncratic stimuli in a generative medium of the computer drawing or an image.

For McCullough, the essence of the generative medium of geometric modelling are cumulative geometric constructions. Such generative constructions can amplify any move made on a single object to affect many other related objects.[416] In these terms, an interaction with one element of a curve would implicate interaction with its other elements at the same time. What McCullough refers to are the parametric attributes of 3D modelling software, which imply usage of NURBS curves and splines. Historically, a base for the word s*pline* regards an instrument called a mechanical spline. This instrument was used in the traditional mode of drawing production by draughtsman as a means for creation of a smooth curve through a given finite set of planar points. The representation of points was through positions on the draughtsman's board. The curve was represented by a thin flexible rod. The rod was positioned throughout the

[414] Marco Frascari, *Eleven Exercises in the Art of Architectural Drawing*, Routledge, New York, 2011, 42.
[415] Ibid., 42.
[416] McCullough, *Abstracting Craft*, 164.

prescribed points with metal ducks.[417] Interaction during the process of spline creation was achieved through a complex set of assembling actions in order to construct the final configuration which outcome was the desired curve.

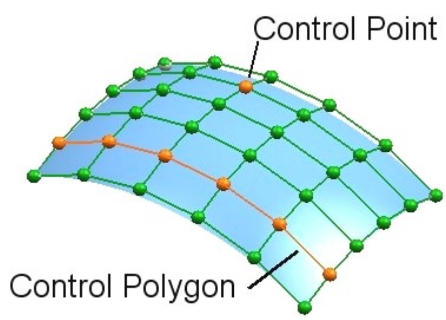


Figure 3.23: NURBS curves control points

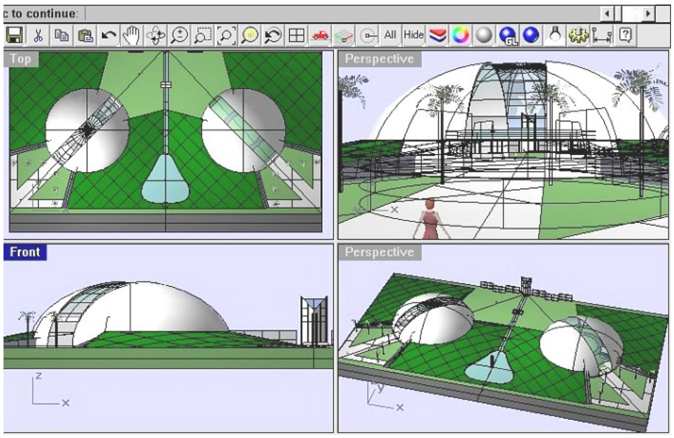


Figure 3.24: Modelling with NURBS curves in Rhino, 2010.

A computer drawn spline is conceptually the same curved line as in the traditional mode of production, only through the digitization of the process the interaction with the elements of the spline changed in such a way that the control points which define the spline are positioned by a set of mouse clicks and the line is formed by a spline function. A subtype of the spline modelling is *NURBS* modelling. It presents a procedure of shape creation through the processing of surfaces constructed with a number of spline curves that are influenced by weight control points, as shown in figure 3.23 above. Real-time interaction with the surface is achieved through these points. The outcome of interaction is an immediately visible formal disposition of a surface or an object, as shown in figure 3.24 above.

In the evolution of three-dimensional geometric modelling types a consecutive stage is *parametric modelling*,[418] which is different from the *free form surface modelling* in that parametric is not only about the surface but also about the relationships between the building's elements in a 3D model. It presents an interactive process in which an architect can create a curvilinear surface by either constructing a spline curve from which the surface is swept or meshed through. Or by creating a polygonal surface with control points that when real-time interacted with, construct a surface. This means that the curves and surfaces created in this manner are spline-based, although not all spline

[417] Ronald A. DeVore and George G. Lorentz, *Constructive Approximation*, Springer – Verlag, Printed in United States, 1993, 151.
[418] Tom Porter, *Archispeak: An Illustrated Guide to Architectural Design Terms*, Taylor & Francis, New York, 2004, 153.

modelling types are parametric. In parametric modelling, the results of interaction are objects that can retain their basic geometrical information, like shape, size or number of constituents. This information can be accessed and changed even after the objects have been modified.[419] In parametric modelling an interaction with an object can happen at any time. This is in opposition to polygonal modelling, in which, if deformation is applied during the interaction with elements of a model, it permanently modifies the object. The usage of curves and splines in architectural design initiated emergence of new concepts and a range of formal compositions, such as *blob* forms. This process is analysed in the next section.

3.5.2 Implications of Curvilinearity: The Concept of Folding and Blob Forms

The introduction of splines and NURBS into architectural design resulted in the emergence of so called *blob* architecture,[420] formulated through the use of *free-formed shapes*.[421] In 1993 Greg Lynn published an essay "Architectural Curvilinearity: The Folded, the Pliant and the Supple" in which he described new approaches to architectural design. These approaches develop a *more fluid logic of connectivity* that diverts from a deconstructivist path of *the logic of conflict and contradiction.*[422] Lynn's fluidity of connectivity is manifested through *folding*. For Lynn, folding is a design strategy that employs a topological conception of form and the flexible geometry of continuous curves and surfaces as its ultimate expression. This new form diverges from the Euclidean geometry of discrete volumes represented in Cartesian space. Such architectural expression is marked in formal terms by biomorphic forms, which are in Lynn's case characterised by the unbroken continuity of the plastic surface.

In his text "Visions Unfolding: Architecture in the Age of Electronic Media", Peter Eisenman proposes a new concept of architecture envisioned as a Moebius strip with a continual connection between a building's interior and exterior.[423] For the new concept he also refers to Gilles Deleuze and his idea of the *fold*.[424] For Deleuze, in folded space,

[419] G. Farin, J. Hoschek and M.-S. Kim (eds.), *Handbook of Computer-Aided Geometric Design*, Elsevier Science B. V., Amsterdam, The Netherlands, 2002, 520-521.
[420] Charles Jencks, *The New Paradigm in Architecture*, Yale University Press, New Haven and London, 2002, 95.
[421] Porter, *Archispeak*, 15.
[422] Greg Lynn, "Architectural Curvilinearity: The Folded, the Pliant and the Supple" in AD Profile 102: Folding in Architecture, Academy Editions, London, 1993, 8-15.
[423] Peter Eisenman, "Visions Unfolding: Architecture in the Age of Electronic Media" in Luca Garofalo (ed.), Lucinda Byatt, translator, *Digital Eisenman: An Office of the Electronic Era*, Birkhauser, Basel, Switzerland, 1999, 87.
[424] Gilles Deleuze, *The Fold: Leibniz and the Baroque*, Continuum, London and New York, 2006, 142.

new relationships are established, relationships between inside and outside, vertical and horizontal, figure and ground, which all present structural elements provided by traditional imagery. The difference in regard to the idea of folded space compared with the space of classical vision however, is that it accentuates temporal modulation and relinquishes framing as an orthodoxy. This implies that instead of planimetric projections, such as top, front and side views, folded space inspires a variable curvature with such traditional structural elements moving in and out of each other. This idea is radical because of the absence of the linear narrative sequence, present in traditional imagery, but instead it contains a quality of the unseen. In this way folding changes the traditional space of vision.

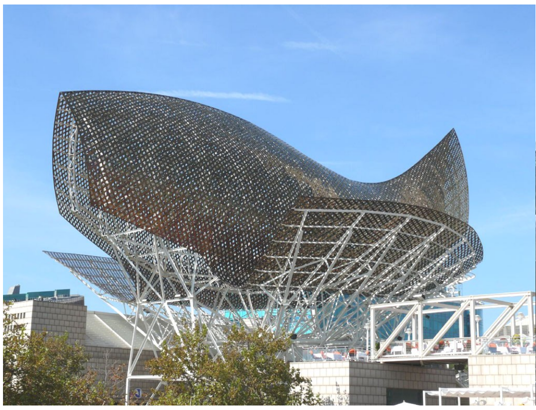


Figure 3.25: Frank Gehry, Pavilion in Barcelona, Spain, 1992.

Figure 3.26: Frank Gehry, Guggenheim Museum in Bilbao, Spain, 1997.

In Eisenman's opinion, the idea of folding that is conceptualised in an architectural space established a transition from effective to affective space that introduces an expressive condition or affect. This implies an understanding of aspects of space that are more than reason, meaning and function. For him, it is necessary to change the relationship between project drawing and real space in order to change the relationship of perspectival projections to three-dimensional space. This implies that the projected space would not be drawn with any level of meaningfulness, which presents the deflection from the scale relationships between lines in space.[425] This approach towards the formal treatment of architectural attributes and space changes the relationship between the building and its surroundings as well as in case of some of Frank Gehry's buildings, illustrated in figures 3.25 and 3.26 above. Computer-aided design was available for utilization in architecture throughout the 1980s, but only in 1990s with the

[425] Ibid., 143.

availability of more powerful computers, did it become a tool for creation of this kind of radical architecture. The first building design that was computer generated was the fish-shaped pavilion in Barcelona by Gehry.[426] This approach will reach its extremis in his Guggenheim Museum in Bilbao, which presents an early influence of blob architecture and for some the putative occurrence of the *Bilbao effect*, involving architectural spectacle as a mode of regeneration.

The development of NURBS, which are used to generate complex geometrical shapes started in 1950s bared around the needs of engineers in aerospace, marine and car industry to utilise mathematically precise representations of free-form surfaces, like those on an aeroplane or car body, ship shells, etc.[427] The pioneer in their development was Pierre Bezier, after whom they were later called B-splines or Bezier-splines. A Bezier-spline curve is composed of local Bezier-curves that are joined in a smooth manner.[428] Their first implementation was in CAD packages used only in car companies but later they became a standard part of computer graphic packages.[429] Nowadays they are a general part of work in CAD, CAM and CAE (Computer-Aided Engineering). The instinctive environment for NURBS and their constitutional properties is projective geometry, which unlike Euclidean geometry, does not have parallel lines. Therefore architects use projective geometry in building design in cases in which the production of drawings requires a view of a building as it would appear to an observer.[430] The background for the development of projective geometry dates from the art of the late middle ages. The renaissance artists, such as Leonardo da Vinci and Albrecht Dürer studied techniques required for construction of realistic renderings.[431] In the seventeenth century the first mathematical explorations with perspective were conducted with B. Pascal and G. Desargues, which will establish perspective as a vital instrument in architecture, art and engineering. Only in the nineteenth century with the theory of projective geometry did perspective became a formal mathematical inquiry, with studies of J. Poncelet, K. von Staudt, F. Moebius and J. Steiner.[432] Nowadays, perspective views are essential representational tools for architectural projects, which can provide its

[426] D. J. M. van der Voordt and H. B. R. van Wegen, *Architecture in Use: An Introduction to the Programming, Design and Evaluation of Buildings*, Architectural Press, Elsevier, Oxford and Delft, 2005, 62.
[427] Gerald E. Farin, *NURBS for Curve and Surface Design*, A. K. Peters Ltd., Natick, Massachusetts, 1999, XIII-XIV.
[428] Giesela Engeln-Müllges and Frank Uhlig, translated by M. Schon and F. Uhlig, *Numerical Algorithms with C*, Springer, Verlag Berlin, Heidelberg, 1996, 313.
[429] Ibid., 313.
[430] Gerald E. Farin, *NURBS for Curve and Surface Design*, A. K. Peters Ltd., Natick, Massachusetts, 1999, 1.
[431] Ibid., 2.
[432] Ibid., 3.

aesthetics with the humanistic quality. This humanistic quality is also achieved through use of NURBS curves that enabled creation of organic forms.

By interaction with NURBS curves through the manipulation of grids and vectors it is possible to create free forms that are amorphous, flexible, fluid, non-ideal and irregular. In regard to building's formal character, this influenced creation of dynamic architecture. Although, only the form of a building indicates movement, while other essential attributes continued to be static.[433] For Marcus Novak, this kind of architecture cannot be exhausted in descriptions of space, form, light and the features of the real world, but it becomes an architecture of fluctuating relations between abstract elements.[434] In regard to Novak's notions of fluid architecture, cybernetic mutualism does not imply the formal representational qualities of architectural space because it can serve as conceptual base for orthogonal as well as blobby shaped spaces. Cybernetic mutualism is not strictly delineated by the form of the building. Its essence is related to the quality of interaction an inhabitant can establish with the space and the sense of the space created through interaction with its elements. The mode of interaction with NURBS curves and splines opened up the possibility for the creation of concepts with aesthetic resonance with those of Archigram in the 1960s, such as Cook and Fournier's Kunsthaus in Graz, in which form was generated through use of NURBS. Because of their accuracy and flexibility they can be used in any process from illustration and animation to manufacturing. This implies a simplification of the manufacturing process that can facilitate the actual realization of complex shapes. The production of physical models and objects created by means of NURBS curves is enabled by CNC and Rapid prototyping digital fabrication processes, discussed previously in the chapter.

NURBS curves provide an architect with a real-time interaction with its elements or control points, that are used in order to make local modifications to existing curves or surfaces. The immediacy of the result provides for visual consistency of form. *Real-time* in this case implies that the software maintains a permanent state of interaction with the user. Natural and intuitive interaction is achieved through the fluidity of movement of virtual 3D elements and possibility for one to use a hand and/or fingers for direct and fine manipulation of virtual objects on the screen. This is enhanced by the

[433] der Voordt and van Wegen, *Architecture in Use*, 63.
[434] Maggie Toy and Charles Jencks, *Ecstatic Architecture: The Surprising Link*, John Wiley and Sons, London, 1999, 76.

performativity of the object, which behaves as a solid material being shaped through the direct interaction with one's hand. This is perhaps achieved through the virtual materiality of three-dimensional objects which digital features are created to correspond to the characteristics of physical materials and the realism of motion that natural materials have when shaped, as perceived by people.

For better understanding of the interaction with virtual materials in the three-dimensional graphical modelling it is important to analyse the rendering process and the mechanisms that operate it, resulting with the architectural imagery that can be said to be decisive in relation to the architect's aesthetic expression.

3.5.3 Algorithmic Procedures in the Rendering Process – Development of Concepts

Rendering is very important process in creation of architectural imagery because it implies the aesthetics of produced image. An interesting attribute in the domain of the three-dimensional geometrical model rendering is *Ray-Tracing*. This is a technique used in computer graphics for generating images, by tracing the path of light through pixels in an image plane. The idea behind ray tracing was formed according to the way visual perception operates in the human visual apparatus. This concerns that usually there is a light source that emits the light. The physically correct images are composed by light in such a way that the light bounces around in a scene as rays, and, in the process, follows a broken line path before it makes contact with the eyes or a camera. The computer simulation reproduces the path followed from a light source to the eye and in this way it is able to determine what can be seen with human eyes.[435] Thus it can be concluded that the principle of the ray-tracing concept is based on the mode of interaction between the light source and the surfaces encountered by the reflected light. The quality of this interaction, and consequentially the quality of the rendered image, will depend on the sophistication of the mathematical models used to process light/surface interaction. Ray tracing presents a complex computational process in which a 3D model rendered with this option demands a high performance CPU engaged through sophisticated software, such as Rhino's Flamingo plug-in.

[435] *Codermind* team, Retrieved March 05, 2009, from http://www.codermind.com/articles/Raytracer-in-C++-Introduction-What-is-ray-tracing.html.

The ray tracing technique was introduced by Rene Descartes through his statement that light is a thing in motion that, through interaction with other things, cause reaction and responses.[436] In his 1637 text, “La dioptrique”(“Optics”), Descartes combines improbable reasoning and immaculate geometry to come to a refraction law that he expressed in terms of the linear components of the incident and refracted rays.[437] The approach he applied is indistinguishable to a comparison of the incidence and the sine formula[438] of refraction angles, which form a constant ratio for a given pair of media regardless of the actual value of the angle of incidence. An important construct that Newton discovered regarding the previous concept is that the ratio that Descartes talks about does not depend only on the two media but also on the colour of the refracted ray.[439] Other scientists of the seventeenth century that dealt with the way light rays interact with objects and surfaces were Johannes Kepler, Christiaan Huygens and Willebrord Snellius. After Huygens' publication of “Traite de la Lumiere” in 1690 his construction was used for tracing geometrical wave-fronts.[440] This brief historical development of interaction between the light ray and the surface of material gives an introduction to the computer rendering methods developed in the 1970s and 1980s.

After previous explorations, the *Scanline* family of algorithms or rendering techniques was among the early developments of computer rendering methods described in the early work of Wylie, Romney, Evans and Erdahl in 1967.[441] Other developments of this rendering method were carried out by W. M. Bouknight in 1969[442] and Newell, Newell and Sancha in 1972.[443] The operational instruction of the scanline algorithm is on a row-by-row basis rather than a polygon-by-polygon or pixel-by-pixel basis. The polygons that are going to be rendered are first sorted by the top *y* coordinate at which they first appear. After that, each row or scan line of the image is computed using the intersection of a scan line with the polygons on the front of the sorted list, while the sorted list is updated to discard a *non-visible* or no longer visible polygon as the active scan line

[436] Rene Descartes, “Discourse 2 of the Dioptrics” in Stephen Gaukroger (ed.), *The World and Other Writings*, Cambridge Univesity Press, Cambridge, New York and Melbourne, 1998, 76-85.
[437] Raymond L. Lee and Alistair B. Fraser, *The Rainbow Bridge: Rainbows in Art, Myth and Science*, Pennsylvania State University Press, University Park, PA, 2001, 183.
[438] *Sine formula* or the *Law of Sines* is in trigonometry an equation relating the lengths of the sides of an arbitrary triangle to the sines of its angles. See Ron Larson, Roland E. Larson and Robert P. Hostetler, *Triginometry*, Houghton Miffin, Boston, USA, Seventh revised edition, 2006, 278.
[439] Ibid., 278.
[440] Barry R. Masters, *Confocal Microscopy and Multiphoton Excitation Microscopy: The Genesis of Live Cell Imaging*, SPIE Press, Bellingham, WA, 2006, 4.
[441] Chris Wylie et all., *Half-tone Perspective Drawings by Computer*, University of Utah, Salt Lake City, USA, 1968, 231.
[442] W. M. Bouknight, *An Improved Procedure for Generation of Half-tone Computer Graphics Presentations*, University of Illinois, Coordinated Science Laboratory, USA, 1969, 34.
[443] M. E. Newell et all., *A New Approach to the Shaded Picture Problem*, Proceedings of the ACM National Conference, Boston, 1972, 22.

advances down the picture,[444] as shown in figure 3.27 below. In this case, the principle of interaction between the light ray and the object on the scene is determined by the way in which the motion of light photons is directed to contact the object.

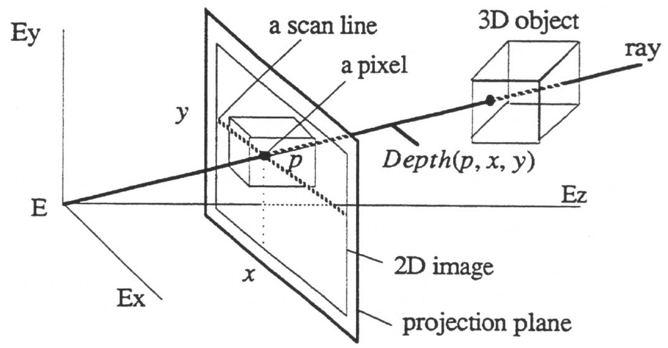


Figure 3.27: Scanline Algorithm Principle.

After the scanline rendering method, in 1968 Arthur Appel presented the first *Ray Casting* algorithm used for rendering. The initial idea behind ray casting was to simulate the propulsion of one ray per pixel and in this way obtain information about the closest object blocking the path of that ray. This algorithm can determine the shading of the object in the scene by determining the level of interaction between the light in the scene and the material properties of an object. This idea was based on the simplifying assumption that if a surface interacts with a light, this interaction will be successful in a way that the light will reach the surface, which means that it will not be blocked or remain in shadow.[445] The advantage that the ray casting algorithm had in relation to the previous scanline algorithms is the quality of non-planar surfaces and solids.[446] In 1979 Turner Whitted extended a basic ray casting algorithm in such a way that in a moment of a ray's interaction with a surface, three new types of rays could be generated: refraction, reflection and shadow,[447] which can suggest three new modes of interaction because they specify the level of interaction of the light ray with each pixel in the scene. These modes of interaction describe the relationship between the virtual material and the light that results in different rendering qualities and greatly determines an aesthetic expression of an acquired image. An aesthetic expression should reflect the substance and atmosphere of a reality in which a building should be perceived through a

[444] Jeremy Birn, *Digital Lighting and Rendering*, New Riders, Berkeley, CA, 2006, 277.
[445] Ibid., 277.
[446] Ibid., 278.
[447] Whitted Turner, “The Hacker's Guide to Making Pretty Pictures” in *Image Rendering Tricks*, Course Notes 12 for Siggraph '85, New York, 1985, 68.

set of idiosyncratic stimuli.

Figure 3.28: Example of ray-traced rendering, 2010.

The first mode of interaction is that in an environment composed of shiny surfaces, reflected rays travel in the mirror-reflected direction from the surface. The result of this interaction is that the closest object intersecting with this ray will be seen in the reflection. The second mode concerns refracted rays and has a similar underlying principle but with the addition of the penetrative property of a refracted ray. This means that this ray could be entering or exiting a material, depending on the density and/or transparency of a material. In the third mode, the shadow ray is included that comprises testing the visibility of the surface to a light. This is useful property because it also reduces the need to trace all rays in the scene. When a ray interacts with a surface that faces the light, the ray is traced between this interaction point and the light.[448] The previous account suggests that the level of different modes of light/surface interaction can be determined by the complexity of the 3D scene and the pre-set material properties of its objects. Recursive ray tracing algorithms are responsible for photo-realistic or super-real images, such as one illustrated in figure 3.28 above. They usually take a long time to render because of the demanding usage of CPU so their completion needs to be planned ahead of time. This is a significant disadvantage of Ray Traced algorithm

[448] Andrew S. Glassner, *An Introduction to Ray Tracing*, Morgan Kaufmann Publishers Inc., San Francisco, CA, USA, 1989, 92.

compared to Scanline and Ray Casting algorithms as rendering approaches.

These modes of light/surface interaction, which result in the rendered virtual representation, strongly influence aesthetic expression in architecture. This will be discussed in the next section.

3.5.4 Architectural Aesthetic Expression in the Rendered Virtual Representation

The previously discussed algorithmic processes influence the architect's expression in regard to the way in which s/he makes the decision about the finalisation level of the rendered image. This is a question of whether to produce hyper-realistic or non-photo-realistic architectural imagery. In regard to the aesthetics of the computer rendered architectural image that emerges from the virtual world of algorithmic processes, we can say that Descartes' abstract realm of geometry[449] presents a type of a virtual world. This kind of virtual world is a mental space, which created a new epistemic order for representing objects in an imaginary, mathematical-coordinate space.[450] It can be said that computer graphics that utilise digital images are mapped onto this abstract mathematical space. In this way the actuality of architecture intermingles with the abstract conception of space inside a coordinate system of an appropriate software application. Instead of an accurate representation of the actual world on a map or a piece of paper, programmers build models to simulate reality. In opposition to architects whose foundation for aesthetic expression is in the actual physical world, the root of a programmer's aesthetic expression is in the virtual world of code, which can be translated into a mathematically constructed image. Representation is not their aesthetic motivation but simulation or hyper-realism is. In this regard, it can be said that digital technologies have increased the capacity of an architect to en-frame the world into a rendered virtual representation. Therefore, this kind of computer rendered visualisation of architecture should be approached from an aesthetic point of view that is different from that typical of architectural imagery.[451] This means that the previously discussed character of the traditional pen-and-ink drawings, renowned through architectural history as well as today, is substituted for the eye-catching aesthetics of vivid colours

[449] Rene Descartes used algebra to develop a coordinate system that removed the necessity of tools or even reference to the real world.
[450] Qiyang Chen, *Human Computer Interaction: Issues and Challenges*, Idea Group Publishing, Hershey and London, 2000, 212.
[451] Daniela Bertol, *Designing Digital Space*, John Wiley and Sons, New York, 1997, 50.

and textures of computer renderings. The comparative evaluation of design alternatives based on the aesthetics of the visual simulation is the realism of these computer-generated images.

Peter Lunenefeld argues that in the moment in which paper architecture becomes virtualised, it adopted the fluid states of liquid architecture.[452] Liquid architecture is a term introduced by Marcos Novak, who applies it to a range of disciplines and concepts which include architecture, such as buildings, models and spaces, then mathematics, such as topology, and computer science, such as ray tracing, animated simulation and fractal geometry. In this regard liquid architecture presents a ramification of experimental architecture which explores the new *immaterial* medium of computer generated data.[453] As discussed in the Materiality parameter in the first chapter, computational processes that operate inside the hardware elements of a computer are not immaterial but feature micro-materiality that cannot be perceived by human visual apparatus and is therefore often regarded as immaterial. Liquid or fluid forms, such as Zaha Hadid's buildings, are generated by means of distinctive software applications with parametric attributes. Parametric processes introduced a new approach in modelling of architectural forms by generation of geometry based on a novel mode of interaction with a software. This mode allows a designer or an architect to generate form by assigning numerical variables or parameters, instead of creating a single set of fixed points in space. Most importantly they create a strong link between the materiality of the software, and that generated as actual architecture and parametric design does this by means of interaction. Because of this revolutionised approach to interaction parametric processes are discussed in the next section.

3.6 The Concept of *Parametricism*[454]

An evolutionary step further in the three-dimensional representation of architectural projects are the parametric design systems. The current practice of structural design is inherently computational, especially in the developments in the respective fields of *non standard* and *free form architecture*. This results a the quest for efficiency in the design

[452] Peter Lunenfeld (ed.), *The Digital Dialectic: New Essays on New Media*, MIT Press, Cambridge, Massachusetts, 2000, 11.
[453] Marcos Novak, “Liquid Architectures in Cyberspace” in Michael Benedikt (ed.), *Cyberspace: First Steps*, MIT Press, Cambridge, Massachusetts, 1991, 112.
[454] Patrik Schumacher, “Parametricism: A New Global Style for Architecture and Urban Design” in Neil Leach (ed.) of *AD Architectural Design: Digital Cities*, Vol 79, No 4, July/August 2009, 14-18.

of structures, for less mistakes, the need for more qualitative answers and faster from advanced technology, such as the Finite Element Method (FEM), Computational Fluid Dynamics (CFD), optimisation, etc. and developments such as performance-based design, Building Information Modelling (BIM), Virtual Construction, advanced manufacturing techniques, etc.[455] The evolutionary step further of the BIM in relation to Auto-CAD and Microstation is in the intelligence of the system based on the interactive modalities and parameters arising between the elements of a model. The primary intention for CAD systems was to automate the task of drafting. In this regard, 2D geometry is represented via graphical elements, like lines, circles, rectangles, etc. In order to establish a meaningful relationship between these graphical elements the concept of layering was introduced. Discrete 2D drawing files could be generated and plotted from CAD by grouping elements into layers. A constraint of CAD however is that more complex information, such as relationships between elements and real-time interaction with the elements, cannot be represented, as discussed previously in the chapter.

The possibility to involve relationships and interactions between a building's elements was partially enabled with the emergence of software applications for three-dimensional graphical modelling. These at first focused entirely on creating geometry in support of visualisation. Consequent progressions were mostly centred on the creation of realistic renderings and lighting effects, as discussed previously. The next stage in the development of 3D software were object-oriented CAD systems.[456] In case of object-oriented systems, 2D symbols are replaced with building elements or objects, which are designed to represent the performance of common building elements. The building elements that such a model consists of, can be created and displayed in multiple views. It is also possible to have additional layers of information attached by non-graphic attributes assigned to them. This information can range from material properties, dimensional constraints, manufacturing specifications, to cost information.[457] In these terms, the variable dimensions and assigned rules that are included in the parametric 3D geometry ascribe intelligence to these objects, allowing the representation of complex

[455] J.L.Coenders, “Interfacing Between Parametric Associative and Structural Software”, Delft University of Technology, The Netherlands and Arup Amsterdam, 2007, 31, Retrieved November 30, 2009, from http://jlcoenders.nl/drupal/sites/default/files/20070418_paper_jlcoenders.pdf

[456] Rabee M. Reffat, “Three-Dimensional CAD Models: Integrating Design and Construction” in Rick Best and Gerard de Valence (eds.), *Design and Construction: Building in Value*, Butterworth-Heinemann, Elsevier Science Limited, Oxford, 2002, 298.

[457] Brown, “For_getting Drawing in Al-Qawasmi and de Velasco, *Changing Trends*, 71.

functional and geometric relationships between building elements. These relationships are determined by the architect's interaction with the software, as well as through the interactive properties of individual elements in the model. Interaction in this case enables the abstract elements, such as space, to be defined by the relationships between physical building elements through their identification and referencing. Parametric modelling software also establish a new mode of interaction between architects, software and idea. This is one of the main characteristics of cybernetic mutualism.

BIM is considered as the latest generation of object-oriented CAD systems. Parametric modelling was the name for this new generation of software, before BIM was perceived to have a potentially artistic character. The origin of the meaning of the word *parametric* and *parameter* is the *one of a measurable set of factors that define a system and determine its behaviour*.[458] The diverse relationships that can be established between different agents in parametric interaction, such as the architect, building elements and the idea, reflect the essence of cybernetic mutualism similarly to the relationships formed in different stages of digital fabrication. The outcome of the interaction among these can be considered to have distinct aesthetic qualities when compared to the interaction during digital fabrication because it deals mostly with soft materials. The collective experience during design is another characteristic of cybernetic mutualism that is present during interaction with parametric software because of the possibility for different professionals to make their contribution to the project.

Another of the revolutionary propositions of BIM is that the design starts to be perceived as a database. This is a novelty in the conceptualization of the database, which is a consequence of the digitization of the design process. Previously in terms of its usage in architectural practice, the database was comprised of a structural assemblage of folders and files allowing a finer management of an architectural project. Through the emergence of object-oriented databases in 1980s and its combinations with the deductive database[459] the mutual relationship between the two influenced their different applications in CAD systems, as discussed in the first chapter. This involves the storage of more complicated data and the involvement of the database in other activities, such as dynamical real-time interaction with a 3D model in the process of

[458] Ibid., 71.
[459] C. Du, “Emerging Database System Architectures” in T. Leondes, *Database and Data Communication Network Systems,* 134.

architectural design, as in case of BIM systems. This new approach does not use the database as a static storage system for faster management of drawings and documents, but establishes it as a dynamic interactive constituent of a three-dimensional architectural representation.

The difference in the mode of interaction from the traditional software, such as Microstation or Auto-Cad, and the utilization of BIM systems is in the predominant usage of the keyboard as a main access point for either design input or the modification of drawings. In regard to interaction with software's interface, all familiar methods for graphical construction still appear with the difference that instead of clicking, pointing and dragging in order to change the shape, position or size of a given element, this kind of modifications is produced by keyboard input.[460] The interactivity of data presents another decisive characteristic of parametric software enabled by the new use of databases. In regard to interaction, if a design is modified in any way through its geometrical, quantitative or material instances, these alterations are instantaneously transmitted, calculated and updated throughout a project without the need to alter elements individually or to change plans, elevations and sections separately. An adjustment made in a plan view directly produces a modification of the perspective view at the same time changing both, the material and manufacturing information. The traditional orthographic, perspective and isometric descriptions of an architectural design are generated in a simple and easy way because of the parametric condition of the system. All the alterations are automatically recorded in the same database that also produces a spreadsheet.[461] In this case, the forms processed by parametric software become materialized through interactive form-finding processes. This mode of interaction presents the most developed state of digitized architectural craftsmanship because it involves interaction of several kinds between architect and system, and many different registers of interaction between element of the system and between the components of the building being planned. Considering that the architect is the one who controls the process of design during parametric interaction, the evolution, in terms of cybernetic mutualism, could be seen in creating a software that is able to learn from previously ascribed information and make proposals for solution of latent problems.

[460] Brown, “For_getting Drawing” in Al-Qawasmi and de Velasco, *Changing Trends*, 71.
[461] Ibid., 71-72.

These advanced software means are highly developed simulation and prediction tools for the potential behaviour of the building and they have changed the approach towards the conceptualization of an architectural design in a sense that a building is not observed in terms of what it represents but in terms of its performative qualities. The segmentation of the design process into phases and stages, which was present in traditional drafting and later transferred to its digitized mode of production, is reduced if not neutralised. This means that parametric software and its consequential impact on architectural design, has established a new approach in which the architectural design is realised. The utilization of parametric systems in architecture resulted in the understanding of architecture not only as a product but also as an interactive process and an event. This concerns a real-time interaction between the architect and hardware/software components. This kind of interactive potential can expand beyond the virtual realm of digitized architectural design to the modalities of interactive physical architectural elements, such as façade walls, discussed in the fourth chapter.

The introduction of parametric software into architectural design in the mid-1990s resulted, according to Patrik Schumacher, in the emergence of *Parametricism*.[462] According to him this is a new style in modern avant-garde architecture that can be compared with Postmodernism, Deconstructivism and Minimalism, all of which are short episodes of the Modernism crisis. For Schumacher, this style is rooted in the digital animation techniques and is developed through interactive implementation of scripting methods into the existing software for three-dimensional modelling and therefore represents a new long wave of systematic innovation.[463] According to Schumacher, Parametricism presents a developed style that emerges as a logical continuation after actualization of mass customization, versioning, *continuous differentiation*[464] and iteration within the architectural avant-garde discourse. The development of parametric design tools and scripts that allow the precise formulation and execution of interactive correlations between elements and subsystems facilitated acceleration of resolution, refinement and virtuosity within architectural design.

Although the architects of Modernism use parametric tools to deal with complexity of large-scale projects and in order to maintain Modernist aesthetics, the direction of

[462] Schumacher, *The Autopoiesis of Architecture*, 129.
[463] Ibid., 113.
[464] Ibid., 141. Patrik Schumacher credits Greg Lynn and Jeff Kipnis for coining this expression.

parametricism leads toward the elegance of ordered complexity and the sense of coherent fluidity, that are constituted in natural systems.[465] Thus an architecture of organic and fluid shapes does not elude nature, as Modernistic architecture did in its linear and orthogonal predispositions, but coexists with the nature in a mutualistic relationship, as suggested by Gordon Pask[466] in a way that becomes increasingly essential in humanity's relationship with the environment as discussed in the previous chapter.

The existence of parametricism, as perceived by Schumacher, is possible only via the continuous advancement and sophisticated appropriation of computational geometry. For him, the development of the parametric paradigm needs further development in order to extend the reach of the new style. His propositions for the areas of development are the parametric inter-articulation of subsystems, parametric accentuation, parametric figuration, parametric responsiveness and parametric urbanism.[467] An interesting aspect from the perspective of interaction, among these, is parametric responsiveness, which Schumacher describes as an inbuilt kinetic capacity of architectural and urban environments, which allows them to adapt in real-time and reconfigure at different time scales in response to prevailing occupation patterns. In terms of cybernetic mutualism, this conception of parametricism combined with further development of technologies such as CNC and Rapid prototyping, can open up possibilities for exploration of concepts for architectural spaces that contain fundamentally evolutionary difference to spaces traditionally perceived as unchangeable and inactive, not only in regard to their formal attributes, but provoking the creation of actually dynamic interactive spaces. These spaces would, through interaction, be in a state of constant redefinition, not only in their formal representational aspects, as in the theory of fold, but also to be observed in terms of the continuous processes of interactive reconfiguration in which for instance up can become down and vertical can become horizontal, something perhaps achieved in Price's *Generator* project. The resultant interactive space would estrange the perceptive notions of the traditional space obtained through Euclidean geometry. This implies a whole new range of interactive modalities that contain the qualities of cybernetic mutualism. Some of the practical applications for creation of computer drawings for such spaces are discussed in the next section.

465 Ibid., 182.
466 Pask, "The Architectural Relevance of Cybernetics" in Spiller, *Cyber Reader*, 17.
467 Ibid., 17.

3.6.1 Parametric Software for Non-Standard Architecture

Contributors to the practical research and theory carried out in the field of parametric design date from the late 1980's[468] and these include Bernard Cache, Greg Lynn, Michael Hensel, Achim Menges, etc., all of whom are in their respective fields of interests related to the parametric software development. Greg Lynn with his conceptual and formal explorations of the fold, discussed previously in the chapter. Hensel and Menges with their architectural enquiry based on the collaboration of diverse fields, such as bioengineering, digital technology, architecture, information theory, mathematics, etc. Their new concept of *emergence* or *evolutionary optimisation* that in an architectural context involves the investigation of evolutionary processes for the composition of new materials as well as for the design of buildings and structural design.[469] Cache with development of the concept of *non-standard architecture*[470] through the development of the *machines dedicated to the production of information* in form of the use of the parametric software Top Solid in his practice. Cache's interest in linking architectural design concepts to the design of various structures and furniture led him to an understanding that by using mathematical functions the production of non-standard items could be more feasible.

Cache argues that this software is a very powerful tool not only for mechanical engineers but also for architects who still need to explore its capabilities in more constructive manner. Exploratory examples of the practical implementation of Top Solid were done through MA student projects at the Berlage Institute in Rotterdam in 2005,[471] University of Toronto in Toronto and University of Catalunya in Barcelona in 2002.[472] Projects at the Berlage Institute were focused on exterior architectural objects in the form of street furniture, such as bicycle racks, lighting, bus stops, benches, etc. In this case, projects addressed the question of a differentiated serialization of an architectural product and its technical and cultural implications, while the projects in

[468] See Top Solid and Objectile, Retrieved November 29, 2009, from http://www.topsolid.com/successes/report/objectile.asp
[469] Michael Hensel, Achim Menges and Michael Weinstock, *Emergent Technologies and Design*, Routledge, New York, 2010, 12-15.
[470] Cache, *Earth Moves*, 44.
[471] Penelope Dean, “Hunch 10: Mediators”, The Berlage Institute Report, Episode Publishers, The Netherlands, 2006, 140.
[472] Emily Abruzzo and Jonathan D. Solomon (eds.), *306090-05: Teaching + Building – Beyond the Imagined*, Princeton Architectural Press, New York, 2003, 187.

Toronto and Barcelona went a step further in scale and designed a façade. The façade design process involved the use of three-dimensional NURBS modelling and a laser cutting CNC machine. Considering current developments in CAD/CAM computer industry, experimentations in architecture are generally limited to the smaller scale objects and elements of architectural and urban spaces. Influential condition of determining such works are construction costs, the time frame in which the projects are to be completed, maintenance costs, safety issues, etc. Because the building process is nevertheless based on the traditional Domino system of building construction, developed by Le Corbusier in the late 1920s,[473] the previously mentioned developments within architecture still remain at the moment in the domain of decoration.

Another interesting parametric and associative modelling system is GenerativeComponents (GC)[474] developed by a team lead by Robert Aish of Bentley Systems, the development of which started more than a decade ago. This system supports many advanced modelling concepts. It provides new ways of efficient exploration of alternative building forms without the necessity to manually build the detailed model design for each scenario. This system has the capability to capture and graphically present design components and abstract relationships between them. Aish describes GC as development environment and, object-oriented and feature-based, modelling system that represents the fusion of design theory with computational theory. This technology is based on the eight key concepts: implication, conditional modelling, extensibility, components, replication, programmatic design, multiple representations and transactional model of design.[475] According to Aish, all software is based on the concept of representation and the GenerativeComponents, at the first glance, is based on the representation of a building through geometry that the user sees on the screen. At the next level of depth, this software through modelling represents more general relations and dependencies between geometry and other non-graphical elements, such as scripts, variables, conditional statement and expressions. The primary representation, however, are design decisions that are translated or transferred through the medium of software. This allows for a continuous construction and evaluation of the sequence of alternative design decisions applied though interaction with the software on several

[473] Le Corbusier, *Towards a New Architecture, 53.*
[474] Bentley, Generative Components, Retrieved November 30, 2009, from http://www.bentley.com/en-US/promo/flash/GenerativeComponents.htm
[475] Achim Menges, "Instrumental Geometry" in Robert Corser (ed.), *Fabricating Architecture: Selected Readings in Digital Design and Manufacturing*, Princeton Architectural Press, New York, 2010, 28.

levels. Most basic is human-computer interaction between the software and a designer, another level is between the building elements of a parametric 3D model and the third level is interaction between software, designer and the idea. At present, the process of parametric modelling corresponds to the process of design at its most fundamental level.

3.7 Conclusions

From the discussion in the third chapter three modes of interaction are obtained: Human-computer interaction during the architectural design production, Parametric interaction and Interaction during digital fabrication, as described in the next sections.

3.7.1 Human-Computer Interaction During the Architectural Design Production

Human-Computer Interaction during architectural design production is based on an advanced form of reactivity, which is commonly misinterpreted as interactivity, and which involves the reaction of the computer to the user's input. This means that the conceptual quality of this interactive modality is based on the elementary form of action-reaction relationship that can be connected to the first order of cybernetics. This mode also includes utilisation of feedback loops, which assumes that a participant in the interaction has a goal, such as to draw a line for example. After participant’s goal is achieved through input into the system, by positioning two points within a computer coordinate space, s/he measures the effect of his/her action in the computational environment. This is achieved though interpretation of the system's output or feedback, which in this case is a drawn line that appears on a computer screen. The comparison of the participant's action with the system's reaction directs further action that begins the cycle again, by the participant drawing another line if necessary. This mode of advanced reaction occurs during the use of an appropriate software application in the architectural design production. Another restriction is that, through interaction with the software, the user cannot establish a dynamic relationship between the elements of a drawing or the drawn elements of the building. Considering the complexity of architectural design and therefore of the variety of software necessary for completion of a design's different stages, it can be concluded that this is the most widespread and commonly interpreted mode of interaction with a computer during design production.

In terms of its material quality, human-computer interaction is enabled by means of hardware components and software processes, both having different levels of perceptive materiality. In the case of interaction with software, the material qualities of the process cannot be fully comprehended because of its speed and the microscopic size of the electrons controlled by the software. The material qualities of software can operate at the range between particular characteristics of language to the events that can occur at the level of models of user subjectivity or forms of computational power.[476] This materiality involves different modes of interaction with the hardware as well, for instance with the mouse and the keyboard. Interaction through the keyboard allows a more direct conversation with the machine because it concerns interaction by means of a command line and offers the possibility for the creation of scripts that can enable a more efficient execution of complex actions during the drawing process. The most effective human-computer interaction results are achieved if the mouse and keyboard are used in combination. This aspect shows that interaction in general implies the way in which the relationship between user and computational device is conceptualised: interaction with software during architectural design did change the speed and organization of the design production. Another consequence relates to the digitization qualities of this interaction changed the way architectural drawings are structured. Structural change is enabled through the use of software features such as layers, reference files and so on. This is concern with how, through interaction with software, formal materialities are routinely established and dissolved as digital objects move between different information states. This means that drawn lines and geometrical shapes that determine the resultant aesthetic qualities of a building are translated into a set of computational formats that change the architect's relation with the building's materiality as it is translated from digital formats to an actual physical building.

Interaction with software can be regarded as the most prescriptive mode because it concerns use of the Graphical User Interface (GUI), which offers a standardisation of what is perceived as human-computer interaction. Instead of a multitude of possible commands, a tight set of options is necessary for the design of a building because of the way in which architectural drawings are produced. In terms of its digitization qualities, standardisation of interaction through the user interface involves utilisation of typical

[476] Fuller, *Software Studies*, 4.

computer icons, which have a common design through different software, such as the arrow sign as the *selection* tool,[477] for example. This kind of visual language created for interaction with GUI involves the use of input devices, such as the computer mouse, to control the position of the cursor, for instance the arrow sign, in order to find information organised in windows or drop-down menus and represented by icons. In the architectural drawing process the interaction with software is based on the previous set of actions. Interaction through the user interface enables a usability of a complex world of digital computation for a wider variety of users but, at the same time, it restricts the way users communicate with a computational device. This limitation could be overcome through an evolution that led to Building Information Modelling (BIM) and use of parametric software for three-dimensional graphical modelling, that can now be explained further.

3.7.2 Parametric Interaction

Parametric interaction involves an advanced level of human-computer interaction in regard to the production of the architectural drawings and 3D models. The development of human-computer interaction from the action-reaction kind of model started with software applications for three-dimensional graphical modelling. 3D software provided the possibility of representing relationships between the building's elements in basic three-dimensional graphic forms, through the construction of virtual 3D models of buildings. In terms of interaction, the basic mechanism of the system's advanced reactivity to the user's input in the human-computer interaction model did not change but the possibility of interacting with a building at a most basic level did. The most basic level concerns the possibility to zoom in and out, rotate a building three-dimensionally, scale and move 3D elements, and model the building as a whole. The further development of interaction with 3D software is in terms of its digitization quality, which is the possibility of having additional layers of information attached by non-graphical attributes assigned to the structural elements of the building's 3D model. This is provided by object-oriented CAD systems. The advance in terms of interaction of these systems lies in the intelligence ascribed to the structural elements of the building's 3D model through variable dimensions and assigned rules included in the

[477] For example Apple Xerox Star computer, released in 1981, was the first computer to have Graphical User Interface (GUI) operating system available for commercial use. See, “Graphical User Interface” in Steve Jones (ed.), *Encyclopedia of New Media: An Essential Reference to Communication and Technology*, Sage Publications, Thousand Oaks, California, 2003, 207.

parametric 3D geometry. This allows the representation of complex functional and geometric relationships to be incorporated into the building elements. This is the key conceptual quality of parametric interaction. It implies that the relationships between building's elements are defined by the architect through interaction with parametric software by the construction of a parametric 3D model of the building. This is achieved through connecting together the interactive properties of the individual elements of the buildings and the mutual relationships that are established through these connections. This means that the essence of cybernetic mutualism is reflected in the diverse relationships that can be established between different agents in parametric interaction, for example the architect, building elements and the idea. Established relationships between elements have flexible numeric and reciprocal properties and interaction in this case enables the abstract elements, such as space, to be defined by the relationships between virtual building elements through their identification and referencing, something which was not possible in human-computer interaction.

Interaction with parametric software provides a novel approach in architectural design production because an architect can design a building through the construction of a generative system that produces a form. The novelty lies in dealing with the material qualities of interaction, so that the building's form is the result of the process. Instead of designing a building though a set of plans, sections and elevations that will be translated into a three-dimensional representation, an architect firstly generates a form, from which plans, sections and elevations can be extracted. The architect controls the behaviour of the system, that is a building, through parametric interaction and adjustment of parameters. As the result of this adjustment, interaction with new construction elements and architectural forms is possible. It is also possible to manipulate these new elements further. This means that the conceptual quality of parametric interaction is also contained in the transfer of the importance from geometry of a form to the relationships between the elements of a drawing and of a building. An architect's aesthetic expression becomes a matter of selected and edited choices within the generative system of a building. Through continuous interpretation and interaction with parametric components, the parametric 3D model continuously reconstitute itself, and through the graphic interface can influence the architect's ideas and concepts about the project. The potential of this mode of interaction lies in the possibility for the architect to directly modify the relationships of the drawing elements through editing the underlying generative software system. Through interaction, the spaces created in this process would be in a state of constant redefinition and not only in their formal representational aspects. In terms of cybernetic mutualism, the new concept of parametricism in combination with developments in CNC and rapid prototyping technologies can open up possibilities for exploration of mutualistic qualities that can create architectural spaces containing fundamentally evolutionary differences not only in regard to the formal attributes of the architectural space, but that can provoke the creation of actually dynamic spaces in which interaction though cybernetic mutualism crates cybernetic architectural environments.

It can be concluded that with the development of software for architectural design production, the mode of human-computer interaction evolved so that relationships can be established between the different elements of a three-dimensional building within a drawing. In terms of interaction's digitization qualities, as the software becomes more complex and enables the storage of more information within a drawing, the parametric interaction between the elements of a drawing can evolve and change the methods for the creation of different spatial modalities. This means that parametric interaction in the architectural design production enables architects to shape the formal outcomes through iterative digital processes. This means that parametric interaction redefines the relationship between the conception and representation of an architectural design. The accent here is on the relationships between the structural elements within a building's parametric 3D model.

The further development of human-computer interaction model is that which occurs during digital fabrication, which differs from the previous mode in the production principle applied to the process, as will be discussed in the next section.

3.7.3 Interaction During Digital Fabrication

This mode of interaction is based on the file-to-factory production principle. This refers to the digitization quality of interaction during digital fabrication due to the complex production processes of the resultant artefact. Besides the human-computer interaction with the software that is required for the digital fabrication processes to occur, it also emphasises the material quality of the interaction that happens between the solid and/or soft materials and the computer, which as a consequence can create any imaginable shape. One of the explanations for the occurrence of these production processes is the possibility to interact with the complex geometry that is enabled by the emergence of NURBS curves and Bezier splines. The new practical instrumental processes that enable the production of forms created by these complex geometrical elements are CNC and Rapid prototyping, both of which imply different modes of interaction with the material. The first creates form through interaction in the two dimensional and subtractive fabrication, while the second implies interaction through additive fabrication. The material quality of subtractive fabrication involves interaction with the solid material whose volume is reduced by the software controlled operations. While additive fabrication involves interaction with the material's particles, whose position in space is specified by the computer. These particles are distributed by means of a sequential delivery of energy to points in space. In both cases, the interaction happens between the computer and the physical material in any form.

In this mode, the combination of digitization and the material qualities of interaction results in distinct aesthetic expressions. This distinction occurs because of the way in which relationships between the materials are structured, which is a distinction of cybernetic mutualism. Architectural forms obtained in this manner are possibly but not necessarily more complex, since they seek instruction through an interaction of numerous environmental constrains and continual feedback. These formal solutions are sought through an adaptive specification situated within a rich multiplicative culture of influences rather than through a singular input, as in the case of basic human-computer action-reaction model. The advances in this mode of production lie in the impossibility of having strict and repeatable structural formal compositions. A very important issue is the environmental conditions, such as humidity and temperature, in which the materials used for fabrication, as well as physical properties, such as the material's thermal capacity, density, strength, etc, interact. The combination of these characteristics and influences determines the final formal outcome of the fabricated structure. Through digital fabrication the emerging spatial forms are created in direct interaction with the physical materials assembled and fused within the environment. There are three different levels of interaction that can determine the formal attributes of these kinds of structures.

The first is the basic human-computer action-reaction relationship that occurs between an architect and software at the design stage, in which the geometry of the form is determined. The second stage is one in which digital and/or robotic fabricators interact with the material in the process of its physical composition according to a previously determined geometrical image. In this stage the material qualities of architectural forms are translated from digital to physical attributes. In the third stage, the material qualities of interaction present a fusion of properties in which the time of material consolidation determines the final formal result. The complex relationships between a number of agents in this mode of interaction, namely architect, computer, digital fabricator, material and environment, imply the possibility for reinvention of the way in which architectural space is designed and perceived and this can be explored through cybernetic mutualism. The accent in this mode is on the material quality of interaction that emphasises relations between the physical materials and their fusion into an architectural form. This implies that the unpredictable outcomes that architectural form obtained through this mode of interaction, could be related to the deliberate actions of the elusive alterations and modifications of the parameters that in the digitized modes of production define the process of design. In the previous stages of additive fabrication, the characteristics of cybernetic mutualism are reflected in the ways digital and physical materials can join. The physical results of these processes are spontaneous and mutable.

In order to develop this interaction, a broad knowledge of the processes, tools and techniques is required. This entails that the form is not the goal but the result of the digital process. This means that the potential improvement in the interaction during the digital fabrication lies in the differentiation and refinement of the interaction with different materials, such as the paper, resin or metallic powders utilised. Such refinement would concern the design development of the fabrication process rather than the formal outcomes. This implies that working with the material qualities of the interaction process is an important attribute. It can be concluded that the potential of the interaction taking place during digital fabrication lies in the possibility of exploring its material and digitization qualities not only in terms of changing the way in which the building is constructed and its elements are produced but also in finding new materials that can allow for a redefinition and re-conception of the architectural design.

An evident distinction between further modes of interaction was made through the analysis conducted in the fourth chapter about Digital Façades. These interactive modalities will be discussed in the following sections.

Chapter 4: Digital Façades – Overlaying the Physical with the Digital

In this fourth chapter, the material implications of the digitization process in architecture will be addressed through its influence on the environment and people who inhabit it. This will be achieved through an analysis of the building's physical manifestation in the form of a façade. In this regard, an interesting feature for analysis is façade's layering with digital properties providing its materiality with a skeuomorphic qualities. This implies that layering and incorporating digital materials in natural materials will be observed as part of the façade's transforming materiality. Interactive qualities digital façades can comprise are observed through mutualistic relationships and interconnection between building's materiality and façade's aesthetic attributes. Different aspects of cybernetic mutualism appearing through interaction with the digital façade will be the characteristics primarily observed, especially in respect to encouragement of social interaction. Another question is about the kind of relationship digital façades achieve with the programme of the building and the activity performed inside that will be considered as a point of articulation for interactivity. This aspect is very important in regard to cybernetic mutualism because it implies its essence: in cybernetic mutualism, *mutualism* concerns the quality of relationships that are established between different artificial and natural agents and *cybernetic* regards the method and plan of activity of the participants that is important for initiation of relationships. The wider writing strategy in this thesis concerns analysis through the use of a number of practical examples. This is important because I aim for a kind of a balance between the theoretical knowledge and the architectural practice, reflected in the concrete examples that are actually realised. This is important because is shows historical developments and current prospects within architecture. Therefore the analysis of the Digital Façades is articulated through a number of build examples, such as *Tower of Winds, Institute du Monda Arabe, KPN building, Aegis Hyposurface, BIX Façade, Galleria Department Store* and *Dexia Tower*. All of the examples are chosen for their specific application of interactivity on the building's façade.

In the long history of architecture, attempts to connect digital technology through its micro-materiality on a computational level and architecture through its macro-materiality in form of a building is present for only four decades. This interval, in comparison with the whole of architectural history, can be considered to be a new condition within contemporary architecture. The façades of key buildings constructed in this period represent different strategies in blending of two fields, the virtual and physical, both fields with their distinct materiality and processes that condition their aesthetic attributes. The projects chosen for this analysis also have different approaches in dealing with issues regarding a building’s relationship with the environment, people and events. The goal of this analysis is not to merely map existing projects in the field but to discuss the selected projects through the previously established set of theoretical qualities: concept, materiality, digitization and interactivity. The chapter will ask how different modes of input, like *direct* through touch screens and body movement and *indirect* through a mediator, such as mobile phone, computer, etc., can influence different modes of interaction. How too does the materialization of the building affiliate with and transforms its concept and interactive qualities? The question of digitization will also be discussed relative to building's condition within the context and the environment.

The choice of façade wall as the principal element for analysis is primarily because, in the design process, the façade acquires most attention as it is the first architectural element in direct communication with its surroundings and people. The façade represents an exterior elevation of the building with a composition of elements according to which the period and style of the building can usually be distinguished. It is important to point out that the significance of the façade is in its possibility to give a character to a building[478] and consequentially to its surroundings as well. Besides the contemporary fascination with possibilities that technology brought, static architectural façades have been a subject of inquiry and theoretical debate for centuries. Therefore, the historical overview of the façade's development is closely bound with the history of architecture in general and could be a topic for another thesis. Many previously developed architectural paradigms focus their attention on how a façade should be composed, materialised and what kind of message it transmits in this way. In this regard, Gottfried Semper makes an interesting observation in his book *The Style* in which he postulates purpose and material characteristics as basic concepts of the building. These characteristics relate to constant and variable factors.[479] The formal

[478] Jonathan Richards, *Facadism*, Routledge, London and New York, 1994, 100.
[479] Gottfried Semper, *The Style in the Technical and Architectural Arts*, Friedrich Bruckmanns Verlag, München, 1863, 204.

articulation of a technical product, according to Semper, remains the same throughout time and is related to human needs and natural laws. Contrastingly, materials and the ways in which people work with them are different according to place and time. In this regard, Semper addresses formal and aesthetic questions as affiliated with purpose of these objects and considers the history of style as focussed on such material aspects. He claims that *any technical product is a result of purpose and materia.*[480] In the case of digital façades both of these criteria are equally important to the accentuation in this thesis on the transient, digital, condition of materiality that is a new element in the evaluation of façade aesthetics.

An important characteristic of Semper's approach is his use of categories through which he attempts to base the concept of style on scientifically objective criteria. Semper formulates four main categories of raw materials, which can be formed in relation to style and these are: flexible, tough; soft, malleable; rodlike, elastic; and solid, of considerable solidity. Later in 1976, Adolf Max Vogt interpreted this sequence of technological categories from soft to solid as an *evolution of the human hand*.[481] Vogt's observation relies on Semper's notice that aesthetics, form, ornaments and symbolic meaning, as the first principles of style, primarily evolved from textiles, as the primordial type of art-technique. Textile, as tender and easily decayable material is considered to be the base for the development and application of aesthetic qualities for later hard and longer lasting materials, such as the stone and brick used for building construction. Nowadays, this sequence of categories from soft to solid can be expanded further and observed in the context of the digitization of materials through combination with software, as a soft material, and solid materials that can be referred as construction materials, such as concrete, steel, glass, etc. Software is considered as a soft material because of its temporary impact, that is, its ephemeral influence on an aesthetic quality of the digital façade, amongst others. This means that façade’s aesthetic quality can be continuously transformed by the software. Through the translation from one aesthetic attribute to another with each new input software provides the cyclical interactive processes to occur. The transient event that appears through software's activity is an additional aesthetic quality determined by the temporal digital processes. At the same time this presents a core argument for cybernetic mutualism because of the alternate

[480] Ibid., 204.
[481] Nold Egenter, “The Metabolism of Form in Antique Architecture”, (paper originally read at the International Seminar 'Architettura in Pietra a Secco', 27. - 30. Sept. 1987), University of Bari, Italy, 1990, 17, Retrieved January 16, 2010, from http://home.worldcom.ch/negenter/458aSemperMTx.html

relationships that signify the aesthetic change that occurs because of the software's activity. The relationship between software, digital façade and the participant implies the initiation of an interactive modality that comprise qualities of cybernetic mutualism in that it provides for spontaneous and fluid events to occur. In this regard digital façades can be considered as cybernetic aesthetic mechanisms. A practical example of the fusion between natural and digital materials and their different aesthetic compositions through the formal qualities of digital façades will be analysed further on in this chapter. In order to understand the methodology of the digital façades and their impact on the environment, further discussion relates to the differentiation between Urban Screens, Media and Digital Façades.

4.0.1 Urban Screens, Media and Digital Façades as Urban Modalities

Through the mobilisation of digital technology and consequentially growing digital culture urban communication environments have dramatically changed, particularly in the large metropolises, such as London, New York and Tokyo. Nowadays, under the influence of a rapidly evolving commercial and civic information sphere of cities diverse digital display technologies are implemented into the tissue of cities through their landscape, such as beam-boards, electronic city information terminals, LED billboards, plasma screens located inside the shop-windows, information systems inside public transportation sites, etc. Dynamic and intelligent screen-like surfaces are rapidly being integrated into architectural façade structures.[482] These surfaces are often called Urban Screens.[483] The point of origin of the Urban Screen phenomena is often named as the installation of the *Spectacolour Board* in New York's Times Square in the mid-1970s, which at that time represented an establishment of a new mode of advertising platform. Time Square has remained as a key site for the installation of the newest version of such technologies. Since then, an emergence of a new pervasive paradigm was evident through cumulative changes in technology, urban space and public culture.[484] The discussion that developed around urban screens was animated by recognition of the growing integration of media into everyday existence. This was a transition in regard to previous attempts to treat the digital realm primarily in terms of its separation from everyday life. The various scales of urban screens, from the large

[482] Struppek, "Urban Screens", 12.
[483] Scott McQuire et al., *Urban Screens Reader*, Inc Reader No.5, Institute of Network Cultures, Amsterdam, 2009, 8.
[484] Ibid., 9.

screens dominating the streetscapes of global cities to the small handheld screens of mobile phones, exemplified a new urban paradigm produced by the layering of physical space and media space. This resulted in what has been variously called *Hertzian*, *hybrid*, *mixed*, *augmented* or *stereoscopic* space.[485] The difference between urban screens and digital façades is, among other things, in the type of the medium used. While the focus of discussion around urban screens is on the utilisation of 'screen' surfaces, in various sizes and uses, as the main visual communicator in an urban environment, the focus around digital façades is also on other media, such as the sonic, kinetic, tactile, etc. and not only the visual. Another difference is in the modes of interaction with the façade and the resultant aesthetic attributes as a consequence of this interaction.

In some of the theoretical and practical descriptions of the new visual qualities of façade's materialisation and formal aesthetics, the term in use is *media façades*.[486] In order to explain the difference between *media* and *digital* façades, it is necessary to establish the meaning of the term *performance*. In architecture this word is related to functional issues, such as those associated with planning, structure and environmental control. The emergence and development of intelligent façades in architecture has introduced an extension of this approach to include performance over time. Kinetic systems are being designed to interactively perform in relation to temporal cycles and changes in user requirements, rather than to be considered as a relatively static envelope optimized for a range of conditions. Media façades, in a parallel development, search for an alternate definition of performance, in which the envelope acts as a site for embedded information or public art.[487] Moloney distinguishes between *kinetic* and *media* façades. In this regard, media façades can be considered to display a particular artistic or commercial content or can be distinguished by their type of a media. Kinetic façades by contrast have more functional attributes with an additional interactive quality that can be achieved in relation with environment or people.

Digital façades as a category can be considered to combine the properties of both, of media and kinetic façades, in their range of kind. The distinction is that the focus of

[485] Ibid., 9.
[486] Jan Adler, "Communicative Display Skin for Buildings: BIX at the Kunsthaus Graz" in Branko Kolarevic and Ali Malkawi (eds.), *Performative Architecture: Beyond Instrumentality*, Spon Press, New York, 2005, 150-160.
[487] J. Moloney, "Designing for Time: The Case of Kinetic Skins" in Susan Roaf and A. Bairstow (eds.), *The Oxford Conference: A Re-evaluation of Education in Architecture*, WIT Press, Southampton, UK and Billerica, MA, USA, 2008, 369.

digital façades is on the process involved in the formal attributes of the material properties and the achievement of interactivity as a result of the conceptual premise utilised in their formulation. In this case, the key part of the process is digitization quality. The particular focus is on the software component that operates the façade, as a consequence of the digitization in architecture that can help in understanding the influence of software on architecture not only in terms of the digitization of the design process but also in terms of the formal aesthetic properties it produces. In this regard, Semper's concept of weaving is interesting because it introduces the idea of dynamic pattern. Semper published his theory in his book "The Four Elements of Architecture and Other Writings" in 1951, in which he categorises construction into four basic elements of *hearth*, *roof*, *mound* and *fence*.[488] Basing his theory on the form of the primitive hut he proposed that the walls of ancient houses were not made of stone but rather of hanging woven fabrics. He regarded these walls as the *fence*, which suggests the idea of the wall as a textile hanging of the supporting structure, similar to curtain wall façade today. If the analogy of the woven wall is expanded to conceptual level it allows for the inclusion of inter-mixture and incorporation of different materials into a wall structure. These materials can be natural, digital, virtual or smart materials which combination can result in interactive digital façades. Dynamic patterns can be in different ways formulated as aesthetic expressions on the surface of these façades.

The previously mentioned façades can be considered as interactive and dynamic. Another term in use is *active façades* and it describes building exterior outfitted with different kinds of shading systems, Smart Glass[489] and other technologies that have the possibility to dynamically change the optical and thermal transmission characteristics of the windows.[490] According to Bernard Grehant, the use of variable shading systems in the design of building façades gives the architect an extra degree of freedom. These façades, like the biological envelope of a living organism, have the potential to adapt naturally to circadian and seasonal rhythms. For Grehant, the aesthetic architectural challenge of these kinds of buildings is in the combination of criteria concerned purely with energy and those for heating and lighting comfort.[491] Research done by Michael Wigginton and Jude Harris on intelligent buildings and therefore intelligent façades

[488] Semper, *The Four Elements of Architecture*, 89.
[489] Smart glass is glass or glazing that can be electrically controlled to vary the amount of light and heat transmitted or to change from transparent to opaque. Intelligent Building Dictionary, 1, Retrieved February 28, 2010, from http://www.intelligent-building-dictionary.com/words.php/t/Smart%20Glass/
[490] Ibid., 1.
[491] Bernard Grehant, *Acoustics in Buildings*, Thomas Telford Publishing, London, 1996, 267.

identifies several operational functions these façades can perform, like the enhancement or maximisation of daylight, protection from the sun, insulation, ventilation, the collection or rejection of heat, the attenuation of sound, the generation of electricity and the exploitation of pressure differentials.[492] This strict functional approach towards active façades is the legacy of a Modernistic concept of mechanization in its various aspects, such as objectivity, consequentiality, prefabrication, mass-production, etc., which dominated as a basic space model of the functionalist architecture in the 1920s. As a result of an ongoing technological development the definition of the *active façade* can be extended to digital façades augmented with different computer controllable light arrays and kinetic devices that have interactive characteristics. Such characteristics can present the socially conceptualised activity that is not limited to changing uses of the façade or reaction to the weather conditions. This can be achieved through a conversation, in cybernetic terms, with the façade's environment and /or people in the close surrounding. Potential interaction can have two levels of directness, the first can happen by sending messages, graphics of video over the Internet or via mobile phones to be displayed on the façade and the result of this interaction is displayed after filtering. A second mode of interaction can occur in a more direct manner through body movement, gestures and sounds.

An important quality in case of digital façades that do not have a physically or technologically formalised structure is the content these façades emit into public space. As the theorist of urban screens Mirjam Struppek notes, content needs to be coordinated with new visions that promote innovative ways in which digital façades are materialised and the specific locations these can be integrated in the urban landscape and its architecture. An interaction that occurs between digital façade and potential participants depends on the balance between content, location and type of façade created. The meaningful proportion of the three can also prevent noise and visual pollution.[493] The essential knowledge that needs to be accumulated is regarding our understanding of the possible perceptional influences digital façades have on the public spaces' visual sphere. This implies development of diverse modes of interaction of digital façades that will apply social interaction in a meaningful way. The omnipresent and emerging culture of *urban screens* must be carefully re-examined regarding the necessity, visual presence

[492] Michael Wigginton and Jude Harris, *Intelligent Skins*, Architectural Press, Elsevier, Oxford and Woburn, MA, 2002, 36.
[493] Struppek, “Urban Screens”, 14.

and the quantity of screen-like surfaces in the urban context.

The potential problem regarding façades that incorporate features of the so called *TV effect* is in their mesmeric influence on the observer and creation of the specific mental state of mind that can influence orientation and coordination in space. Instead of developments in the direction of screen culture, more interesting explorations can be made if the cybernetic relations toward environment are examined further. The façades that operate as kinetically facilitated systems generate more freedom in formal and interactive potentials than their screen-like-surface equivalents. The potential goal is a new mode of interaction in such an environment that is interactive in its entirety. When the entire environment becomes an interactive environment that can mediate specific conditions regarding its participants and at the same time can intercede in conditions outside the environment, this kind of environment must facilitate communication through physical space itself. In this way the physical structure and communicative character of a building become inseparable.

It can be concluded that the main objective in this chapter is an analysis of dynamic digital façades that through different material modalities can inspire a developing range of possibilities to transmit into and influence their environment. Through this transition of material properties, the digital façade's dominance over the public space is substantially more direct and instantaneous. The most apparent transformation of public space materialises through the introduction of screens. As McQuire notes, one of the most visible tendencies of contemporary urbanism has become the migration of electronic screens into the external cityscape.[494] Considering that streetscapes and public squares within cities are layered with digital infrastructure, it is a great challenge to broaden the use of these *moving billboards*, as Lev Manovich calls them, instead of flooding urban space with new techno-objects.[495] The development of these new techno-objects within architecture is usually dictated by industry because of the high costs of their realization. More imaginative and cultural concepts of digital façades are realised in ways which in their material finalisation avoids a so called *TV effect*, or in façades that are created by completely other means than those of a TV screen, as discussed further below.

[494] S. McQuire, "The Politics of Public Space in the Media City" in "Urban Screens: Discovering the potential of outdoor screens for urban society", First Monday Special Issue No 4 (February 2006), http://www.firstmonday.org, quoted in Struppek, "Urban Screens", 16.
[495] Struppek, "Urban Screens", 16.

4.1 Cybernetic Virtuality[496] – *Tower of Winds*

Figure 4.0: *Tower of Winds*, Toyo Ito, Yokohama, Japan, 1986.

The analysis starts with Toyo Ito's project *Tower of Winds* located in front of Yokohama station in Japan. This building was finished in 1986. Ito's main tendency in his architecture is the creation of conceptually advanced buildings in which he searches for a fusion of physical and virtual worlds. The virtuality of Ito's projects, such as his *Tower of Winds* among others, addresses the contemporary notion of a *simulated* city, Ito's principal architectural concept, readily recognised in his work.[497] In order to achieve this concept *Tower of Winds* introduced other media, such as the digital, into the materialisation of the Tower's façade, as shown on figure 4.0 above. Ito achieved this by converting the wind into light in order to map the cityscape through sound in such a way that the tower appears to dematerialise at the moment when the level of surrounding sounds is lower than required for the sound sensors to detect them. In this moment, the lights on the façade are off. The wind-speed and direction affect the light pattern at night. When the ambient noise levels again reach the point of detection the tower re-appears in the cityscape through the play of light controlled by the computer.[498]

[496] The term 'Virtuality' refers to the concept of the third wave of cybernetics as distinguished by K. Hayles and as discussed in the second chapter.
[497] Toyo Ito, "Architecture in a Simulated City" in K. Gerbel and P. Weibel (eds.), *Intelligent Environments*, Ars Electronica 1994, Vol. 1, PVS Verleger, Vienna, 1994, 84-91.
[498] Ulrich Schneider et al., *Toyo Ito: Blurring Architecture 1971-2005 – Rethinking the Relationship Between Architecture and the Media*, Edizioni Charta Srl, 2000, 86.

The building is in the shape of a cylinder and the façade is enclosed by circular neon lights. During the night, the activation of different parameters, such as noise levels and wind speed and direction as mentioned previously, switch the light of the neon rings on and off, in this way, producing beautiful light patterns that give an uncanny connection to other phenomena in the area, highlighting one's sensation of the city.

Ito's *Tower of Winds* does not use much in the way of high technology but implements technology in a clever and creative manner. He finds a playful way to set in motion the boundary between sheltered and unsheltered space and to change the notion of the architectural wall. This boundary can extend and distort our notions of reality and ourselves, bringing new modes of consciousness about our environment. As A. Sergio and A. Bdeir suggest, when our focus shifts from the inertness of material culture and the stasis that is inevitably bounded with architecture and moves towards to the perception of motion, that is from inactive to the responsive, or from static to kinetic space, our perception of embodiment will change as well.[499] Ito does not create a kinetic façade that produces such motion but rather makes a façade that translates this motion into a different visual medium. In this way Ito changes our perception of the object and the space around it. This is an important aspect for architecture because it implies a new artistic language that can be established within architecture, something partly lost during Modernism and the reduction of form to mechanistic functionality.

According to J. Pallasmaa, the language of art is actually the language of symbols that can find an identification with our existence.[500] This means that the experience of art or architecture is in the interaction between our embodied memories and our surroundings. In an architectural context of use this is related to Aldo Rossi's notion of memory embedded into an object.[501] For Pallasmaa, it is essential that an experience of architectural meaning and sense that the effect of the building should find a counterpart in the world of the viewer's experience. Pallasmaa considers architecture as a direct expression of human existence which is mostly based on the language of the body. In these terms, digital façades gain an artistic character through transformations of symbolic meaning triggering different people's experiences of buildings through their

[499] A. Sergio and A. Bdeir, "KINET: Towards Animated Architecture Through Responsive Modular Walls" in *Game Set and Match II*, 370.
[500] Juhani Pallasmaa, "The Geometry of Feeling: A Look at the Phenomenology of Architecture" in Kate Nesbitt (ed.), *Theorizing a New Agenda for Architecture: Anthology of Architectural Theory 1965-1995*, Princeton Architectural Press, New York, 1996, 450.
[501] Rossi, *The Architecture of the City*, 24.

façades. In this way, digital façades become signs of culture and points of reference in the landscape. Digitization provides an opportunity for layering meaning over the traditionally conceptualised façade and so changing the notions of a building's materiality, as discussed in the first chapter. Following from this, the modalities of the digital façade's impact on public space within cities will be discussed in the next section.

4.1.1 Digitization of Cities

When discussing such phenomena within the city, Ito makes a distinction between the *body of mechanistic modernism*[502] and the *body of electronic modernism*[503]. Ito explains that contemporary life takes place in two completely separate cities. One to which the living biological body adapts and the other in which an extended body produced by the electronic networks coexist. The question that he poses is whether an architect can provide the invisible city of electronic networks with a visible image and whether this image can be recorded in the city of living experience to which the body adapts. For this he gives examples, such as the *Ville Contemporaine Pour Trois Millions Habitants* by Le Corbusier or the *Friedrichstrassen Project* by Mies van der Rohe. This remains a very interesting question because of the general unawareness of the new informational layers that have overlaid cities in the last couple of decades as a result of developing technologies.

In order to understand the level of complexity digital technologies have introduced within cities, besides the inherited one that is a result of its physical or built structure, we will discuss this process further. Stephen Graham and Simon Marvin discuss about this issues in their book “Splintering Urbanism” in which they refer to a modern urbanism *as an extraordinarily complex and dynamic socio-technical process.*[504] They see the city in a constant flux that is composed of numerous infrastructural *landscapes,* that are layered and interconnected and in competition with each other. These landscapes present intercessors between culture, nature and what they call *the production of the city*.[505] They have different qualities relational to the function they perform: *electropolis* concerned with energy and power, *informational* or *cybercity*

[502] Schneider et al., *Toyo Ito*, 55.
[503] Ibid., 55.
[504] Stephen Graham and Simon Marvin, *Splintering Urbanism*, Routledge, London, 2001, 7.
[505] Ibid., 8.

representing electronic communication, *hydropolis* that refers to water and waste, *autocity* involved with motorised roadscapes, etc. For them, they are only physically separated but not autonomous and rely on each other in their correlative co-evolution through urban development and with constantly evolving urban space.

According to Graham and Marvin a city, as a complex system, consists of other systems, all with their respective functionality which provide the possibility for a specific service and distinctive operational modules of a city. These systems are not grouped within a city but fragmented into components or nodes that formally occupy a space. At the same time, they are rather dispersed and fluid, layering a city with complex relationships, aspects and processes. Their interpretation of these *landscapes* refers to the ongoing technical processes existing in the city in its everyday life, which present a kind of a software that operates beneath the built structure of cities. Technical processes present only one aspect necessary for a city to function, with a diversity of layers between them. A different kind are social processes, happening parallel to the technical ones within a city but are not necessarily connected with the operational aspects of the city's unimpeded functioning and development. These processes are equally important for a city because they determine diverse relationships between inhabitants and signify different modes of interaction provided by different digitized means of communication. These social processes are related to Arjun Appadurai's idea of scapes.

The term *scape*[506] indicates that cultural flow is a theoretical model that can be apprehended as a *perspectival construct* rather than fixed one. Appadurai distinguishes five *scapes*: *ethnoscapes*, which are people in motion, immigrants, tourists, refugees; *mediascapes*, which are media images of the world; *technoscapes*, which are transboarder communications; *financescapes*, which are global flows of capital and *ideoscapes*, which are conflicts between state and non-state ideologies. His differentiation of the *scapes* proposes a spatial interpretation of the present in an alternative way. An alternative for Appadurai is a scape that is not *fixed* and of various and disjunctive sizes, one that is flowing and amorphous, which can be in opposition with a typical understanding of a landscape as static and determined. Appadurai

[506] Arjun Appadurai, "Disjuncture and Difference in the Global Cultural Economy" in Mike Featherstone (ed.), *Global Culture*, Sage Publications, Ltd., London, 1990, 295.

illustrates scapes as *building blocks* of contemporary imagined worlds. An important point about such scapes is that they show a world in which is not possible for economy, culture and politics to peacefully coexist together. It is the disjunctures between these elements that facilitate global flows. These disjunctures between *scapes* do not imply the absence of logic or pattern but imply that the traditional spatial models for understanding the link between the *scapes* will not be helpful. The events that determine the scapes appear regularly and are simultaneously spatially extended and temporally accelerated. The spatial links and borders between different events become blurred and elongated while the temporal links happen very quick and disappear before it is possible to study them.

The generic example Appadurai gives are the new kinds of relations established by means of media flows that bring the feeling of closeness and connection with people we may be intimately connected with.[507] Here he refers to people who migrated from their home countries in search for work and better living conditions and are in contact with their friends and family through means of digital technologies, such as the Internet. Appadurai points towards new and more abstract kinds of scapes, closely related to social and cultural changes emerging everywhere under the influence of technology. These changes are reflected at all levels of living, through exchange of digital images, plans and projects between the diasporic populations creating, what Appadurai calls, *diasporic public sphere*. It can be said that media flows also influence changes in the ways in which spatial understanding was formed so far, which concerns change in the typology of buildings for example. Appadurai considers imagination to be the means by which individuals connect with these new global opportunities. The difference between Appadurai's concept of *scapes* and Graham and Marvin's concept of *landscapes* is in their physicality or materiality.

While Graham and Marvin describe the relationships between physical infrastructural elements that are more static in nature because of their fixed purpose, Appadurai points out more impalpable and diverse elements that determine spatial relationships. Both concepts are inseparable from the city and both contain multiple layers of performance. The combination of the two concepts presents the potentially futuristic representation of

[507] Translocation_New Media/Art: Modernity at Large, Interview 1999 with Arjun Appadurai by Anette Baldauf and Christian Hoeller, 2, Retrieved January 22, 2010, from http://www.arjunappadurai.org/translocation_new-mediaart-modernity-at-large-appadurai-interview-1999/

the different ways people will relate with build structures of the cities. Wider understanding and more creative implementations of digital façades can make some propositions towards bridging the gap between the alienation of the people and their habitats. This may be achieved by intuitive engagement through a meaningful content that will be introduced into the digital façade's performance. In this way, façades are created to be open for interaction and participation reflecting the potential to establish a relationship with city's inhabitants. One mode of such development are *open participating platforms*, as discussed further on in the chapter. Another mode of materialisation can be as *interactive urban artifacts* that contribute to rejuvenation of undeveloped parts of cities. These are only a couple of kinds of implementation in which digital façades can occur as meaningful cultural sites of cities. In order to understand digital façades as urban artifacts that can transform public space through meaningful content it is necessary to point out their skeuomorphic qualities.

4.1.2 Transition of Materiality Through Skeuomorphism

Making landscapes, such as those of the informational or cybercity, and scapes, such as mediascapes or technoscapes, visible became possible because of the accelerating development rate of communication engineering and computer technology and through the digitization of once analogue objects and processes. A problem that remains is in the ideas that, instead of being innovative, linger in the loop of constant reprocessing. This results in the improvement of old technologies and their adjustment in order that the new digital objects obtain faster responsiveness and gain smaller size but without meaningful conceptual development. These objects can be referred to as skeuomorphs. This term relates to V. Gordon Childe's conception of skeuomorphism, who describes it as *the manufacture of vessels in one material intended to evoke the appearance of vessels regularly made in another*[508] who cites his attribution of the term to Sir John Myres. In Nicholas Gessler's interpretation of skeuomorphs, they can be regarded as material metaphors that are represented through technologies in artifacts. They can supply familiar clues to an unfamiliar domain, which can result in stipulation of either the correct guidance or a complete deviation from the proper direction of use and understanding. In Gessler's opinion computational methods are abundant with a number

[508] V. G. Childe, *Piecing Together the Past: The Interpretation of Archaeological Data*, London, 1956, p. 13, cited in Michael Vickers and David Gill, *Artful Crafts: Ancient Greek Silverware and Pottery*, Clarendon Press, Oxford, UK, 1996, pp. 106-107. Childe attributes the term ' skeuomorph' to Sir John Myres.

of these structures revived from the past practices and adopted from analogies in non-computational domains.[509] They can present informational attributes of artefacts that accommodate clues in the browsing of the unfamiliar territory. Skeuomorphs can be the means of developing the new structures onto the old ones and in the process it can be possible to find a starting point to commence and mentally create additional alternative solutions. Katherine Hayles relates the term to a design feature that is not functional in itself in the present time but refers to a time in the past when it was functional.[510] For Hayles, they present a social and psychological tendency towards innovation that is reduced to a simplified representational quality of replication. In the history of cybernetics skeuomorphs acted as threshold devices smoothing the transition between one conceptual constellation to another and are deeply characteristic of the evolution of concepts and artifacts. This can be related to one of the underlying constructs of skeuomorphs and that is the concept of *remediation*, discussed further.

4.1.3 Digital Façades as Extensions of the Architectural Medium

The practical implementation of the concept of remediation can be found in the digital façades and has been a focus of discussion among media theorists for the last decade. This discussion revolves more specifically around the influence of new media on culture in general and on the relation towards the already existing media in particular. The root of the concept of remediation can be found in Marshal McLuhan's view that *the content of any medium is always another medium*,[511] by which can be interpreted that the content of the medium is not as important as the medium itself. This is arguably a pretentious statement that excludes people's needs for meaningful interaction. But the position is more subtle in that in McLuhan's example of the light bulb as a medium without content that provides ground for social encounters to happen during night, which is his proof that the medium effects society not through the content it delivers but though the medium itself. Regarding the interaction with the medium, Bolter and Grusin argue that the immediacy of interaction is potentially the point beyond mediation. In their elaboration of immediacy they emphasise that it is necessary to have a contact point between the medium and what it represents.[512] This connection between the

[509] Nicholas Gessler, "Skeuomorphs and Cultural Algorithms" in *Lecture Notes in Computer Science, Proceedings on the 7th International Conference on Evolutionary Programming VII*, Springer - Verlag, Berlin and Heidelberg, 1998, 229-238.
[510] Hayles, *How We Became Posthuman*, 17.
[511] McLuhan, *Undestanding Media*, 7.
[512] Jay David Bolter and Richard Grusin, *Remediation: Understanding New Media*, MIT Press, Cambridge,

medium and the what it represents can be individual. This can imply that the connection can be established through different modes of interaction, which, in the case of digital façades, can be reflected through diverse modes of materialisation. This kind of interaction can foster a sense of presence in a participant, which Bolter and Grusin argue as important through an example of virtual reality.

In McLuhan's case the concept of remediation is an attempt to bridge the differences between the traditional printed book by transforming it from within rather than replacing it by a new medium. McLuhan's aims were to create a new writing space corresponding to the electronic sphere formed through unification rather than segmentation, by simultaneity and not continuity, by involvement rather than detachment, outlined by rhythm and change and not by monotony and repetition, etc.[513] At first glance McLuhan's argument tends towards affirming the meaningless production of digital devices that have no effects except the superficial ones that Hayles refers to as guided towards replication. Nonetheless, if interpreted more carefully they can also point out towards the events happening around these artifacts as those that deserve full attention. In this respect, the materiality of a built structure and more specifically the building's façade can present a base for a skeuomorphism to happen because of the inherited logic according to which building's façades are designed through architectural history. Façade walls, as those that communicate a building's character, have the capacity to obtain new qualities through the digitization of their materiality, which can influence the experience of the building in its environment and provoke different reactions. Cybernetic mutualism can introduce new digital aesthetic qualities that, through software, provide physical entities with distinct characteristics.

In this regard, digital façades have the capacity for remediation in terms of event creation provoking participation by different individuals and/or social groups. At the same time, they can be regarded as skeuomorphs because of their capacity to communicate intentions and carry historically transmitted resemblances to the façades of the past with the possibility to remediate these elements in new digital forms. One way to achieve this may be that different elements, ornamental components and decorations that present constitutional elements of the façade can be remediated through

Massachusetts, 2000, 30.

[513] Jan Baetens, “Looking at McLuhan 'Remediation', Iconophobia and Denial of the Body in The Medium is the Massage”, *Image & Narrative Online magazine of the Visual Narrative*, Issue number 5: 'The Uncanny', January 2003, 1.

images. This kind of façade treatment happened in the past with application of mosaic and stucco techniques and introduction of mural walls as means of expression, as discussed in the first chapter. These modalities represent a façade's transition of materiality through layering of two-dimensional representation onto an exterior wall. In case of some digital façades, which belong to a category of superficial attempts to replicate the visual resemblances of fashioned images either through advertisements or other trivial content, they miss the opportunity to become culturally significant structures that will provide engaged relationship with the inhabitants of these buildings and create events around them. Instead of being advertisement billboards, digital façades can reflect different cultural *scapes,* in the sense that Appadurai uses the term, and mark transitions between different processes that appear in society. An example of such a conceptually strong cultural significance is digital façade of the Institute du Monde Arabe discussed in the next section.

4.2 Dynamic Patterns – *Institute du Monde Arabe*

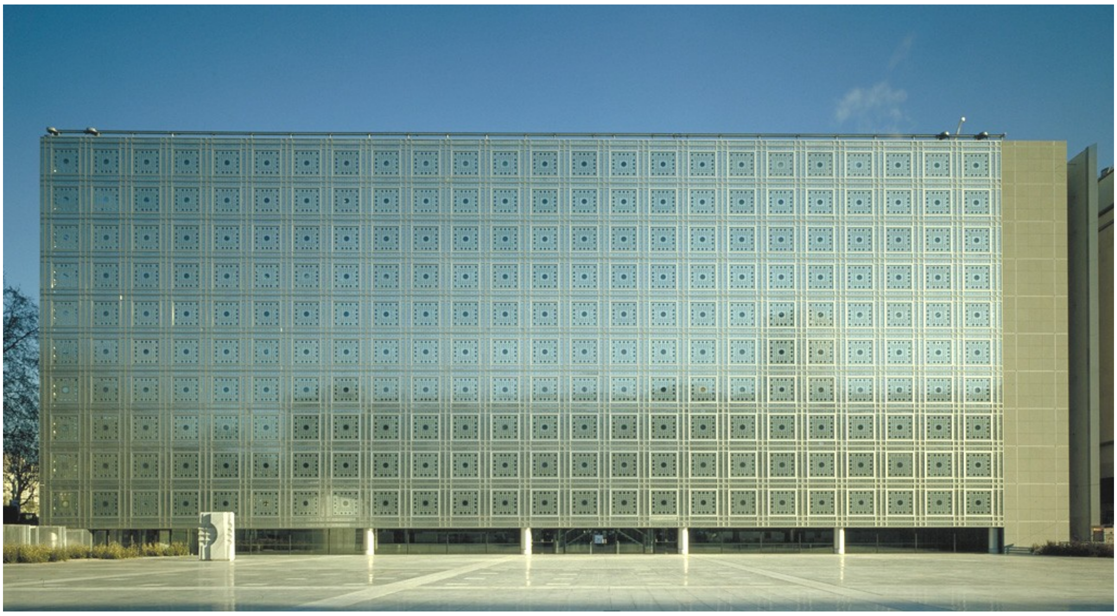


Figure 4.1: *Institute du Monde Arabe*, South façade, Jean Nouvel, Paris, France, 1981-1987.

The next example of culturally significant digital façades is *Institute du Monde Arabe* in Paris, France by Jean Nouvel constructed from 1981-1987. This building is one of the Francois Mitterand's Grand Projects for representing France as twentieth century centre for art, world economy and politics. The concept the building reflects is the French affiliation with Arab culture, realised through the building's façade, exhibition spaces, library and other spaces. In these terms, *Institute du Monde Arabe* represents a cultural landmark. The building's formal composition consists of two parts, one which follows the curve of the motor route next to the Seine and the other, which has a simple and minimal rectangular form, the façade of which contains a kinetically interactive façade, as shown in figure 4.1 above. The archetypal elements of traditional Arab architecture are highlighted in the building's concept, and these are: the treatment of light by means of frames and filters, an accent on the interior of the building and the overlaying of grids. This is particularly delineated on the south façade facing the rectangular horizontal open area which contains one large flat glass surface with aluminium framing located on the interior side of the façade.[514] The aluminium frames contain deconstructed and kinetically interpreted theme of the Arabic arabesque and Islamic geometrics and mechanisms, as shown in figure 4.2 below.

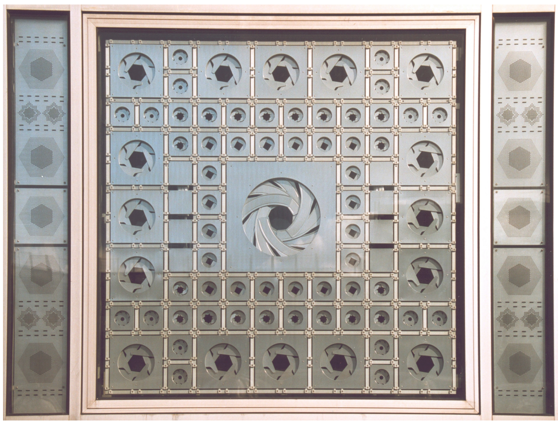


Figure 4.2: Façade detail

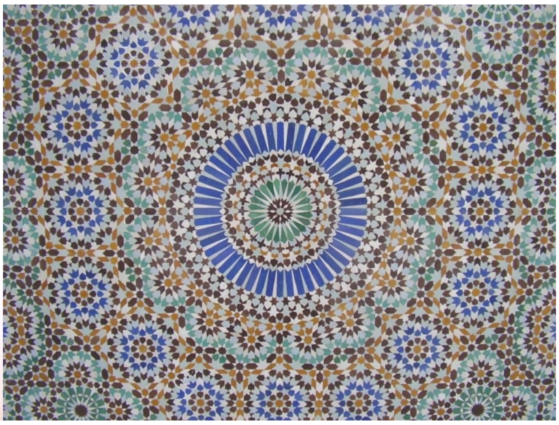


Figure 4.3: An example of geometric arabesque

The basic formal definition of an *arabesque* is that it is a bifurcated shape extending out from a curving root. Art historian Ernst Kuhnel writes that the idea behind the creation of the arabesque is one of a vegetable theme. And just as branches turn to form unnatural waves and spirals, so do leaves branch and split into forms that do not occur in nature.[515] Kuhnel's perception of an arabesque was that of an aesthetic asceticism.[516] The origin of the arabesque lies in the style known as Samarra style, which is characterised by the repetition of curved lines without identifiable foreground or

[514] Jean Nouvel, Emmanuel Cattani et Associes, *Nouvel*, Artemis arc en reve centre d'architecture (ICA), Artemis Verlags AG, Zürich, München and London, 1992, 35.
[515] Ernst Kühnel, *The Arabesque: Meaning and Transformation of an Ornament*, Verlag für Sammler, Graz, Austria, 1977, 5.
[516] Doris Behrens-Abouseif, *Beauty in Arabic Culture*, C. H. Beck'sche Verlagsbuchhandlung, Munich, 1998, 145.

background. In this way the abstract motifs were produced with an ornamental effect, with lines playing the major role. The relationship and interplay between the lines creates an image where subject and background are interchangeable according to the viewer's wondering of the eye. An addition to the poetic imagery is an absence of thematic hierarchy. Other motifs, such as the shell, the Sun, etc., were stylised besides plants. In this case stylization was based on giving these motif patterns a geometric interpretation. In some cases arabesques were combined with Islamic geometrics. The relation between the two is in the constructive combination of the two different graphical styles. While Islamic geometrics consist of reticular straight lines forming endless star patterns, arabesque is an interlacing of curved lines representing stylized vegetable motifs forming polygonal figures,[517] as shown in figure 4.3 above.

The kinds of motifs used for this geometric standardization, absence of thematic hierarchy and mode of pattern translation are significant components of the poetic qualities of arabesques, also because the poetic thematics of these objects that have also been standardised, determining their cultural symbolism and aesthetics. As M. Alexenberg states, such symbolic art represents ideas or things through usage of signs that are assigned meaning maintained by convention. The convention is determined by the agreement of the community. Dissimilar to an icon that bears the likeness to that which it signifies, a symbol does not have such a direct or necessary connection.[518] In regard to its traditional significance therefore the treatment of the Institute du Monde Arabe's façade surface makes an interesting conceptualisation of the conventional arabesque motifs translated to the modern language of digitised ambiguity. Façade's concept by means of this intriguing interaction between tradition and technology obtains a strong cultural connotation. The importance of this connotation is in the meaning and poetry of arabesque translated from the traditional two-dimensional form to the interactive and dynamic pattern.

At time it was made, this façade represented a unique use of high-tech photosensitive mechanical devices used to control light levels and transparency, and was an achievement in the field of kinetic art. Historically, the root of the technological developments of mechanisms related to concepts examined in the example of the kinetic

[517] Ibid., 146.
[518] Mel Alexenberg, *The Future of Art in a Digital Age: From Hellenistic to Hebraic Consciousness*, Intellect Books Ltd., Bristol, UK, 2006, 38.

geometrical arabesque mechanism of Institute du Monde Arabe's façade, can be found in the form of human or animal-like *automatons* or self-operating machines*,* which are known from the Mediaeval times and discussed in the following section.

4.2.1 Early Automata Mechanisms

Although automatons can be regarded as more adequate references for the field of robotics, in the case of digital façades this relation is important because it exemplifies the level of abstraction that can be achieved with such mechanisms. If the basic functional principles and different modes of mechanical operation of these self-operating machines can be extrapolated and applied to digital façades with a kinetic character, new modes of digital façade composition can be initiated. Medieval engineers, like Villard de Honnecourt in the fifteenth century, created early sketches of animal automatons.[519] Further, we can consider the work of Giacomo Fontana (1393-1455)[520] from the period of the Renaissance artist-technician and the contemporary of Brunellesco (1377-1446). Fontana and Brunelleschi were part of the Italian school and were interested in the *theatre of machines* concerned with hydraulic matters, fountains and water channels. Fontana created sketches for automata that used rope/string transmission, according to the drawings found in his notebook. [521] Another man that made a substantial contribution in this field is Francesco di Giorgio Martini (1439-1534) who was a sculptor, architect and military engineer. Most of his contributions were in the field of hydraulic machines, early conceptualisations of the first *automobile* vehicle, clocks, lifting apparatuses, pile drivers, etc.[522] Leonardo da Vinci (1452-1519) was a contemporary with Francesco di Giorgio Martini's pupils.[523] From the tremendous opus of his work in many fields Leonardo contributed to the development of automata in their property of being a mechanical reproduction of nature as in his studies for a flying machine, a walking mechanical lion, and a humanoid automaton, designed by da Vinci in 1495.[524] Da Vinci's automaton is a knight wearing Italian-German armour traditional to the time it was conceived, as illustrated in figure 4.4 below. The automaton was actually produced much later and had the capability to walk, sit and

[519] Bertrand Gille, *The Renaissance Engineers*, Lund Humphries/London, 1966, 27.
[520] This is only an approximate estimation of Giacomo Fontana's biographical details. There is not enough evidence for more precise determination of the exact years.
[521] Gille, *The Renaissance Engineers*, 81.
[522] Ibid., 101-120.
[523] Ibid., 122.
[524] Mark Elling Rosheim, *Leonardo's Lost Robots*, Springer – Verlag, Berlin and Heidelberg, 2006, 69-108.

stand, to raise its arms, move its head from side to side and open and close its mouth.

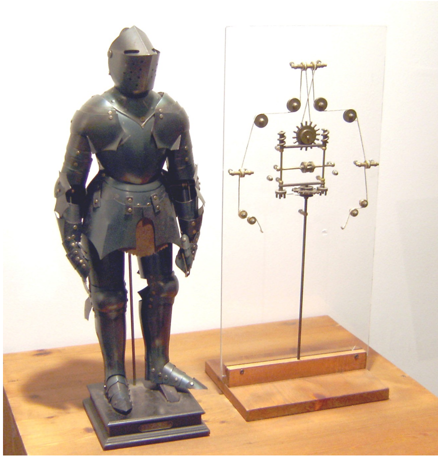


Figure 4.4: Model of Leonardo da Vinci's humanoid automaton, 1495.

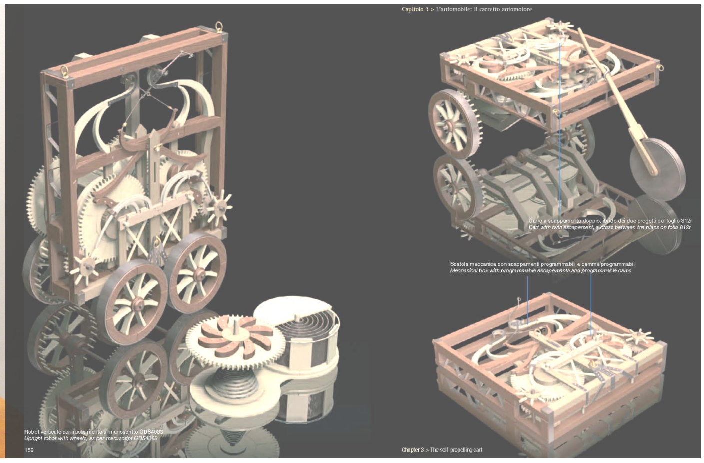


Figure 4.5: Model of Leonardo da Vinci's self-propelled vehicle, 1478.

An interesting premise in this regard is not in the formal representational qualities of automatons but in the formulation of processes which, in physically developed mechanisms, can imitate a movement. For the imitation of movement an artist-technician used different kinds of mechanical elements, such as gears, cranks, ratchets or pulleys and the automaton commonly consisted of their combination. Further on in the list of Leonardo's inventions, another important one is a self-propelled vehicle in 1478, shown in figure 4.5 above. This design is significant because it is considered to be the first programmable computational machine. It is considered computational machine because it had programmable steering and a brake that could be released at distance by an operator with a hidden rope. It was designed to operate independently and could travel for around 40 meters in a self-sustainable manner.[525] This short historical overview of Medieval automata development is important because of their potential self-operating principle and the significance of this concept for development of later cybernetic principles of self-reproducing automata[526] and influence on the development of concepts for digital façade design with kinetic character. The connection with digital façades is also seen in the resultant dynamic mechanical principles that were essential elements in the conception of the movement of the façade's components.

The previously described automaton's mechanisms can present a base for the operational logic of mechanical instrumentation applied on the Institutes façade with the

[525] Ibid., 22.
[526] John Von Neumann in Arthur Walter Burks (ed.), *Theory of Self-Reproducing Automata*, University of Illinois Press, Urbana, Illinois, 1966, 58.

difference that the movement of the automatic optical lenses is controlled by a computer. The mechanical quality and the materials chosen for construction of the façade's mechanism render a very distinct aesthetics that suggests a resemblance to the familiar and an outlook towards the novel. The aesthetic attributes of the steel used for production of the mechanism give the façade a connection with traditional craftsmanship, such as the crafting of clock mechanisms, which combined with a glass surface arranged into a modular composition, suggests a connection with modern materials. The design process employed in creation of the Institutes façade and the connection with the cultural heritage materialised in the dynamic pattern gives the façade a distinct aesthetic. The intelligence of this façade lies in this interesting combination of formal aesthetics and functional mechanics. Formal aesthetics is reflected in geometric forms of the patterns, their composition and materialisation, while the functional mechanics implies the digitization of the façade and the obtained dynamic quality of its elements. Interactivity of the façade is the link between the two that creates a dialogue between the inside and outside, the sheltered and unsheltered space. The digitization of the façade's materiality is achieved through implementation of a software instrumentation of the façade's movement regulation. Because of the absence of natural agents in the interaction process this façade cannot be characterised as exhibiting cybernetic mutualism. In this regard and in order to understand the evolution of automata, it is interesting to address the digital interpretations of the principles of automata.

4.2.2 The Principles of Digital Automata

The principle of the Mediaeval automaton's function or their applied mechanisms present simple assemblages of elements composed in regard to the basic physical laws. Even the most complex machine can be based on a few of those core mechanical principles. These principles can be divided into six main categories: cams, cranks, gears, ratchets, levers and pulleys. Nowadays, machines and automata are constructed from well known dynamic elements, such as sensors, switches, valves, relays, wires, wheels, modulators, amplifiers, etc. Machines, devices and automata can be built out of these elements if appropriately chosen and connected.[527] The base for modern application of automata was given by John von Neumann who speculated on the possibility to

[527] Tibor Ganti (ed.), *The Principles of Life*, Oxford Biology, Oxford University Press Inc., New York, 2003, 121.

construct artificial self-reproducing automata. Besides the Turing machine, his source of inspiration was the paper "A Logical Calculus of the Ideas Immanent in Nervous Activity" by cyberneticians Warren McCulloch and Walter Pitts.[528] Development of Von Neumann's idea resulted in the digital conceptualisation of cellular automata. Regarding the design of digital façades, it can be said that the idea of mechanical correspondence and interchangeable dependency between different elements or units in a system can be recognised in their creation.

For Gessler, cellular automata illustrate individual actors that operate under individual local rules. Collective global patterns of behaviour can be automatically produced by these individual actors and the patterns can emerge entirely through their mutual interactions. The important aspect of cellular automata is that the global patterns of behaviour are not programmed into the simulation and have no existence within the individual actors. Instead they appear through the process of system's operation. According to Gessler a number of similar processes occur in culture as well.[529] An interesting example of the cultural implementation of the cellular automata is the project *The Human Cellular Automata* by Matthew Fuller in which each cell is portrayed by a person.[530] Through the application of predetermined rules each person performs two states, actions of being *dead* or *alive*. Through the performance dynamic patterns are formed. An important aspect of the cellular automata are the relationships cells have between themselves and the interactive qualities realized through their performance.

If applied in the conception of architectural spaces, the concept of cellular automata can provide a more liberated understanding of spatial relationships and people's interaction with them, that can unfold new, fresh and playful methods for construction. In an architectural context, interesting examples of application of cellular automata principles may be the building's construction methods influencing the continuous change in the building's structure, (in line with Buckminster Fuller's ideas discussed in the first chapter and Cedric Price's ideas discussed in the second chapter), or in the conception of the building's programme influencing the application of interactive attributes to the

528 John Avery, *Information Theory and Evolution*, World Scientific Publishing Co. Pte. Ltd., Singapore, New York and London, 2003, 165-166.
529 Nicholas Gessler, "Artificial Culture" in Rodney Brooks and Pattie Maes (eds.), *Artificial Life IV*, MIT Press, Cambridge, 1994, 432.
530 Matthew Fuller, "The Human Cellular Automata", performed at Software Summer School, TechNiks, London and 2000 Wisards of OS 2, Berlin, 2001, Retrieved January 29, 2009, from http://www.spc.org/fuller/projects/the-human-cellular-automata/.

physical spatial characteristics. These interactive attributes of digital façades are discussed in the next section.

4.2.3 Digital Façade's Modes of Interaction

Concerning the Institute du Monde Arabe, the use of interior spaces in Arab culture, which are renowned for implementation of the light through various application of semi-transparent arabesque craft work on the partition walls as well as their façades, was an addition to the witty solution for this façade.[531] The arabesque can change according to the amount of light insulating the building, resulting in the lively play of light and an interior space that is always different because the amount of light is never the same. This façade can be compared with the *Aegis Hyposurface* project by dECOi architects, discussed below, that came some years later and the *KINET* project done at Massachusetts Institute of Technology, Cambridge, USA, in their Computation and Design department and Computing Culture Group, Media Lab.[532] These structures present interactive systems that, as Usman Haque puts it, in order to be genuinely *interactive*, work with a definition of interaction as circular and not merely as *reacting*. A truly interactive system for Haque is a multiple-loop system in which one enters into a conversation or a continual and constructive information exchange.[533] This kind of interactive architecture started appearing in the 1990's when the long history of kinetics in architecture began to be re-examined regarding the postulate that performance could be optimised if it could use computational information and processing to control physical adaptation in new ways to respond to contemporary culture.[534] The base for the research in this field can be found in the work of Gordon Pask.

In the 1960s Gordon Pask and other cyberneticians made distinct progress toward understanding and identifying the field of interactive architecture, as discussed in the second chapter.[535] According to Pask, who during 1970s and 1980s collaborated with a number of architects, an interactive environment should not strictly interpret our desires but instead should allow the users or participants, as Haque addresses them, to take a bottom-up role in configuring their surroundings in a tractable way without specific

531 Nouvel et Associates, *Nouvel*, 35.
532 Kinetic Design Group, Retrieved February 05, 2010, from http://www.robotecture.com/kdg/project.html.
533 Usman Haque, "Architecture, Interactions, Systems" in *AU: Arquitetura & Urbanismo*, Number 149, August 2006, 27.
534 Fox and Kemp, *Interactive Architecture*, 13-14.
535 Ibid., 14.

goals.[536] During this time Pask formulated a *conversation theory*[537] that at the time served as the basis for some developments in the field of interactive architecture because, later, the process of *conversation* Pask refined into a theory of interaction. Regarding this, projects such as the Institute du Monde Arabe or Aegis Hyposurface can be considered as representatives of a specific stream in the field of interactive kinetic architectural walls. Developments of this kinds of walls may be categorised into the dynamic walls that deal with a) motion as a reaction to the weather conditions (wind, light/insulation, rain, temperature, etc.); b) motion as a reaction to body movement or a sound and c) motion as an transient effect, fluid random vibration, interpreting liquid like effects, etc. The downside of this kind of experiment within architecture is that through time, if not properly maintained they stop operating. As is the case with the light responsive kinetic pattern on the Institute du Monde Arabe's façade which is no longer functional. In other instances, where interactive architectural elements and spaces are used as pavilion structures to exemplify certain ideas, such as Fresh *Water Pavilion* by NOX Architects discussed in the second chapter, they get to be dismantled.

Digital façades reflect the inevitable condition of change introduced by the new constructs of society and culture and with constant movements and exchange among the two. This is greatly in opposition to traditional conception of architecture that was built for stability inside the social structures by using static materials without an attempt to achieve something else than durability and in some cases even eternity. Conceptually and instrumentally digital design technologies magnified the abstract space of design and made the gap between the freedom and fluidity of thought and what practically can be drawn on paper or computer smaller. Consequentially, a new notion of space is created, a space that does not consist of opaque elements that are there to protect and enclose our bodies but a space that performs, adjusts, alters and moves. The wall becomes an active intervention in space, like a moving canvas for a painter. The inhabitant of such a non-defined space is at the same time the actor and the spectator because his actions influence the change the space is going through, the space adjusts and shapes under the hand and mind of the inhabitant. In this new situation, by provoking human interaction, usually neutral and constant parts of the architectural materiality become a platform for a new relation between human body and architectural

[536] Pask, “Architectural Relevance of Cybernetics” in *CyberReader*, 76-82.
[537] Gordon Pask, *Conversation, Cognition and Learning: A Cybernetic Theory and Methodology*, Elsevier, New York, 1975, 78.

space forming a new dialogue between the two. This dialogue with the environment is possible to achieve through the meaningful content emitted into the cultural landscape with digital façades as integral part of it, as discussed in the next section.

4.3 Cultural Landscape With Content – *The KPN building*

Figure 4.6: *KPN building* , Renzo Piano, Rotterdam, The Netherlands, 1997-2000.

The next example is the *KPN building* in Rotterdam, The Netherlands, constructed from 1997 to 2000. Designed by Renzo Piano while the design for the interactive façade wall was by Henri Ritzen from Studio Dunbar. *KPN* is a structural curtain wall façade with glass panels augmented with digital elements in form of a light grid that functions similarly to a monochromatic billboard.[538] One can send an sms message to the building that is displayed on the façade sometimes even several days later as a digitized and pixelated image or animation, as can be seen in figure 4.6 above. These projected images and animations can be seen in the range of up to two kilometres from the building because of the scale of the screen-like surface. This kind of façade augmentation with still or moving digital image gives the cityscape a cybernetic aesthetics. In this case, the cybernetic aesthetic is related to a communication between the viewer and the building accomplished through the screen-like surface that represents

538 Renzo Piano Building Workshop, *KPN Telecom Office Tower*, 1, Retrieved February 12, 2008, from www.rpbw.r.ui-pro.com.

the building's interface in its urban context. The aesthetic principle of *KPN* is not focused exclusively on the object/building itself but on the digital process, on its system and context that broadly links different disciplines, from architects to software and hardware engineers. In this way the building reformulates the roles of the maker and the viewer.

KPN's façade provides a possibility for a new mode of communication between the parties involved. It is an artificial system based on the technical process of information communication that does not refer to a meaning but to the quantity of signals contained in a message, as is illustrated in Claude E. Shannon's *Diagram of the Communication System* from 1949.[539] This diagram is a graphical representation of Shannon's quantitative theory of information based on his work at Bell Labs, focused on reduction of noise in telephone lines. This theory takes into account the entire process of encoding a message in a signal or medium, transmitting it through a channel impeded by noise and decoding the message at the receiver's end. According to Shannon, noise in communication systems causes uncertainty altering the received message in comparison with the message sent. The concept that makes the uncertainty quantitative and measurable is the core of Shannon's theory, is that of *information,* defined as a function of probabilities not related to meaning.[540] In this regard, a key concept for understanding aesthetic processes in cybernetics is information. An interesting example that illustrates the concept of uncertainty and the aesthetics of information and is therefore important for understanding of cybernetic aesthetics is Gordon Pask's *Musicolour machine*.

Musicolour was a device that utilised the sound of a musical performance in order to control a light show with the intention of achieving a synthetic combination of sounds and light. An interest in synaesthesia and the question of whether a machine could learn relations between sounds and visual patterns and in doing so enhance a musical performance was Pask's initial motivation for building the system.[541] In terms of Musicolour's materiality, the music was converted into an electrical signal by a microphone. Within the device, the signal passed through a set of filters, sensitive to different frequencies. The output of the filters controlled different lights. Pask wanted to

[539] Claude E. Shanon and Warren Weaver, *The Mathematical Theory of Communication*, University of Illinois Press, Urbana, Illinois, 1949, 34.
[540] John Johnston, “Machinic Philosophy: Assemblages, Information, Chaotic Flow” in *Allure of Mechanic Life: Cybernetics, Artificial Life and the New AI*, MIT Press, Cambridge, 2008, 136-137.
[541] Gordon Pask, “Musicolour” in I. M. Good (ed.), *A Scientist Speculates*, Heinemann, London, 1962, 158.

achieve an analogy to biological neurons and therefore the internal parameters of *Musicolour* were not constant. If the output from the relevant filter exceeded a certain threshold value, floodlights would be activated. These thresholds varied in time as charges built up on capacitors according to the development of the performance and the prior behaviour of the machine.[542] In its poetic characterisation and representational attributes, the concept of *Musicolour* is similar to Toyo Ito's *Tower of Winds*, which translates the wind into light. In its interpretation of communication systems and the translation of information, as a function of probabilities from one medium to another, the concept of *Musicolour* is related to *KPN* building's façade. A difference with *Musicolour* is in the mode of interaction, which is direct in the case of *Musicolour* and indirect in case of KPN's façade. As well in their cybernetic aesthetics, which have abstracted formal qualities represented through flood of differently coloured light in case of *Musicolour* and the possibility to display a deconstructed but still figure based aesthetics, if people would send such in, in case of the *KPN* façade. *KPN* presents a cultural artifact that gives a meaningful content to is surrounding which with the façade’s interactivity gives a new significance to an interactive interface in architecture, as discussed further.

4.3.1 Interactive Interface as a Cultural Artifact

The plural character of the digital façade's materiality can be observed through the different scales in which these distinct layers of materiality coexist. Its macro-materiality can be regarded as façade's hardware or the structural elements incorporated in the construction process. While micro-materiality can be regarded as the hidden digital micro-particles which cannot be seen with a naked eye but can be translated to a visible representation and displayed through an interface. As Steven Johnson states, we relate with the computer via the interface and not directly with the zeros and ones of digital code. Johnson defines an interface as a certain form of translator, which mediates between the two parties in order to achieve a sensible relationship between the two.[543] In case of digital façades this translation is achieved by means of appropriate software applications. In regard to aesthetic qualities, it can be said that digital façades may be composed of topological and semiotic-topological methodological elements.

[542] Pickering, *The Cybernetic Brain*, 315-316.
[543] Steven Johnson, *Interface Culture*, Basic Books, New York, 1997, 78.

Topological elements concern visual and plastic qualitative properties of geometrical figures that can be diplayed, while semiotic-topological elements concern the qualitative properties of space in cases when it is transformed by narrative devices of text.[544] For example, a knot can be regarded as a semiotic-topological element. The digital aesthetics of the *KPN* façade can perhaps be observed in terms of the transformation of our sense perceptions by the digital, through various interfaces.

Figure 4.7: *KPN building* , Renzo Piano, Rotterdam, The Netherlands, 1997-2000.

In this regard, all analysed digital façades exemplify different kinds of interfaces and reflect different characters within a specific urban context. *KPN* façade was conceived as a display surface. The originality of the façade's design approach is not in making it merely a huge flat screen but in creating a 'screen like' modular interface that could be used for interactive means. The design aesthetics are reminiscent of the old TTL (Transistor-Transistor Logic) computer monitors used on early IBM PCs, as can be seen in figure 4.7 above. In the times they were created these monitors had disadvantage because of the limited number of colours available for the screens due to the low number of digital bits used for video signalling. Nowadays, this liability is considered to be an aesthetic choice. Available colours were green, orange and *warm white* although a green monochrome screen was the most popular in the 1980's.[545] These monitors had a

[544] Massimo Leone, "Words, Images, Knots", in Alan English and Rosalind Silvester (eds.), *Reading Images and Seeing Words*, Rodopi B. V., Amsterdam, New York, 2004, 86-87.
[545] Patricia A. Moore (ed.), *Computer Graphic Hardware*, Harvard University, Laboratory of Computer Graphics and

black background and visible green pixels that composed the picture. Compared to the direction the industry is taking with the development of screen size and resolution, the *KPN* façade becomes a symbol of an archaic computer culture that will over time become rare and extinct. The creation of the façade resembling a computer screen translates the building from a static to a dynamic object of constant movement and variation which alters direction and changes exterior representational qualities of the façade wall continuously.

A novelty of the *KPN building* is in the mode of interaction with its façade that presents an indirect level of communication with the building carried out via mobile phone. In this way the boundary between the inside and outside of the building becomes a public screen open for participation to everyone. The artificiality of a screen becomes a part of reality. In previous examples, a building's façade was in direct or indirect communication with its surroundings through environmentally specific parameters. Façades are located in culturally different contexts – such as Tokyo, Paris and Rotterdam, there is a specific locality within the city the building is placed in – waterfront, open public space or traffic connection, the building has different communicative aspects – sounds, wind or light. The substantially different mode of interaction in the case of the *KPN* façade is that the communication is established with people. Building's façade in this way becomes a social mediator between people and their urban condition.

This means that the mode of interaction digital façades can have is limited by the manner in which the system manages the information. As in case of *KPN* the message can be only of a limited size and quality. A moment of interaction is slightly delayed because when sent, sms goes through two levels of filtering. The first filtering level is concerned with the content of the picture or animation, whether it is too rude or obscene to be published on the façade. The second level of filtering is concerned with technical issues, such as whether the resolution of the image or animation can be applied to the resolution of the façade wall, etc. Unlike the *BIX* building in Graz, where digital elements are integrated beneath the skin, or tattooed into the surface, in the case of *KPN* the light elements are openly exposed on the outer surface of the façade. Disclosure of light elements openly on the façade's surface was designer's choice. Considering its

Spatial Analysis, USA, 1980, 56.

communication feature on a larger scale, it is important to address the contextual effects this kind of façade can have on its surroundings, which is addressed in the following section.

4.3.2 Contextualisation Effects – The Regulation of Information Flow

The thrilling aspects and possibilities brought by science to the creative sphere in terms of light usage sometimes results in light over-usage as often happens with advertising billboards, shop windows, media façades, etc. Usage of digital façade walls as billboards can produce an effect of *light nausea* on the observers. This happens when the building is placed in such a way and located in a specific position that it does not allow for appropriate distance between the observer and the façade, when an inappropriate light sources are used, unsuitable light intensity and cycle, etc. She criticise this kind of façade because of the possible light pollution that can happen in such cases, and encourages implementation of regulations, which would regulate the amount of light-intensive signage of the large light displays and their effects on the inhabitants.[546] Fatah does not give a very thorough analysis although some elements of her critique could be applied to buildings which façade's treatment is in the same category as those conceived as digital advertising billboards. Façades of these buildings are substituted for TV screens playing out commercials without any meaningful interaction with the surroundings or the people who inhabit them. The accustomed case is that the information they transmit is meaninglessly imposed onto the inhabitants. Examples of this kind of façade can famously be found at the Ginza shopping and entertainment district in Tokyo, Japan or at Times Square in New York.

Such environments have an intense influence on their inhabitants because of the continuous bombardment of the senses with information which can cause information overload in its users. This continuous bombardment of senses with redundant information can be compared with the *information pollution*, as referred by Jakob Nielsen and discussed in the first chapter. This phenomena is present in email communication and is regarded as an overload of one or more senses that can result in disorientation and lack of responsiveness.[547] Information pollution as a process can

[546] A. Fatah gen. Schieck, "Towards an Integrated Architectural Media Space", First Monday, Special Issue number 4: Urban Screens: Discovering the potential of outdoor screens for urban society, February 2006, 2, Retrieved April 28, 2008, from http://firstmonday.org/issues/special11_2/fatah/index.html.

[547] Michael Thomas (ed.), *Handbook of Research on Web 2.0 and Second Language Learning*, Information Science

emerge within the architectural cybernetic environments allocated within urban areas of cities. As Anne Beamish and Geert Lovnik notice, the idea of modern city has powerfully influenced the development and representation of the Internet and vice versa.[548] This concerns that some processes that emerge on the Internet could be materialised in the physical environment as well. Although information pollution refers to the phenomenon that happens in cyberspace, it can be compared with the advertisements on the digital façades because it implies the basic over-abundance of information that invades public space. In these terms, as the unnecessary emails present the noise in the signal on the internet, digital advertisements present the noise within urban spaces. Alvin Toffler relates the term *information pollution* with the stress and disorientation that can be induced on individuals by subjecting them to accelerating rate of change in a short period of time. Toffler points out that the *rate* of change has different implications than the *direction* of change and in order to define the *content* of change one must include the consequences of pace as a part of that content.[549] While Toffler points out towards the importance of the displayed information content and the meaningfulness of the transmitted content, Nielsen refers to the perceptual influence on the senses. In the process of digital façade design, both of these considerations are equally important to be analysed in regard to façade's influence on its surroundings and consequentially people that inhabit it.

As another line of thought, Clay Shirky points out that the problem is not in the information overload, because this condition is present from 15th century, due then, to the printing press and book publishing. The problem for Shirky is in the lack of information filtering and lack of mechanisms for individualised parameters of privacy preferences and that therefore implies privacy as problem of individuals.[550] The deficiency of information filtering that Shirky addresses is among other things related to spam email messages. In this regard, digital façades that constantly impose different kind of advertisements into the environment can be regarded as redundant visual spam emitters that inflict unessential information on the inhabitants. In case of *KPN*, the problem of information filtering that Shirky addresses is solved with the two previously

Reference, Hershey, PA, 2009, 39.

548 Anne Beamish, "The City in Cyberspace" and Geert Lovink, "The Rise and Fall of the Digital City Metaphor and Community in 1990s Amsterdam" in Steve Graham (ed.), *The Cybercities Reader*, Routledge, Urban Reader Series, London, San Francisco and Stanford, 2003, 86.

549 Alvin Toffler, *Future Shock*, Bantam Books, USA, 1984, 2-3.

550 Clay Shirky, "It's Not Information Overload. It's Filter failure" lecture for Web 2.0 Expo NY, January 2009 at blip.tv, Retrieved February 12, 2010, from http://web2expo.blip.tv/file/1277460/.

mentioned levels of filtering, with a deficiency in the delay of the information display.

The critique of light pollution, information overload and/or lack of filtering, is not appropriate in the case of the *KPN building* because the façade's design approach reflects awareness of such issues in that it presents a kind of disintegration of a high resolution screen surface. This disintegration results in the inability to assimilate complex pictures or videos that require high resolution displays in order to be identifiable. An image created through the process of resolution disintegration can be anticipated as an occurrence or event and in this way can enable diverse comprehensions of the image's content. An interesting example in this regard is the *Blinkenlights project*,[551] organised by a hacker community, a project that converts modular façades into interactive computer displays. In case of *KPN*, the design decision was to display only one colour without the possibility of colour valorisation within an image. This results in a certain aesthetic two-dimensionality of the images and animations. This kind of flatness and reduction of plasticity is characterised by very simplified graphic elements and the same intensity of light in each bulb. Another kind of aesthetics and a different mode of interaction is illustrated through Aegis Hyposurface project discussed in the next section.

4.4 Aesthetics of Kinetic Motion – *Aegis Hyposurface*

Among the first projects involved in the exploration of kinetic motion applications, beside The *Institute du Monde Arabe*, is the project *Aegis Hyposurface* by dECOi Architects completed in 2000. This project was developed as a response to the competition for an interactive art piece intended as a part of the scenography for theatre plays in Birmingham's Hippodrome Theatre.[552] The project was a proposition for a kinetic, decomposable surface capable of real-time responsiveness to events on the stage, like body movements or sounds, as illustrated in figure 4.8 below. As Branko Kolarevic notes, *Aegis* presents a *dynamically reconfigurable screen*[553], whose dynamic quality of an elastic surface is achieved by a matrix of actuators controlled by a computer that are positioned behind the kinetic surface. Actuators control depth of the surface on the side visible to the observer, as shown in figures 4.9 and 4.11 below. One

[551] Blinkenlights Project, Retrieved September 18, 2010, from http://blinkenlights.net/
[552] Goulthorpe, *The Possibility of (an) Architecture,* 89.
[553] Kolarevic, *Architecture in the Digital Age*, 174.

of the highlights of *Aegis* is that it reveals a whole new field in formal design approach that is characteristic for architecture, a moving, fluid form that can change its texture and patterns. This kind of wall, instead of being a separator, becomes a place of playful interaction. For Kolarevic, the proposals that involve genuinely physically responsive architecture driven by projects such as *Aegis* imply a conceptualization of the building with developed electronic central nervous system and the surfaces of which respond by digital means to any digital input, such as Internet or sms messages, and analogue input, such as body movement or sound.

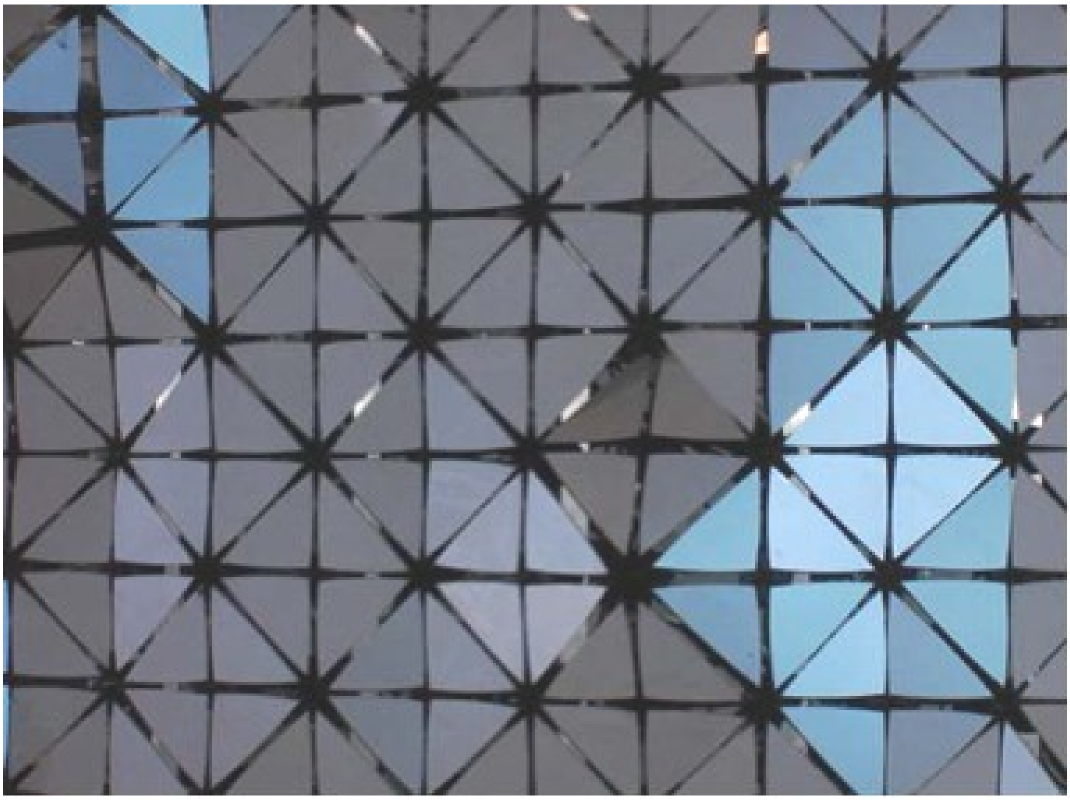


Figure 4.8: *Aegis Hyposurface,* deCOi Architects, Birmingham's Hippodrome Theatre, UK, 2000.

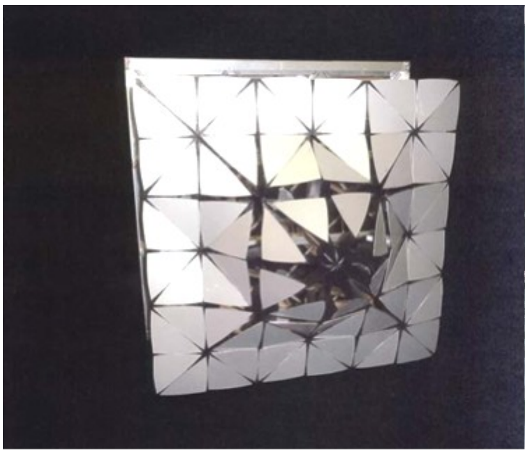


Figure 4.9: *Aegis Hyposurface*, detail of a module.

Figure 4.11: *Aegis Hyposurface*, pneumatic actuators.

From an architectural point of view this project is interesting because it marks the transition from *autoplastic* to *alloplastic* spaces.[554] In his explanation of the meaning of these terms, Goulthorpe refers to their development by the psychoanalyst Sandor Ferenczi. In relation to the term *trauma*, Ferenczi defines both terms, *autoplastic* and *alloplastic,* as two different types of reaction or adaptation.[555] According to Goulthorpe's translation of Ferenczi's work, autoplastic consists of the modification of the organism alone and alloplastic concerns modification of the surrounding environment. In his essay “From Autoplastic to Alloplastic Tendency”, Goulthorpe notes that *trauma*[556] is a common process in which autoplastic reaction is predetermined by the inertia and indifference to the environment. He associates the term *trauma* with the term *shock*, as developed by Martin Heideger and Walter Benjamin, who deploy the term to account for changes in aesthetic experience occasioned by the technological change with the specific accent on cultural effects of technical change. Goulthorpe is interested in the relations of trauma to the patterns of creativity propagated by digital technology, in order to counter the reincorporation of electronic technologies within traditional ideological frameworks. For him, the ultimate examples of the literally alloplastic architecture are spaces that move in response to people, who are put in a physically reciprocal relation with the environment. This environment is a dynamically interactive architecture attuned to people's activity.[557]

For Goulthorpe, in cases in which trauma becomes culturally operative, it is possible to characterise it as a shift from an autoplastic to alloplastic mode, both in a productive and receptive sense. Therefore, according to him, *autoplastic* is characterized as a self-determinate operational strategy and *alloplastic* as mutual environmental adjustments. In the creative mode of operation humans function within an alloplastic space, as one begins to work in a response and related to conditional environment. The working environment is largely determined by the growing capacity of generative software, which is in itself a transformative creative medium. In his remarks about writing, Goulthorpe refers to the basic premise of the *Aegis* project, which aims to appropriate a technological shift in cultural experience by prioritising the extent to which writing and translation mechanisms effect digitized processes. In case of the *Aegis* project, the mechanisms of translation are determining factors of its interactivity, which is evident

[554] Goulthorpe, *The Possibility of (an) Architecture*, 94.
[555] Sandor Ferenczi, *Vocabulaire de la Psychanalise*, Presses Universitaires de France, Paris, 1973, 45.
[556] Goulthorpe, *The Possibility of (an) Architecture*, 93.
[557] Ibid., 127.

in the process of instant transfer from one medium to another, such as sound to light, movement to sound, etc.[558] In this regard a link can be established with the concept of remediation, as discussed previously in the chapter, which in this case has a constant and cyclical character. This cyclical character of the process, the possibility of software translating from one medium to another, the direct interaction with the physical entity and the immediate speed of transformations are all aspects of cybernetic mutualism. In case of *Aegis*, cybernetic mutualism is reflected in most aspects of its performance. The only characteristic that prevents it from genuinely exhibiting cybernetic mutualism is the system's inability to learn from a participant or its environment.

A particularity of the *Hyposurface* is in its balance between different physical states achieved through the cycle between its solid and fluid condition. This is characteristic of cybernetic mutualism. According to Goulthorpe, indeterminacy of the surface is expressed in its physical statelessness. He concludes that if conditioned in such a manner the surface is in a mesomorphic state. This state is characterized by the point in which the liquid-crystal reaches the stage of an immanent crystallization or melt-down. According to Goulthorpe, Aegis's smectic[559] surface is neither object nor image, but constantly transforms from one to another and vice versa.[560] In terms of its aesthetic qualities, the surface of *Aegis* is a dynamic pattern with the physical indeterminacy that is represented in its potential to dynamically change the form of the surface in relation to different events. These surface events, created through bodily movements and sounds, generate different forms of experiences. These experiences evolves through farther interaction with the surface. As in the case of *Aegis*, a propitiation of entirely new cultural forms and processes are initiated through the digitization of the wall surface. Contemporary technologies provide the possibility to change notions of the modalities in which the space is used and the modes of interaction within the space. In these terms Aegis corresponds to what Stephen Parrella refers as the relation between media and topological surfaces in architecture.

According to Stephen Perrella the hypersurface architecture is a way of thinking about architecture that does not assume a relation between real and unreal or material and

[558] Ibid., 97.
[559] Smectic in liquid crystals notes a mesomorphic state in which the arrangement of the molecules is in layers or planes. See, Patrick Oswald and Pawel Pieranski, *Smectic and Columnar Liquid Crystals: Concepts and Physical Properties*, 86.
[560] Goulthorpe, *The Possibility of (an) Architecture*, 97.

immaterial dichotomies.[561] For him, hypersurface is a word that describes any set of relationships that behave as systems of exchange.[562] Parrella is interesting in regard to *Aegis* because of his theory of liquid-embodied architecture. One of the techniques often associated with him is the texture mapping of images onto the surfaces of 3D geometric models. An imagery and a surface form a combination that often results in the production of very abstract patterned objects. The material aspect that Parrella mentions, concerns the way in which a multitude of forms can be conceived and realised by means of digital representation. Parrella's concept of hypersurface is an attempt to link hypermedia with topological surface. In this regard, complex geometries can simultaneously be interactive and communicative media.[563] Parrella's concept of hypersurface combined with Marcos Novak's idea that the form needs to become a technological event[564] can provide a theoretical background for conceptions of interactive digital walls, such as *Aegis Hyposurface*. In this way and in relation between a building and its digital façade, the building becomes more than a location for urban activities, as in case of *Kunsthaus* in Graz. The connection between the building's structure and the dynamically variable and tactile *informatic* surfaces of digital façades creates a mutualistic relationship between the building and its environment. In this case, the translation of the information into a form depends on the participant's interaction with the surface that has the spatial and dynamic character. This implies some attributes of cybernetic mutualism.

The beauty of the *Aegis Hyposurface* is in its concept and design, which presents another dimension that disassociate it from purely functional projects in this field, previously regarded those that simply measure and control the environment. The project was conceived according to its capacity to absorb events from the surrounding environments and to change the colour of its surface in relation to the pattern of activity around it. The digital *Aegis* contains a multiplicity of cultural layering in a sense that in one moment it can be an abstract pattern of traditional African cloth and in the other it can be covered in Chinese signs. Such decorative potentials, in terms of pattern usage and ornamentation on façade walls, offers an additional layer of possibility seen in

[561] Stephen Perrella, "Hypersurface Architecture", Second Doors of Perception conference, the Netherlands Design Institute, Amsterdam, the Netherlands, in Mediamatic Volume 8, No2/3, 1994, 34.
[562] Parrella, *Hypersurface Architecture II*, 49.
[563] Perrella, *Hypersurface Architecture*, 53.
[564] Marcos Novak, "Cognitive Cities: Intelligence, Environment and Space" in Peter Droege (ed.), *Intelligent Environments: Spacial Aspects of the Information Revolution*, Elsevier Science Ltd, Amsterdam, The Netherlands, 1997, 386-420.

deployment of their temporal usage and mutual communication in the sense of morphing from one to the other, or emerging one from the other. An interactive environment created through this kind of spatial relations involves more than the processes of monitoring and controlling events in an environment via predefined settings. It involves a constant and context related response loop between the participant(s) and the interactive surface of a wall. Cybernetic mutualism in this case is reflected in the multiplicity of relationships that can be established between the artificial system and natural agents and in the aesthetic quality of the outcome in the process. The quality of these relationships can be regarded as providing the space with a character or a sense of a place. In this regard, the concept of cybernetic mutualism incorporates smooth transitions between virtual, physical and digital materialities in which a participant can experience these aesthetic transformations of space as fluid events that encourage further interaction with the environment.

For Denise Scott Brown and Robert Venturi[565] these kind of impressions within architecture present particular modes of communications. For Brown and Venturi the architecture of styles and signs is anti-spatial, which means that it is an architecture of communication over space. Communication, as an architectural element, in this kind of architecture and landscape dominates space and brings a new scale to the landscape. Their position is that the complexity of settings and programs required by more complex built structures also require a complex combination of media that exist no longer as a service of a space but present indispensable constituent of the space. Brown and Venturi are critical of large billboard display surfaces that invade urban space with the communicative aspects that impose direct relationship with an environment these billboards create. Instead of this kind of spaces, they suggest new architectural conceptions that comprise bold communication rather than subtle expression.[566] Aegis can be regarded to communicate boldly, but abstracted to the point of relation through action of bodily movements and creation of sounds that interact with the surface, as they change with the new situation occurring as a result of these actions. Compared with the *Institute du Monde Arabe*, one of *Aegis's* aesthetic differences is in the mechanisms that operate digital façade structures. While the *Aegis* has computer controlled pneumatic pumps, *Institute du Monde Arabe* has computer controllable mechanical lenses. Both of

[565] Denise Scott Brown, “Talking Sheds”, Architecture Week, page D1.1, April 2005, Retrieved February 15, 2010, from http://www.architectureweek.com/2005/0406/design_1-1.html.
[566] Robert Venturi et al., *Learning from Las Vegas*, The MIT Press, Cambridge, Massachusetts and London, England, 1977, 8-9.

which are kinetic elements that operate in relation to different kinds of input, one reacts to light and other to sound and movement. The way in which movement is produced is another category. The different developmental modalities emerging with the introduction of the *Aegis's* kinetic structure are discussed in the next section.

4.4.1 The Space of Flux

An origin of the relationship towards built structures as the spaces of flux can be found in the work of Nicholas Negroponte and the Architecture Machine Group that operated during 1960s and 1970s. They argued for the integration of intelligent minicomputers in architectural spaces in their search for an intensification of peoples' relationships with environments. In this regard, Negroponte and his followers adopted a concept that comprised an environment that had a functional image of itself and through this image it was able to map existent occupants' activity in addition to sensors and actuators.[567] In this way they were able to monitor and regulate environmental conditions within the space and to mediate activity patterns through allocation of functional spaces.[568] Besides its basic and predefined settings, a precondition of these abilities is that the building begins to familiarise itself with the inhabitant and to distinguish his/her behavioural patterns and through this cognition to respond to occurring contextual variations.

Negroponte claimed that the future state of an architectural space is to be in a flux, the transformation of space from a former static modular order into a topological field which responses to bodily activity, as in case of *Aegis*. The scope of responses depends on the question regarding the person-environment relationships.[569] The concept of cybernetic mutualism presents a proposal for continuation of this line of thought in that it accentuates the interaction between a participant and environment and not merely the environment’s responsiveness to participant's input. Anther proposal for continuation of Negroponte's line of thought can be seen in the work of Tristan d'Estree Sterk and the Office for Robotic Architectural Media & Bureau for Responsive Architecture's active recognition of the recent developments in the fields of robotics and machine intelligence. Sterk points out that in responsive architecture the next architectural state of a building is determined treating the needs and wants of users as a set of ever-

[567] Nicholas Negroponte, *Soft Architecture Machines*, The MIT Press, Cambridge, London, 1975, 46.
[568] Sean Wellesley Miller, “Intelligent Environments” in *Soft Architecture Machines*.
[569] Negroponte, *Soft Architecture Machines*, 53.

changing conditions.[570] In this regard, *Aegis Hyposurface* cannot be categorised as merely a responsive architectural component that has mostly functional attributes because of its cultural significance and the aesthetic properties of the wall surface that interacts with participants' input, and changes according to the programmed set of steps. This change does not stop once the commands are executed but continues and alters as long as there is a participant's input. This system can be regarded as interactive in terms of the definition proposed by Usman Haque. In this regard, building's skins or envelopes intelligibly show intermediation between human needs and the conditions of natural environments.

According to Tristan d'Estrée Sterk an advantage of responsive building envelopes in relation to traditional ones is in their possibility of actively working with features of the natural environment to condition the spaces inside.[571] They have an advantage over conventional buildings in terms of load transmission because this kind of building can facilitate and self-regulate load transmittance. Digital façades do not carry the load or weight of a building's construction elements only their own load, which allows them an amount of structural flexibility. Because of this property, and according to an engineer's approach towards façade utilisation, they can minimize risky loads and enable faster and more direct coordination of the space with air conditioning and other systems that are implemented in order to meet occupants' needs. In relation to this, Sterk proposes different methodologies architects might need to apply in their practice, as compared to those of engineers, in order to produce such buildings. Architects would need to employ cladding[572] and response methodologies that have a possibility of adaptation according to personal spatial requirements and which should work with rigid structural criteria.

This refers to modular architecture, any system composed of individual components that can be connected together in which the component can be added or removed without affecting the rest of the system. Application of this concept implies both aspects of digitized building's materiality: the traditional materials employed and the digital materials, both hardware and software. For example, in order to produce programs that are more readable, reliable and easily maintained, a programmer uses modular software

---

[570] Tristan d´Estrée Sterk, "Building Upon Negroponte: A Hybridized Model of Control for Responsive Architecture", Graz 2003, 5, Retrieved February 13, 2010, from http://www.orambra.com/papers/negroponte/sterkECAADE_03.pdf.
[571] Tristan d'Estrée Sterk, "Shape Control in Responsive Architectural Structures: Current Reasons and Challenges", (paper for 4th World Conference on Structural Control and Monitoring), 2006, 6.
[572] Cladding is regarded as a protective, insulated or aesthetic fixed layer added to the exterior walls of the building. See, Alan J. Brookes and Maarten Meijs, *Cladding of Buildings*, Taylor & Francis, New York, 2008, 68.

design, for instance object-oriented programming, but also at a larger scale a design strategy in which a system is composed of relatively small and autonomous parts or routines that compose the system and work together. Software modules are incorporated into a system through interfaces. This kind of interpolation of physical and digital materiality can be regarded as characteristic of cybernetic mutualism. In the conceptualisation of these kind of buildings, individual requirements should have a range in possible choices from aesthetic to environmental heterogeneity, for example from diversity in lighting, thermal and acoustic functionality to mutualistic interactions between different spatial elements. In order to appoint these personalized systems it is necessary to establish operating mechanisms that are capable of creating user models. These models should process three types of input: users' activity data, information about environmental conditions, and data regarding user's adjustments of the system. In this regard, Sterk positions some of the essential characteristics of structural systems that can be used within these frameworks: the possibility to have controllable rigidity of materials, utilisation of lightweight elements and the possibility of materials and elements to endure asymmetrical deformations.[573] In their combination these characteristics can provide vigorous and flexible results. Considering Sterk's interest in robotic buildings and responsive architectural technologies it is necessary to point out that his experiments with the composition of modular structural components and materials is considered as important for this thesis and not his relation to interaction. The strong point of Sterk's research is exploration of modular structures that are flexible to maintain constructive stability and have the possibility for kinetic motion. Supplementation of an interactive quality to these kind of structures is the next step after the adequate composition of structural elements is found.

According to Sterk there are two early models for user-centred interaction in architecture, first one by Andrew Rabeneck and the second by Yona Friedman.[574] Rabeneck states the use of cybernetic devices within an automated architecture introduces the concept of flexibility because of the overall inflexibility of architectural buildings traditionally created. He said that by using cybernetic technologies, an architect should be able to produce new types of flexible and user-centred buildings. After Rabeneck, Friedman was implying that a new design methodology is needed

[573] Sterk, “Shape Control in Responsive Architectural Structures”, 3.
[574] Sterk, “Responsive Architecture: User-centered Interactions within the Hybridized Model of Control” in *Game Set and Match II*, 494.

because of the architects' inability to anticipate precisely enough the future spatial needs of the users of a particular building. The first method describes the benefit of automation and predictive technologies and the second explicates the advantage of user intervention and direct manipulation. The third method called *the hybridized model of control* is proposed by Sterk and it implies something of a combination of Rabeneck's and Friedman's approaches with a reconsideration of human-computer interaction. Sterk's hybrid model, at the same time, enables lower level processes like those engaged within automated response systems to be integrated with higher level deliberative or intelligent processes. The advantage of this system is in its possibility to have an adjustable criteria in relation to the users' input. Experimentation with Sterk's model can help in construction of contextual models that can be based on the modalities in which the occupants use the space through interaction, instead through its responsiveness to users' input.

Another approach in the conceptualisation of digital façades are interactive communication surfaces, such as the *BIX façade*, discussed in the next section.

4.5 Interactive Communication Surfaces – *BIX Façade*

The architectural design for the *Kunsthaus* in Graz, Austria was carried out by Peter Cook and Colin Fournier, a building put into function by 2003 as a part of the presentation of Graz as Cultural Capital of Europe. The design for the *skin* belongs to *realities: united*, a studio for art, architecture and technologies from Berlin, Germany[575] and is called the *BIX Communicative Display Skin*. The whole façade is treated as a free-formed curvilinear surface and its structural conception contains a triangular support system with implementation of hexagonal ports which extend into peculiar looking openings in the ceiling and roof of the building.[576] With the goal of overcoming the traditional structural role of the façade as an enclosing system of exhibition space the designers of the system, Jan and Tim Edler, took a progressive position. This was the creation of a dynamic aesthetic conception creating choreographies that present the continuation of an architectural culture that took centuries to evolve.[577] The creation of the façade comprised a development of a kind of an experimental laboratory that was

[575] realities:united, 1, Retrieved February 19, 2010, from http://www.realities-united.de/#SHOWINFO,1,1.
[576] Colin Fournier, et al., *Friendly Alien*, Hatje Cantz Books, Cologne, 2004, 38.
[577] See, Jan and Tim Edler, "Message vs. Architecture? Dynamic Media as a Continuation of Architecture" in *Game Set and Match II*, 182.

supposed to appoint and distribute an original communication style within the urban tissue of Graz and afterwards at Potsdamer Platz in Berlin with their *SPOTS* façade installation. With these projects they established a language which is synchronized with the architecture and the users of the public space around it and which at the same time yields to its urban context.

As an exhibit, the *BIX façade* extends the possible communication range of the Kunsthaus, complementing its programmatically formulated purpose. This digital façade can transmit some of the internal processes of the Kunsthaus into the public space in an abstract and mediated form. In order to obtain advantages of a modular structure a main design characteristic of conventional large screen displays were not included in the design of the *BIX façade*, a screen-like surface that can show only a low resolution images, which like the *KPN* façade imposed limitations concerning the display potential. The deconstruction of the principal design characteristics of a displaying surface was imposed by the shape of the building but also by the the modular structure that enabled the screen interface to be highly integrated into the architecture.[578] Considering that the displayed art pieces include a certain content, this opens a manifold of chances that will allow for development of methods for dynamic communication between building and surroundings, between content and outside perception.

The façade is conceived as a low resolution computer screen with its unique pixelation, at much lower resolution than that of a typical TV screen, as it can be seen in figure 4.12 below. In making the façade-screen resolution low, the designers' intentions were to disengage the possibility for a façade to become a commercial tool for selling advertisement time.[579] The creative and cultural tendencies reflected in the work displayed on the *BIX façade* is one of the positive impacts this façade can have on its surroundings in relation to people. Allowing advertisements to be displayed on the *BIX façade* would be in opposition with these dispositions. In this sense, the concept of the façade is similar to the *KPN* building with a difference that the light rings can have different tones of one colour while on *KPN* light sources can have only one tone, as shown in figure 4.13 below.

[578] realities:united, 2, Retrieved February 19, 2010, from http://www.realities-united.de/#PROJECT,69,1.
[579] Fournier, *Friendly Alien*, 40.

Figure 4.12: *BIX Communicative Display Skin*, Kunsthaus Graz, façade detail, 2003 and Figure 4.13: The Façade's front view, 2003.

Figure 4.14: *BIX Communicative Display Skin*, Kunsthaus Graz, Peter Cook and Colin Fournier, Graz, Austria, 2003.

The problem that occurs with projects, such as the Kunsthaus, is the well discussed *Bilbao effect* or *Bilbao factor*, [580] when a building serves more as a marketing strategy for a city or an institution in order for them to obtain their place on the world's map as a renowned place, supplying a city with a large annual tourist revenue. The term originally addresses Frank Gehry's *Guggenheim museum* in Bilbao, Spain. When constructed in depressed area of the city such a museum is intended to revive part of the

[580] Paul L. Knox, *Cities and Design*, Routledge, New York, 2010, 186.

financial income of the city. This kind of reinvention of cities by means of revitalization of their underdeveloped parts through values given by culture is a common strategy in urban regeneration. A good example of a prosperous urban regeneration is Tate Modern in London, which cannot be put into the category of *Bilbao factor* buildings. It rejuvenated the Bankside area of the South Bank in London through cultural content and activity and not through the fantastical form of a building. In this regard, if observed through the unusual form of a building, also regarded as 'friendly alien' by Cook and Fournier,[581] Kunsthaus Graz could be put into a category of Bilbao factor buildings. According to Peter Cook, the building's positive effects on its surroundings are in rejuvenation, which is reflected in that before the building was constructed, the area around was an isolated and relatively non-functional place. With the construction of the Kunsthaus and the conversion of some 18th century buildings, the area has been transformed into a little cultural enclave.[582] The biomorphic structure of the building, as shown in figure 4.14 above, distinguishes itself from the surrounding architecture and in this way interpose its existence in the wider urban tissue of the city. And through its digital façade it establishes a communication with its surroundings.

An interesting aspect of this building's façade is in its potential as an interactive participating platform, as discussed further.

4.5.1 Interactive Participating Platforms

A different approach to the one described previously in the chapter and regarding the content filtering are platforms. According to Olga Goriunova and Alexei Shulgin, platforms are web sites organised as a comparatively elementary database populated with artifacts or as more complex portals created around a database. In technical terms, a platform can have an open database with an interface that will allow for an easy access and contribution in form of uploaded or downloaded files.[583] A platform is a kind of creative tool that is aimed to support and stimulate creative initiatives and work by providing the possibility for continuous exhibition of artifacts that are usually followed by various discussions as a public's reaction to the topics and issues involved. In some

[581] Fournier, *Friendly Alien*, 41.
[582] Interview with Peter Cook, “Peter Cook RA and the Friendly Alien”, Retrieved February 21, 2010, from http://www.royalacademy.org.uk/architecture/interviews/peter-cook-ra-and-the-friendly-alien,211,AR.html.
[583] Olga Goriunova and Alexei Shulgin, “From Art on Networks to Art on Platforms” in Joasia Krysa (ed.), *Curating Immateriality: The Work of the Curator in the Age of Network Systems*, Autonomedia, 2006, 237-238.

cases platforms can translate digital creative processes into offline events and in this way establish links between cultural movements that can occur in different periods and orders.

In order to make a qualitative distinction between projects every platform has a filtering mechanism that functions as undetectable back-end process that is always present. This filtering process is conveyed by a number of people with consistent judgements that influence taste and decisions. It is commonly an absolutist process that maintains the quality of the resource and in the same time is democratic in order to allow for a variety of works and approaches.[584] The quality of the resource and the democracy in the participation is maintained by adaptation of platforms to different conditions. The conceptualisation of a platform can have a distinct aim but through interaction with its users the platform changes and evolves in order to accommodate different categories of submitted works. If observed as a social platform in such terms, a digital façade can become more than just a *face*, it can obtain a capacity to be a message transmitting implement and can provide a possibility for open public expression. Consequentially, it can render a cultural section through societal interests and dispositions. Further methods for dynamic communication between the building and people can be developed. The development and adaptation of such interactive participating platforms can happen with the needs and interests of the inhabitants.

In this regard, *BIX façade* is an interactive device. Besides an option to upload images and animations/videos produced by the artists and designers onto the façade, there is also a possibility for people who are not designers, artists or involved in related fields to send an image or animation to the Kunsthaus via Internet for display. After the Kunsthaus institution has evaluated the content, and resolution adjustments of the image are made, a picture or video can be displayed on the façade. This is similar to the content filtering of *KPN* building. There is a *BIX* website, http://www.bix.at, where software allows simulation of an image or animation visualisation when played on the façade. In the case of this project, the Internet is used as a mediator between people and the object of interaction. This project presents a brave attempt although the comprehension and proposition of the interactive property is quite apparent and oversimplified because even after the complex procedure one has to go through,

[584] Ibid., 239.

interaction is reduced to a very simplified level of information display.

As far as the transparency of information and content that Kunsthaus wanted to achieve, the moment in which a representative of the Kunsthaus decides what will be and will not be displayed presents a political decision about what kind of ideas and policies are approved by the establishment. From the previous discussion about content filtering it can be concluded that there are two distinct levels of information filtering here. One level concerns the evaluation and selection of work made by established individuals in related art, design, architecture or other fields. Considering the professional assessment these kinds of artifacts need to pass, the level of criteria is formed according to the artistic value set by the Kunsthaus. A different mode of content filtering, one that concerns participants who are non-occupationally related to art, design or other similar fields, potentially involves criteria regarding potential discourtesy or indecency of the content. Considering content filtering in institutions like Kunsthaus, the displayed projects should be perceived through the prism of the social processes that are called art which involve cultural contexts of production and reception in which art is articulated. This would concern the development of the meaningful social interactive potentials these institutions have in order to influence and activate their surroundings. An interesting example, in terms of interactive relation and activation of its surroundings, is the façade of the *Galleria department store* discussed in the next section.

4.6 Software as an Aesthetic Quality – *Galleria Department Store*

The next example in the analysis of digital façades is the *Galleria Department Store* by UN studio and ARUP Lighting in Seoul, South Korea constructed in 2004. This building is a refurbishment of an old department store with a windowless decaying façade. The general idea was to make a landmark building with a changeable façade surface that would reflect the surroundings, define its own distinctiveness, and represent a quality of its content.[585] Relationally to the position of the sun and the position of a viewer the colour of the façade can change from green to amber during the day. During the night, the system of waterproof colour-changing Xilver RainDrop RGB LED fixtures was developed to illuminate the frosted glass discs.[586] The façade was

[585] UN studio, Retrieved October 26, 2009, from http://www.unstudio.com/nl/unstudio/projects/galleria-department-store.
[586] Xilver, Retrieved February 22, 2010, from http://www.xilver.nl/Xilver-winner-in-Seoul.aspx.

developed in a modular manner that allows control over the colour for each individual light, as it can be seen in figure 4.15 below.

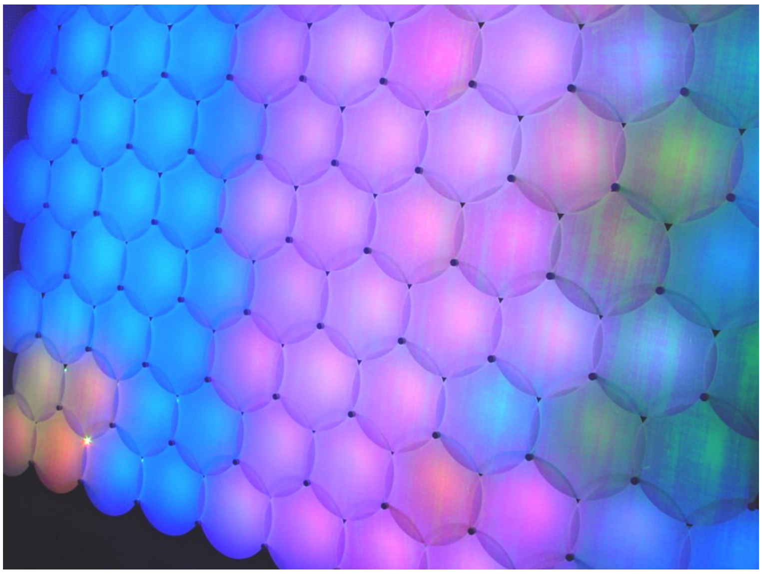


Figure 4.15: *Galleria Department Store*, façade detail, 2004.

The big issue for the light engineers was to achieve a standard aesthetic quality of each disc, so they can have the same light with the same colour characteristics without hue variations between them. As explained by engineers, this was achieved by choosing a red, green and blue LED as benchmark for all other LED's. In order to adjust the colours of one fixture to match the benchmark feature light engineers varied the intensity and wavelength of three colours. The option to automatically adjust the intensity and wavelength values for each fixture related to the individual embedded LED was made possible by development of special software, named e:cue Programmer.[587] The protocol that controls the specially developed light features is called DMX-512 part of the e:cue software, which describes a method of digital data transmission between controllers and dimmers. DMX-512 is a serial protocol, which means that it can be transmitted across one pair of wires. It is also an asynchronous protocol, which means that packets of data are transmitted only when an update is needed and not at regular intervals. Because the data are not timed by a separate time circuit it requires a Reset signal to be sent to the receivers to indicate that a new data packet will be sent down the line. The values for each of a maximum 512 dimmers can be sent in sequential order by the time the Reset signal is sent.[588]

[587] Stijn Brocker, "Transformation of Luxurious Department Store in Seoul, Korea", 2, Retrieved May 11, 2008, from http://www.xilver.nl/gallaria.php.
[588] Richrad Cadena, *Automated Lighting: The Art and Science of Moving Light in Theatre, Live Performance, Broadcast and Entertainment*, Focal Press, Elsevier, Amsterdam, Boston, Heidelberg, London, New York, Oxford, Paris, San

Another problem that engineers had to solve was a very large number of DMX channels, because the software had to control 32 lines and considering there are 5000 light discs on the façade this makes approximately 15.000 DMX channels that this software and the 8 E-Link Ethernet nodes of e:cue had to control.[589] With a help of the created software each lighting fixture acts similar to a pixel or a video screen. This software intelligently uses the combination of lighting control features and the façade's display attributes, which allows for videos and bitmap images to be exhibited through the Xilver colour changing LED lighting fixtures. Potentially different kind of effects can be added to the images. The e:cue lighting system combines the e:cue Programmer, which fuses lighting consoles and a Windows user interface, and appropriate devices, such as e:cue *nano* or *butler*, which are external DMX Interfaces.[590] These devices have two possible uses: the first is the 'live mode' in which the DMX output is directly controlled by a PC with e:cue Programmer, which is part of the e:cue software created for real-time interaction with the lights on the façade, and the second is the 'replay mode' that is active when devices are disconnected and in which they replay a preprogrammed set of imaginary from memory created with e:cue Programmer. Different devices have different memory capacities and possibilities for user interaction and external control and they can differ depending on the façade design, while the control software and the handling remain consistent regardless of which device is used. E:cue software, the e:cue Programmer, can react to external events by receiving many different input signals ranging from MIDI, Timecode and Audio to DMX, Serial control and Electrical inputs. There are input interfaces, such as e:com or Ethernet user terminal, that allow for interactive alternatives. All these software features imply a distinctive façade aesthetics that creates a specific character in the building's surrounding context, as discussed in the next section.

4.6.1 Aesthetic Characterisation of the Context

In the line of projects that develop decomposed screen-like façade surfaces the novelty applied in case of *Galleria* is the possibility to have colour with changeable hue, saturation and intensity on the façade, which was difficult to achieve, as previously

Diego, San Francisco, Singapore, Sydney, Tokyo, 2006, 280.

589 Brocker, “Transformation of Luxurious Department Store”, 4.

590 E:cue Lighting Control, “System Overview” in “System Manual: Basic. Programmer 5.1”, e:cue control GmbH, 2009, 11.

explained. The façade's concept is envisioned in more abstract manner because it does not simply utilise LED lights, as do many buildings of this kind, like those at Ginza in Tokyo. A novelty is in its utilisation of high-tech developed LED technology instead of neon lights,[591] as in case of *Tower of Winds*, or simple waterproof light bulbs, as in case of *KPN* building. The disc shape units and their small dimension are reminiscent of the surface structure of a reptile skin. Interestingly, the façades of *Galleria* and *Dexia Tower* can produce two types of imagery. The first kind is non-figurative in the form of colourful surfaces that can change one after the other and result in different contrasting colours. The second kind is figurative, that can display different patterns and simplified delineated drawings. The figurative one is of limited potential because of the manner in which the façade is composed, out of visibly divided elements, their size, which represent pixels of the screen, and the distance between those elements. This can be seen in figure 4.16 below. The *BIX* and *KPN* façades for example do not have the possibility to change colour but can potentially display more figurative imaginary because the distance between the light elements is more expedient in the construction of two-dimensional images.

Figure 4.16: *Galleria Department Store*, UN studio and ARUP Lighting, Seoul, South Korea, 2004.

The *Galleria* façade has a visual aspect that can change during different periods of day and night. During the day weather and atmospheric changes influence the degree of

[591] Gerfried Stocker, et al. (eds.), *Interactive Art Research*, Springer, Vienna and New York, 2009, 96.

reflection and absorption of light and colour on the glass discs. This mode of interaction is not digitised but analog because it depends on the optical variation of the disc's colour contained in foil mounted to the disc. This change is conditioned by external factors that are not programmable and cannot be altered though the façades digital system. During the night, it is possible to create a range of different colourful patters that can be created prior to a specific event or in the indirect real-time interaction with the façade. The façade can be altered to adapt to special occasions and altered over time according to seasons, fashion events or artistic inspiration.[592] The usage of patter- like graphics as image representation raises a question of their cultural context.

A very good example of a building with depictive cultural context is the *Institute du Monde Arabe*, the façade of which operates through a kinetically adapted variation of arabesque. The difference is that the means for these two building's activation and representation are different. The pattern usage on the Institute is quite intelligent because it does not relate only to the visual effects of the ornament as a detail of cultural significance but adds the quality in creation of an interior atmosphere or the sense of a place inside the building. In this way observer does not only experience the building through its outer glitter but can experience a specific atmosphere while being inside the space enclosed with the pattern engaged façade. In case of *Galleria* the purpose of the building, the shopping mall, conditioned the interior design. In this sense, the exterior and interior accentuate the second goal the designers had, which is the renovation of the interior into a luxurious integrated design, inspired by the fashion catwalk.[593] The dynamic visual impression of the façade during the night reflects the energetic impulse of the events happening during the day. The potential for pattern usage on this façade this is discussed further in the following.

4.6.2 Digital Pattern Aesthetics

The reappearance of pattern on façades, in their digital form, reopens a debate that was very acute during 20th century architecture with Adolf Loos as one of the leading protagonist of the stream that was against application of any kind of ornaments on the façades of buildings.[594] He considered ornament as criminal and degenerate, in line with

[592] e-architect, “Seoul Building: Galleria Hall West”, Retrieved October 26, 2009, from http://www.e-architect.co.uk/korea/galleria_department_store_seoul.htm.
[593] UN studio, Retrieved February 22, 2010, from http://www.unstudio.com/unstudio/projects/galleria-department-store.
[594] Adolf Loos, *Ornament and Crime*, Ariadne Press, Riverside, 1998, 53.

his philosophy that ornamentation can cause objects or buildings to go out of style over time, considering its suppression as necessary for regulation of modern society. However, perhaps following the postmodern break in some respects, in the mid 1990's, experimentation with complex geometries provided, through the usage of software applications, the opportunity for reconsideration of the façade's ornamentation. The reasons for the impulse towards decoration, ornamentation or patternization can be found in the practical requirements that were formulated through history and set up as crucial in terms of the criteria a building's skin or a façade should meet. Another consideration was aesthetic and the third one was building scale. As Fernand Braudel observes, ornamentation was used since ancient times for the exterior and interior decoration of buildings in order to give scale and texture through complex treatment of surfaces, to intensify and enlarge presence and appearance and to certify the level of mastery the craftsman and artisans had.[595]

Through history ornamentation was developed and applied to answer different purposes, to amplify the most important parts of buildings, to decorate residences, etc. For many architects, like Gottfried Semper, ornament represented a primary element of architecture with such a scope that Semper claimed that *architecture comes to be defined in its essence as an ornamental activity*.[596] In his 1856 essay, "Concerning the Formal Principles of Ornament and its Significance as Artistic Symbol", Semper criticise the idealist aesthetics of *pure beauty* and proposes a *practical aesthetics*, which he articulated and explained more thoroughly in his work on Style. For Semper, every system of aesthetics has to be materially grounded in dynamics and statics, which is interpreted by Aby Warburg as stating that aesthetics should be grounded in physics and science in general.[597] In some respect, Semper introduces the transformation of the architectural conception in his statement that the archetypical origin of any built form comes from ancient textile production such as weaving and not from a stable architectural formal system.[598] In these terms, he regards the knot as the archetypical joint. Semper's position that adornment is not merely an addition but architecture's constitutive structural element therefore creates a base for the relevance of the ornament

[595] Fernand Braudel, *Civilization and Capitalism*, Volume 2, University of California Press, Berkeley and Los Angeles, California, 1992, 76.
[596] Gottfried Semper, *Concerning the Formal Principles of Ornament and its Significance as Artistic Symbol*, The Warburg Institute Archive, London, 1856, 112.
[597] Spyros Papapetros, "Aby Warburg as Reader of Gottfried Semper: Reflections on the Cosmic Character of Ornament" in Catriona MacLeod et al.(eds.), *Elective Affinities: Testing Word and Image Relationships*, Editions Rodopi B. V. Amsterdam and New York, 2009, 317.
[598] Semper, *Concerning the Formal Principles of Ornament*, 114.

for architecture.

In modern times the term *decorative* is usually used to describe an artifact that is in its essence superficial, without any deeper meaning because its form often does not follow the structure or materials. Today, with the range of possibilities provided by use of digital patterns and ornaments the question of their cultural context and meaningful use arises. For James Trilling, a rediscovery of ornament offers more than a new infusion of decorative forms, or a rethinking of architecture and design to accommodate them. For him, ornament is a style that has always been a powerful tool in terms of ethnic and cultural self-definition.[599] At times it behaved as a symbolic construct constituting the base for a construction of meaning. In this regard, it is important that patterns and ornaments applied on contemporary building's façade at least resemble abstracted motifs of the culture they symbolize, whether this is architectural, urban, street, software or some other culture. There is an alleged certainty of their implementation in the globalised context in which the questions of identity and specific cultural traditions and customs are no longer viable. This kind of comprehension of an ornament reflects the position that the buildings are shaped by cultural, social, economical and political contexts and that with digital façades the possibility is provided for people to choose if certain influences should be ignored, rejected or selected in relation to building's urban and architectural dispositions.

A potential subject for exploration would be what kind of meaning digital patterns have when different cultural contexts are concerned. When observed through the division of ornaments proposed by B. Kolarevic, digital ornaments could be put into the category of *mimetic* or *imitative* ornaments that characterise an ambiguous meaning or symbolic significance and therefore their purpose is purely figural.[600] This and the fact that they are temporary does not give them a significant role in their influence on their surroundings except for the requirement to be entertaining, shiny and seductive in a way the TV screen is. Because of their more or less recent implementation on the façade walls they present more of a technological phenomenon that has an interactive component or not, as in case of *Galleria's* façade which does not initiate a direct relation between the observer and the building. A digital façade that accomplishes a new

[599] James Trilling, *Ornament: A Modern Perspective*, University of Washington Press, Washington, USA, 2003, 3.
[600] Branko Kolarevic, "Surface Effects: Ornament in Contemporary Architecture" in *Game, Set and Match II*, 180.

level of interaction with participants and therefore has a larger potential to develop meaningful relationships with its surroundings is the *Dexia Tower*, discussed in the next section.

4.7 Transparent Digital Façade – *Dexia Tower*

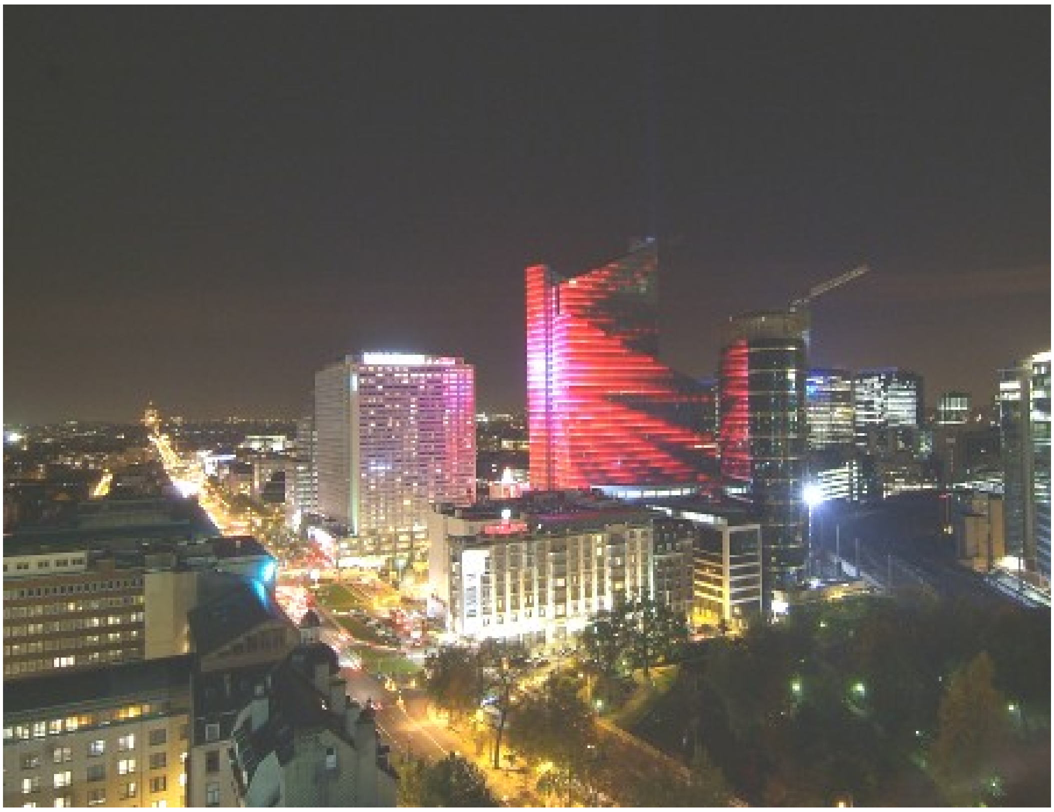


Figure 4.17: *Dexia Tower*, M.&J-M. Jaspers – J. Eyers & Partners and Samyn and Partners, Brussels, Belgium, 2006.

Another project in the series dealing with formalising the façade as large display surface is *Dexia Tower* by M.&J-M. Jaspers – J. Eyers & Partners and Samyn and Partners in Brussels, Belgium constructed in 2006. An interesting addition to this concept is an interactive console positioned as a tool for the interaction that happens in real time. The resultant graphical output on the building's façade is changed live through an interaction with the console.[601] This means that the light bars placed above and beneath the curtain wall windows can be programmed to display different colours. An impression of movement is made possible by rapid changes of colour. The possibilities of formal expression are diverse, it can show letters, figures, geometric shapes graphics and various visual effects, as shown in figure 4.17 above. In order for the façade to work, all

[601] Creative Review, Retrieved May 24, 2008, from http://www.creativereview.co.uk/crblog/dexia-tower-and-the-light-fantastic/.

the blinds need to be closed. In the case that a blind remains open, one can see only a horizontal line at the bottom of the window. The whole system is controlled by a central computer, so the result of the input is entered in a software that then translates this input for the lighting system. An image, a visual effect or letters are only visible when some windows are lit. This is made possible by the individual control of each light unit that can be illuminated in the exact colour. In terms of electrical energy consumption, the building uses highly effective energy saving LED system that uses 1 Watt of electricity at their maximum capacity. As a result of the various colour and movement effects, this maximum capacity is never achieved. The different creations presented so far have never exceeded one third of this total capacity.

Figure 4.18 and 4.19: *Dexia Tower*, interactive console and its interface.

Interestingly in the case of *Dexia Tower*, its authors did not envision the façade as a flat screen surface for pre-rendered video loops, even given the more direct relation of the building's surface to a screen a classical glass curtain wall façade. The designers did not treat the surface literally as a screen but were looking for a connection to the architectural characteristics of the tower, such as the orientation, volume, scale, and the urban context it resides in. The whole façade, that is all four sides of the building, are treated as a display surface that reacts to user input. As a result users creates the appearance of the whole building in that particular moment. An interactive console is placed at the Tower's base. Interaction happens in real-time via a multi-touch screen mounted to the stationary table. Users can interact individually or collectively. Touch and/or gesture are responsible for generating an elemental graphical language of points, lines and surfaces, which when combined with physical behaviour, create a monochromatic colour palette as a background that is combined with graphical elements that are black and white.[602] The main interactive console is responsive to multiple inputs so it permits interaction with a number of fingers and different participants at the same time, as shown in figures 4.18 and 4.19 above. Through multiple levels of interaction this building became an interactive urban artifact, as explained further.

4.7.1. Building as Urban Interactive Artifact

The façade examples analysed previously do not include a multi user interaction that can be seen in real-time while one interacts. This means that in case of *Dexia Tower* there are no mediators, such as mobile phones, as in case of *KPN building,* or Internet, as in case of or *BIX communicative display skin,* where interaction is not real-time but delayed in such a way that one can wait for several days in order to see the result of interaction. In the case of *Dexia Tower*, the filtering problem is resolved with a limited number of graphical elements or abstract colouring patterns one can choose to create a composition that will be displayed. For Arjen Mulder, in the past thirty years hybrid forms in art constitute a mix of classical sculpture and technical media. This occurrence firstly influenced the rise of video installations. At first, interpretations of the media, in this case video installations, were manifest by a screen showing moving images created by means of different digital instruments. The screen was commonly positioned within a sculpture in such a way that it draws attention to the status of the produced images, an example would be the work of Nam June Paik. The next stage in the development of hybrid forms in art was an interactive installation. According to Mulder, interactive installation is *a technical-sculptural set-up that requires some sort of intervention by the spectator to evoke the art experience: if you remain inactive, nothing happens.*[603]

Concerning architecture, the hybridization of technical media and architectural elements of the space originated from a related background. This means that in the development of space augmentation with different media, interaction presents a final stage of development. Screens, because of their flat form, corresponding to the flatness of the wall, and potential decorative qualities became the most frequent media components in

[602] Media Architecture Group (MAG), Retrieved May 24, 2008, from http://www.mediaarchitecture.org/dexia-tower-brussles/
[603] Mulder, "The Object of Interactivity" in *NOX*, 332.

architecture. For Mulder, there are two streams in interactive architecture and the first prefers the use of monitors. This not only for decorative purposes to intensify the experience of the observer, but to facilitate routing and security and to channel advertisements and other information into the immediate surroundings. The second stream, where neither the building provokes the activity of the users, nor users activate the building in terms of interaction that should trigger certain event that invites for participation. The two modes of interactive architecture that Mulder provides are not adequate because they exclusively include the media used for creation of interactive architecture, not dealing with the question of interaction as a meaningful moment in the relationship between the participant and the urban artifact. Through their development, digital façades, evolved from the mere advertisement tools that Mulder talks about to the playful and interactive urban artifacts that materialise a relationship with their surroundings and the people who inhabit it.

All previously analysed digital façades belong to the category of the creative interpretation and implementation of mediated technologies. They show the transition from the architectural tendencies Mulder describes to a future conception of digital façades as urban entities that invite participation and substantiate relationships that are formed around digital façades. Public events that are created around digital façades are the main actuators of interaction. Urban or architectural space created in this way can be defined as a cybernetic environment of continuous conversation. In regard to cybernetic mutualism, the façade of *Dexia Tower* presents the most developed idea in terms of the encouragement of social interaction because it implies multiple inputs that can happen at the same time and have real-time results. Interaction with the façade directly influences changes of patterns on the façade and this happens through multiple feedback loops. This is one of main characteristics of cybernetic mutualism. Mode of interaction that happens with façades in this way have the potential to evolve to become an actual cybernetically mutualistic façade. This can happen when participants are able to interact with the façade by directly touching the façade surface without interaction with objects, such as consoles, tables or boards. This would also imply that each element of the façade is a discrete computational device able to learn from the participant and capable of suggesting possible options for aesthetic change. Possible fields for development could be temperature-reactive materials or the movement-sensitive colouration of materials.

Mulder notes that, any system can be called interactive when the changes within an environment the system creates is a continuous cyclical process. This process implies flexibility of the system that can adapt to use and in turn that can change its users through the changes its users cause within the system.[604] In this way, all the participants in the system present systems for themselves, and the processes that are happening in one system reflect on the other in the moment of interaction. This is a cybernetic principle. An illustrative example of this he finds in the animal kingdom where animals dig a hole to use it as a shelter and in this way change the surroundings, but also change lifestyle, adapting to the new circumstances that this hole can offer. The relationships that can be created in this way between the building and its surroundings and inhabitants can influence the relationship between a designer of a system and the system s/he creates. This can be regarded as characteristic of cybernetic mutualism. If architects and designers do not make a leap towards deeper understanding of human needs and evolve in their work and creation from purely functional methods towards objectives more engaging and playful and towards interactive modes of inhabitation, most developments in the field of digitalization of architectural spaces will end up in the creation of hyper-functional spaces.

This is not to claim that functionality is inadequate or undesirable but that the possibility to interact with our habitats not merely in terms of adjusting the right temperature, calibration of shading for provision of an adequate amount of light or the alteration of different kinds of infrastructural constituents of the space to provide ideal living conditions can and should be surpassed. There is a need for experimentation with different kinds of activities that could be developed in connection with the environment and in communication with the inhabitants. Conceptually these interactive habitats are more advanced compared to Modernistic period in terms of the digitalization of architectural elements, such as walls, in which case the aesthetics is not only applied to their surface but integrated within the façade elements, for example. This kind of quality of architectural elements' digitalization provides for conceptualisation of transparent and interactive habitats that include a variety of choice and flexible use. A kind of hyper-functional developments should be redirected towards creation of digitized habitats that can offer engaging and meaningful interactive characters and can create more than

[604] Ibid., 332.

screen mediated virtual environments but can encourage exploration and experimentation with new modes of peoples ways of living. This implies the creation of environments with the concept of cybernetic mutualism involving the introduction of cybernetic relations and interactions, leading to more complex, rich, real-time, spontaneous, non-instrumental interaction with people, processes, signals and events in the building's interior and exterior.

In terms of an aesthetic difference between *KPN, BIX, Galleria* and *Dexia Tower*, the first and last have similar formal attributes in terms that they both have an orthogonal composition, while *BIX* is very organic and curvilinear. In these cases, the form of the building influenced the type of light source used and the way it is integrated into the façade surface. All four buildings have a simple modular division of façade and the light systems are integrated in such a way that they are either immediately under the glass of the structural curtain wall façade, directly on top of it, or the façade modules are the light system, as in case of *Galleria*. Most of the buildings that use the façade as a display surface show dual functionality in terms of their usage period, meaning that there is a strong division between night and day appearance and usage. During daytime these types of buildings, like museums (*BIX*), office and administrative buildings (*KPN* and *Dexia Tower*), are used according to their nominated functional purpose, while during the night they can be used in a different manner through their exterior appearance by activation of their digital façades. Through the façade interaction buildings become cultural artifacts and urban events in a city, which can become gravitational nodes for people who want to have more engaged relationship with a city. These urban artifacts create cybernetic environments which have their own distinctive aesthetic that is not formal in character but can be referenced through the experience one can have through an interaction with an artifact. The potential of the message these digital façades transmit is not about calmness and stillness as in Modernistic façades, but that they invite participation and interaction.

4.8 Conclusions

From the analysis of digital façades two modes of interaction can be extracted: Kinetic interaction with dynamic architectural forms and Interaction with façades, discussed in the following sections.

4.8.1 Kinetic Interaction with Dynamic Architectural Forms

This mode of interaction refers to those architectural elements, such as façade or interior walls, that have a kinetic character. This means that their operation is managed through a series of computer controlled sensors and actuators that perform an action and are responsible for the regulation of the interaction. The interaction is based on feedback loop mechanisms, as in the previous modes, with additional complexity due to the kind of engaged relationship that is achieved with the environment. The material quality of this mode of interaction lies in its direct contact with a physical/construction element, which means that there are no intermediary components, such as a computer mouse or a keyboard, to mediate the interaction. It can happen though a body movement, through sound, light, touch, etc. The key conceptual quality is that this kind of environment presents a truly interactive multiple-loop system in which one enters into a conversation or a continual and constructive communication with the environment. This is one of the main characteristics of cybernetic mutualism. In this regard, the interactive cybernetic environment created due to the introduction of dynamic architectural physical elements does not strictly interpret the desires of the participants in the interaction but instead allows them to take a bottom-up role in configuring their surroundings in a tractable way without specific goals, as Pask considered should be the case. The dynamic character of the multiple-loop processes, the direct interaction with the physical entity and real-time transformations, the possibility to have a conversation with the environment through the software, which translates materiality from one medium to another, and the systems' capability of learning from participants are all characteristics of cybernetic mutualism. This kind of interactive cybernetic environment allows for spontaneous and intuitive exploration. Another advantage lies in the possibility for the participant to move freely, instead of being coupled with a stationary desktop computer. It can be concluded that *mutualism* regards the quality of relationships that are established between different artificial and natural agents within an environment and their possibility to learn for each other and *cybernetic* regards the method and plan of action of the participants that can initiate a multiplicity of spontaneous and changeable events within an environment.

As a consequence of this mode of interaction a new perception of the architectural space is created. This means that the material qualities of interaction change the space through augmenting it with digital qualities. A fluid space that performs, adjusts, alters and moves is created, one which does not consist of opaque elements that are there to protect and enclose human bodies. The material quality of this mode introduces a wall as an active intervention in space, and not its static divider. The participant in this mode of interaction is at the same time the actor and the spectator because his/her actions influence the change the space is going through in real-time. At the same time, the participant is able to observe how performed actions influence the space and through the continuous feedback loops with the system create an ongoing conversation with the environment. In this new situation, through the involvement of the conceptual qualities of interaction, the elements of the architectural materiality that are usually neutral, which are indifferent to their environment, transform into platforms for the exploration of new relations between the human body and architectural space. In Modernism, space was largely regulated by the numerically calculable size of the human body.[605] This changed with the introduction of the material and digital qualities of kinetic interaction integrated with the architectural space that enabled its conceptualisation through more than its three-dimensional properties.

The important aspects of kinetic interaction are its digitization qualities employed through the mechanisms of translation that are the determining factors of the environment's interactivity. An important constituent of these digitization qualities is software that is perceived as the transformative creative medium with the capacity for the translation of the information necessary to enable its transfer from one form to the other. This is evident in the process of instant transfer from one medium to another, such as sound to light or movement to sound. This translation can influence the material qualities of the interaction through the way space oscillates between solid and fluid, which can form an architectural cybernetic environment that is constantly balanced between physical states. It can also determine the conceptual quality of interaction because, if the transition between one medium to another is not smoothly performed, then the interaction will lose its spontaneity and sophistication. Conceptually, kinetically interactive architectural elements and surfaces present artificial transferring devices that

[605] Le Corbusier, *The Modulor: A Harmonious Scale Universally Applicable to Architecture and Mechanics*, Birkhauser, Basel, Switzerland, 2000, 47.

can be changed into a movement that creates real-time events. Interpreted in this way, interaction with a surface becomes an active, playful and stimulating process through which a relationship between a participant and a computational device can be established on a level higher than the responsive one. The higher level of interaction involves an ongoing dialogue between the participant and the kinetic surface that is achieved through multiple-loop systems, which can change the direction of the interaction and create new ways of communication relative to the participant's choice of activity.

The next mode of interaction is influenced by the introduction of so called *Urban Screens* into urban environments created around public spaces within cities. This mode differs from the previous one in both the material medium and the way in which the relationship with digital objects/elements is achieved.

4.8.2 Interaction with Façades

Interaction occurs with digital façades, as urban communication artefacts, as part of the transformation of public space within cities, primarily through their integration in the build environment. This happens through the digitization qualities of the interaction being integrated into large screen-like surfaces, whose formalization ranges from digital displays to communication media technologies. Interaction is usually mediated through a computer console, mobile phone or Internet. It differs from the basic model of human-computer interaction in its key characteristics, which are the change of the material qualities of interaction in terms of its relocation from the computer desk to an urban environment, the possibility it has to develop the digitization qualities in order to create an individual sense of place with an urban artefact, and the development of the conceptual qualities through socially engaging content that can be transmitted through an urban artefact. The conceptual quality of interaction is in this case directly linked to creating a sense of place, which reflects the personal symbolic inscription the participant records on the façade in form of a text message, image or animation. Another conceptual quality that arises lies in the fact that the social content relates to the events created around these urban communication artefacts, which present platforms for a new form of social interaction to occur. These social events present a transition from individual capsulized attention to focused collective action. In this shared activity the participants commit themselves to the action and communicate their opinions through a dialogue with each other and with the urban artefact. The consequence of this dialogue is then visible on the façade’s surface. This mode of interaction can happen in real-time and have a multiplicity of meaning that is reflected through the digital display surface.

In regard to cybernetic mutualism, interaction with façades is most developed in terms of the encouragement of social interaction because it implies multiple inputs by a number of people that can happen at the same time and have real-time results. Interaction with the façade directly influences changeability of events on the façade. This happens through multiple feedback loops and presents one of the main characteristics of cybernetic mutualism. The modes of interaction that happens with façades in this way have the potential to evolve to become actual cybernetically mutualistic mode of interaction - the possibility for participants to interact with the façade directly through, for instance, touching its surface. This would also imply the modular composition of the façade requiring each element of the façade to be a discrete computational device that is able to learn from the participant and capable of *proposing* possible options for aesthetic change.

Unlike Internet based social platforms, which enable interaction with other participants only through an interface with a predetermined set of hypertext forms in the context of the participants’ homes, the conceptual quality of this mode lies in the social interaction that allows for collective action while the participants at the same time share the same physical space. This postulates interpersonal behaviour and face-to-face encounters. It is very important quality because the basic mode of human-computer interaction is restricted to the individual's capsularisation with the computer screen. The novelty in this mode of interaction lies in its digitization qualities that are reflected in the translation of behavioural actions, such as the participant's gestures, movements, positions, into digital forms that can be continuously fed into the event, whether intentionally or not. Translation in this case differs from the previous mode in relation to the medium that communicates the message. In the case of the digitization qualities of kinetic interaction, the translator is a dynamically sensitive surface that can interact with the participant directly through touch, body movement or sound. In the case of interaction with façades, this happens indirectly through an interactive computer console or mobile phone.

The transformative potential of this interactive modality is in the social engagement and dialogue that can be established between the inhabitants of cities and their neighbourhoods. This will depend on the location of the urban artefacts and therefore of the environmental context in the city, their purpose in terms of whether they are for public use, or are used by an art or commercial institution, and the interaction level involved. The interaction level relates to the material quality of real-time interaction, which assumes that the participant can immediately see the result of interaction on the façade. The purpose of these artefacts is important because it can determine the site specific nature of the content displayed and therefore can imply a specific way in which this mode of interaction should engage the participation of the inhabitants, whether they are in transit or are more permanent visitors. This also changes the material qualities and the nature of the architectural façade wall. The façade becomes a fluid and mutable element that creates a transitional space between the wall and the actual enclosure of the activity performed inside the building relative but not necessarily dependent upon the activity on the building's façade. A development of Digital Façades as interactive urban artefacts should consider their conceptual and contextual implication in the life of the city that should enhance social engagement and participation in the events formed around them.

Conclusion – Interaction

The discussion pursued throughout the previous chapters was centred on the observation of different modalities of computational architecture, digital interior spaces, digitized design processes and communicational exterior environments, and these modalities were analysed with the use of four qualities: Concept, Materiality, Digitization and Interactivity; of these, interactivity was crucial. It became the key in part because it presents a moment in which an idea becomes formalised through an architect's relationship with natural, digital, and/or virtual materials. It was also important because it distinguishes the quality of the relationships which the inhabitants of digitized architectural spaces can establish with the interior and exterior elements of a building. The communication that occurs through interaction between the space and those who inhabit it is different from the interaction that occurs between the inhabitants of digitized space. The boundaries between these forms of interactions are blurred, so a certain mode of interaction can have qualities of two forms. The mutual thread of thought between these different forms of interaction lies in the way in which the relationships are established. This is usually achieved through a number of feedback loops integrated into the dynamic systems within the space. Multiple feedback loops are therefore the key mechanisms of interaction because they determine the kind of relationships that are established with the dynamic system and, through it, with the space. In this way the participant and the dynamic system are closely coupled without any need to specify the nature of the dynamic system. This can provide spontaneous and intuitive interaction. Genuine interaction is therefore a spontaneous and intuitive conversation with the environment that is a dynamic system, which has multiple feedback loops that provide a continuously changeable relationship with it. The relationship can be altered and adjusted with the real-time results. This form of comprehension of interaction differs from what is commonly understood as human-computer interaction in that it provides for the new kind of relationship between the dynamic system and the participant.

The nature of interaction within computational architecture implies other qualities of cybernetic architectural environments, such as concept, materiality and digitization. This means that the combination of different aspects of these qualities can form diverse interactive modalities. Concept gives a specific quality to an environment in that it is able to determine the structure of the conversation between the participant and the environment. The character of the interaction could be determined by the diverse set of relations that are established between the constitutive elements of the environment. Considering that the nature of an architectural space involves different levels of materiality, the nature of cybernetic architectural environments integrates materiality that can be shaped and developed under the influence of interaction during digital processes. This means that the new digital materiality constitutes material properties that can be conceptualised by the digital logics of processual nature and calculatory precision. Throughout this thesis digitization has been understood as the process of translation of peoples' actions, such as gestures and body movements, into digital forms that are processed according to an algorithm. This translation influences a transformation between different states, solid and fluid, of a dynamic system within an architectural space. In this regard, digitization entails the quality of the computational processes involved in the interaction and their distinct adaptation to the different interactive modalities.

The definition of interaction proposed by this thesis is that it presents a dialogue between the participant and the cybernetic architectural environment, conditioned by the conceptual, materiality and digitization qualities of interaction. The observed qualities are impelled by the nature of the architecture that involves interconnection between different areas of investigation and their mutual relationships. The conceptual quality is the structural construction and signification of thought in the design of interactive cybernetic environments. This is important for the engagement of participants in the process of interaction because it indicates the mutual relationships that have been established during the interaction. The material quality implies the diversity of modalities in which natural, digital and virtual materials connect and relate to each other. This is important because it provides the basis for transformation between the solid and fluid states of the space while introducing architectural elements as active interventions in space. The digitization quality of the interaction entails augmentation of architectural space with digital objects. It is reflected in the flexibility and adaptability of the processes of translation between the different material states of the space during interaction. As observed through these qualities it can be said that interaction is a spontaneous and intuitive conversation with the environment enabled by flexible and adaptable processes of translation between solid and fluid material states that, through employment of multiple feedback loops to provide a continuously changeable relationship with the environment, can be altered with real-time results.

The proposed interaction creates a fluid space that performs, adjusts, alters and moves, but which does not consist of opaque architectural elements that are designed to protect and enclose human bodies. This kind of cybernetic architectural environment is constantly balanced between physical states and does not interpret the desires of the participants in the interaction, but allows them to take a role in configuring their surroundings in a tractable way without specific goals. The environment changes through peoples' participation in the activities inside the space. An important characteristic of interaction is that its conceptual, material and digitization qualities are concerted in such a way as to generate social activities with meaningful content. This implies that interaction depends on the meaningful connections established between the architectural/digital elements and the participants in the process. The generation of meaningful social content is provided through mutualistic relations between the participants and the dynamic system embedded in the environment. This implies that both systems, natural and artificial, will learn from each other. Learning is regarded as the possibility to continuously adapt to the new conditions in the environment. The environment's performative capacities in terms of continual real-time interaction depend on the system's flexibility and adaptability. The base for novel approaches in the environment's formalisation may be generated through collective interaction of ideas and concepts. In this regard, an important aspect of collective interaction is the attribute of self-organization, which depends on multiple real-time interactions with an accent on their non-linear structure. Non-linearity is the key because it does not prescribe the way in which interaction should be accomplished but offers a multiplicity of choices with flexible and changeable outcomes. It can be said that cybernetic architectural environments, as proposed by this thesis, can evolve in performative rather than representative interactions with one another and are thus regarded as *transparent*. These environments are *transparent* because they are open for public participation, the communication between natural and artificial systems is spontaneous and intuitive and interaction occupies people in playful and performative activity.

The combination of the digitization and material qualities of interaction in this kind of environment can result in distinct aesthetic expressions. The ways in which relationships between different materials are structured determines this differentiation. The forms of cybernetic architectural environments obtained in this manner are in a continual search for instruction through interaction and feedback with a number of environmental constraints. The production of such environments could be possible through improved processes of digital fabrication. This implies that the wider discourse of thinking about the new materials used during digital fabrication will hopefully continue to open new processes and treatments of materials able to improve the notions of cybernetic architectural environment development. This further implies the development of material qualities during fabrication, not only in terms of their function as efficiency measurements but also in terms of the exploratory moments of interaction. The emerging spatial forms may be created in direct interaction with the physical materials assembled and fused in real-time interactions within the environment.

The previous discussion concerns the mode of interaction proposed in this thesis as *cybernetic mutualism*. In this formulation, the *mutualism* concerns the quality of relationships that are established between different artificial and natural agents within an environment and their possibility to learn from each other and the *cybernetic* regards the method and plan of action of the participants that may initiate a multiplicity of spontaneous and changeable events within such an environment. The interactive cybernetic environment created due to the introduction of dynamic architectural elements allows participants to take a bottom-up role in configuring their surroundings. Some of the characteristics of cybernetic mutualism are the dynamic character of the multiple-loop processes, the direct interaction with the physical entity and real-time transformations, the possibility to have a conversation with the environment through the software, which translates materiality from one medium to another and the systems' capability to learn from a participant. In cybernetic mutualism, interaction implies the relationship that a participant has with the environment when using a computer as a mediator. This means that the interaction frames the possibility of a conversation between a participant and an environment. In a cybernetically mutualistic interaction, the architectural environment is augmented with digital objects, which mediate the interaction. The digital objects observe the action that happens within the environment and are able to react to the quantitative attributes of the participant's activity. The interaction with the system is determined by the complexity of the system. The complex system can be adaptive in that it can have a capacity to learn from experience, which implies that complex systems can self-organize over time. The system's collective behaviour can emerge from the interaction that takes place between a number of simple elements within the system. Therefore, cybernetically mutualistic interaction has to be with the right level of complexity in order to encourage playfulness and arouse curiosity. This concerns characteristics such as spontaneousness and intuitive exploration. This means that intuitive learning takes place through discovery of the system's characteristics by means of use and feedback. An important issue here then is the decision of what will be predetermined as being significant to the system.

In this thesis, human-computer interaction during the production of architectural designs is regarded as based on an advanced form of reactivity, which is commonly misinterpreted as interactivity, and which involves the reaction of the computer to the user's input. This means that the modality commonly perceived as human-computer interaction is based on the elementary form of action-reaction relationship that can be connected to the first order of cybernetics. The argument that this thesis offers is that there are many different modes of interaction between humans and computers. These modes are discussed in regard to the different characteristics and diverse relationships established in their processes. One is the thematic mode of interaction in which the theme is the starting point in the conversation with the environment. The *thematic* in this case is concerned with the grouping and assembling of the common attributes and characteristics of the digital objects used for the augmentation of cybernetic architectural environments with the aim of creating a characteristic and consistent conversation with the environment. Considering that the theme of the conversation can inspire further communication, this can determine the direction and quality of the interaction. This means that a participant and a system can establish a relationship through feedback loops that are framed by the ways in which the interaction with environment functions in relation to the theme.

In terms of the other modes of interaction analysed in this thesis, interaction as participatory process was observed through spontaneous processes that emerge within cybernetic environments between people and architectural space: inside the space but not involving use of digital objects within it. An important prerequisite for the space is that it should be flexible enough to generate social activities with a meaningful content.

The activities are organized through the building's program. This means that different activities are organised within the space and that the form of the building is adjustable and transformable according to need. Through an engagement with various activities participants establish spontaneous connections between themselves and the space they inhabit and create. In this case, interaction becomes a moment in which a participant is encouraged to make decisions about his/her level of participation in different activities. This creates a focus on the process as a means of creation. Because of the state of continual real-time interaction, this kind of space can incorporate cyclical feed-back loops of programmed activity with algorithmically changeable content that does not involve digital objects and interaction with discrete computational units. In this case interaction directly depends on the essence of the action or the meaningful connections established through the relationships between the elements in space and the participants in the process.

Another mode differentiated in this thesis is interaction with parametric software that provides a novel approach in the production of architectural designs because an architect can design a building through the construction of a generative system that produces a form. The novelty lies in dealing with the material qualities of interaction, so that the building's form is the result of the process. The potential of this mode of interaction lies in the possibility for the architect to directly modify the relationships of the drawn elements through editing the underlying generative software system. Through interaction, the spaces created in this process would be in a state of constant redefinition and not only in formal representational terms. In terms of cybernetic mutualism, the new concept of parametricism in combination with developments in CNC and Rapid Prototyping technologies can open up possibilities for the exploration of mutualistic qualities that can create architectural spaces that contain fundamentally evolutionary difference not only in regard to the formal attributes of the architectural space, but in regard to creation of actually dynamic spaces in which interaction though cybernetic mutualism crates cybernetic architectural environments.

Interaction during digital fabrication is differentiated because it is based on the file-to-factory production principle. In this mode, the combination of digitization and the material qualities of interaction result in distinct aesthetic expressions. This distinction occurs because of the way in which relationships between the materials are structured in a way that is distinct to cybernetic mutualism. In this mode the accent is on the material quality of interaction that emphasises relations between the physical materials and their fusion into an architectural form. This implies that the unpredictable architectural forms obtained through this mode of interaction, could be related to the deliberate alteration and modification of the parameters that, in the digitized modes of production, define the process of design. In the various stages of additive fabrication, the characteristics of cybernetic mutualism are reflected in the ways digital and physical materials can combine. The physical results of these processes are spontaneous and mutable, implying some attributes of cybernetic mutualism.

In the modes of interaction that happen with Digital Façades, kinetic interactions with dynamic architectural forms refers to those architectural elements that have a kinetic character. This means that their operation is managed through a series of computer controlled sensors and actuators that perform an action and are responsible for the regulation of the interaction. The interaction is based on feedback loop mechanisms, as in the previous modes, with additional complexity due to the kind of engaged relationship that is achieved with the environment. An important characteristic of this mode of interaction lies in its direct contact with a physical/construction element, which means that there are no intermediary components to mediate the interaction. It can happen though a body movement, sound, light, touch, etc. This kind of environment presents a truly interactive multiple-loop system in which one enters into a direct conversation with the environment. This is one of the main characteristics of cybernetic mutualism.

Another mode of interaction that occurs with Digital Façades is through the integration of large screen-like surfaces into building façades. Their formalization ranges from digital displays to communication media technologies. Such interaction is usually mediated through a computer console, mobile phone or Internet. The conceptual quality of interaction is directly linked to creating a sense of place, which reflects the personal symbolic inscription the participant records on the façade in form of a text message, image or animation. Another quality that arises lies in the fact that the social content relates to the events created around these urban communication artefacts, which present platforms for a new form of social interaction to occur. These social events present a transition from individual capsulized attention to focused collective action. The novelty in this mode of interaction lies in the way in which the translation of behavioural actions, such as the participant's gestures, movements, positions, into digital forms can be continuously fed into the event via digitization. The potential of this interactive modality is in the social engagement and dialogue that can be established between the inhabitants of cities and their neighbourhoods. This will depend on the location of the urban artefacts and therefore of the environmental context in the city, their purpose in terms of whether they are for public use, or are used by an art or commercial institution, and the interaction level involved. The interaction level relates to the material quality of real-time interaction, which assumes that the participant can immediately see and engage with the result of interaction on the façade. The purpose of these artefacts is important because it can determine the site-specific nature of the content displayed and therefore can imply a specific way in which this mode of interaction can engage the participation of the inhabitants, whether they are in transit or are more permanent visitors.

It can be concluded that the importance of interaction for architecture pervades many of its aspects, from the architectural design conception to its materialisation in form of a digital façade. With the introduction of digital technologies into numerous aspects of everyday life and the emergence of ubiquitous computing, interaction will gain more significance for architecture in the future because of the change in the way people relate to their habitats and each other. Cybernetic mutualism offers a proposition about how these relationships can be established in a meaningful way so that all the agents in the interaction can reflect upon their actions in the environment and to each other. It can imply guidelines that will involve interdependence between natural and artificial agents and their reciprocal learning. Cybernetic mutualism can also encourage the creation of new mechanisms for design conceptualisation through participation and collaboration. New relations between an architect, idea and the form of the building can be accomplished through correlation of different digital processes, such as rapid prototyping and parametric modelling and the creation of interactive events on building façades with characteristics of cybernetic mutualism may inspire collective actions which can initiate further complex social interactions.

Bibliography:

Abruzzo, Emily and Solomon, Jonathan D. (eds.), *306090-05: Teaching + Building – Beyond the Imagined,* Architecture Journal, September 2003, Princeton Architectural Press, New York, 2003.

Alexander, Christopher, Ishikawa, Sara and Silverstein, Murray, *A Pattern Language: Towns, Buildings, Construction*, Oxford University Press, New York, 1977.

Alexenberg, Mel, *The Future of Art in a Digital Age: From Hellenistic to Hebraic Consciousness*, Intellect Books Ltd., Bristol, UK, 2006.

Aldrich, Frances K., "Smart Homes: Past, Present and Future" in Richard Harper (ed.), *Inside the Smart Home*, Springer – Verlag, London, 2003

Alison, Jane, Brayer, Marie-Ange, Migayrou, Frederic and Spiller, Neil, *Future City: Experiment and Utopia in Architecture*, Thames & Hudson, London, 2006.

Amirante, Isabella M. and Ernesto, Burattini, "Automatic Procedures for Bioclimatic Control" in J. Klercker (ed.), *Education for Practice* Proceedings of the 14th eCAADe Conference, Lund, Sweden, 12-14 September 1996.

Anders, Peter and Phillips, Michael, *Arch-OS: An operating system for buildings*, paper for ACADIA conference 2004, Retrieved March 20, 2011, from http://www.mike-phillips.net/pdf/Acadia.pdf

Antonelli, Paola and Riley, Terence (eds.), "Interview with Pierre Apraxine" in *The Changing of the Avant-Garde: Visionary Architectural Drawings from the Howard Gilman Collection*, Museum of Modern Art, New York, 2002.

Appadurai, Arjun, "Disjuncture and Difference in the Global Cultural Economy" in Mike Featherstone (ed.), *Global Culture*, Sage Publications, Ltd., London, 1990.

Architectural Research Centres Consortium, *ARCC Conference Proceedings*, ARCC Spring Research Conference, The School of Architecture and Applied Arts, University of Oregon, Eugene 16-18 April 2007.

Ashby, William Ross, "Principles of the Self-Organizing Dynamic System" in *Journal of General Psychology*, Volume 37, 1947.

Ashby, William Ross, *Design for Brain*, John Wiley & Sons Inc., New York, 1954.

Ashby, William Ross, *An Introduction to Cybernetics*, Chapman & Hall Ltd., London, 1957.

Aspray, William, *John Von Neumann and the Origins of Modern Computing*, The MIT Press, Cambridge, Massachusetts, 1990.

Avery, John, *Information Theory and Evolution*, World Scientific Publishing Co. Pte. Ltd., Singapore, New York and London, 2003.

Bachelard, Gaston, *The Poetics of Space*, Beacon Press, Boston, 1969.

Baecker, Ronald M., Grudin, Jonathan, Buxton, William and Greenberg, Saul, *Readings in Human-Computer Interaction: Toward the Year 2000*, Morgan Kaufmann Publishers Inc., San Francisco, CA, Second edition, 1995

Baetens, Jan, “An Example of Remediation” in *Looking at McLuhan 'Remediation', Iconophobia and Denial of the Body in The Medium is the Massage*, Image & Narrative Online magazine of the Visual Narrative, Issue number 5: 'The Uncanny', January 2003.

Baldwin, J., *BuckyWorks: Buckminster Fuller's Ideas for Today*, John Wiley & Sons Inc., New York, 1996.

Balmond, Cecil (with Jannuzzi Smith), *Informal*, Prestel Verlag, Munich, 2002.

Banham, Reyner, *The Architecture of Well Tempered Environment*, The Architectural Press, London, 1969.

Banham, Reyner, *Theory and Design in the First Machine Age*, The MIT Press, Cambridge, Massachusetts, 1980.

Banks, Jerry, Carson II, John S., Nelson, Barry L. and Nicol, David M., *Discrete Event System Simulation*, International Series in Industrial and Systems Engineering, Prentice Hall, Upper Saddle River, New Jersey, Fourth edition, 2005.

Barr, Michael and Massa, Anthony J., *Programming Embedded Systems: with C and GNU Development Tools*, O'Reilly Media Inc., Sebastopol, CA, USA, 2006.

Batchelor, Ray, *Henry Ford, Modernism and Design: A Twentieth Century Cultural Phenomenon*, Manchester University Press, USA, 1994.

Beauce, Patrick and Cache, Bernard, “Towards a Non-Standard Mode of Production” in *Foreign Office Architects, Phylogenesis – Foa’s Ark*, Actar, Barcelona, 2004.

Beecher, Jonathan, “The Creation of Phalanx” in *Charles Fourier: The Visionary and His World*, University of California Press, Berkeley, Los Angeles and London, 1986.

Behrens-Abouseif, Doris, “Arabesque and Geometry” in *Beauty in Arabic Culture*, C. H. Beck'sche Verlagsbuchhandlung, Munich, 1998.

Benjamin, Andrew, “Notes on the Surfacing of Walls: NOX, Kiesler, Semper”, in Lars Spuybroek, *NOX: Machining Architecture*, Thames & Hudson, London, 2004.

Berkel, Ben van and Bos, Caroline, UNStudio, *MOVE*, vol. 2, Good Press, Netherlands, 1999.

Bertol, Daniela, *Designing Digital Space: Architect's Guide to Virtual Reality*, John

Wiley and Sons, New York, 1997.

Birn, Jeremy, *Digital Lighting and Rendering*, New Riders, Berkeley, CA, 2006.

Bishop, Richard and Crittenden, Richard, *Geometry of Manifolds*, American Mathematical Society, USA, 2001.

Blomfield, Reginald, *Architectural Drawing and Draughtsmen*, Cassell & Co., London, New York, Toronto, Melbourne, 1912.

Bonabeau, Eric, Dorigo, Marco and Theraulaz, Guy, *Swarm Intelligence: From Natural to Artificial Systems*, A Volume in the Santa Fe Institute Studies on the Sciences of Complexity, Oxford University Press, New York, 1999.

Boucher, Douglas H. (ed.), *The Biology of Mutualism: Ecology and Evolution*, Oxford University Press, New York, 1985.

Bouknight, W. M., *An Improved Procedure for Generation of Half-tone Computer Graphics Presentations* (Report/Coordinated Science Laboratory), University of Illinois, Coordinated Science Laboratory, USA, 1969.

Braham, William W. & Hale, Jonathan A. (eds.), *Rethinking Technology: A Reader in Architectural Theory*, Routledge, London and New York, 2007.

Braudel, Fernand, *Civilization and Capitalism, 15th-18th Century: The Wheels of Commerce*, Volume 2, University of California Press, Berkeley and Los Angeles, California, 1992.

Brent, Batstra, Graafland, Arie, Pinilla, Camilo and Maas, Winy (eds.), *Spacefighter: The Evolutionary City (Game)*, Actar, Barcelona, 2007.

Brodey, Warren, *Soft Architecture: The Design of Intelligent Environments*, Landscape 17, Number 1, Autumn 1967.

Brookes, Alan J. and Meijs, Maarten, *Cladding of Buildings*, Taylor & Francis, New York, 2008.

Brooks, Rodney A., *The Intelligent Room Project*, MIT Artificial Intelligence Lab, Retrieved April 24, 2010, from http://people.csail.mit.edu/brooks/papers/aizu.pdf

Brown, Denise Scott, "Talking Sheds", *Architecture Week*, page D1.1, April 2005, Retrieved February 15, 2010, from http://www.architectureweek.com/2005/0406/design_1-1.html

Brown, Marshall, "For_getting Drawing: Toward an Architectural Pedagogy for Digital Media" in Jamal Al-Qawasmi and Guillermo Vasquez de Velasco (eds.), *Changing Trends in Architectural Design Education*, CSAAR Publications, Amman, Morocco, 2006.

Brownell, Blaine (ed.), *Transmaterial 2: A Catalogue of Materials That Redefine Our*

Physical Environment, Princeton Architectural Press, New York, 2008.

Burke, Anthony and Tierney, Therese (eds.), *Network Practices: New Strategies in Architecture and Design*, Princeton Architectural Press, New York, 2007.

Cache, Bernard, *Earth Moves: The Furnishing of Territories*, MIT Press, Cambridge, Massachusetts, 1996.

Cache, Bernard, "Digital Semper" in William W. Braham and Jonathan A. Hale with John Stanislav Sadar (eds.), *Rethinking Technology: A Reader in Architectural Theory*, Routledge, New York and London, 2007.

Cache, Bernard, *Plea for Euclid*, Retrieved October 10, 2010, from http://architettura.supereva.com/extended/19990501/index_en.htm

Cadena, Richrad, *Automated Lighting: The Art and Science of Moving Light in Theatre, Live Performance, Broadcast and Entertainment*, Focal Press, Elsevier, Amsterdam, Boston, Heidelberg, London, New York, Oxford, Paris, San Diego, San Francisco, Singapore, Sydney, Tokyo, 2006.

Calvino, Italo, *Invisible Cities*, Vintage Books, London, 1997.

Camazine, Scott, *Self-organizing Systems*, Boalsburg, Pennsylvania, USA, p. 1, Retrieved April 05, 2010, from http://web.mac.com/camazine/Camazine/Self-organization_files/Self-organization.pdf

Camazine, Scott, Deneubourg, Jean-Louis, Franks, Nigel R., Sneyd, James and Theraula, Guy, *Self-Organization in Biological Systems*, Princeton Studies in Complexity, Princeton University Press, Princeton, New Jersey and Woodstock, Oxfordshire, UK, 2001

Cannon, Walter Bradford, "Homeostasis" in *The Wisdom of the Body*, (1932), Norton, New York, 1939.

Carroll, J. M. and Carrithers, C., *Blocking Learning Error States in a Training Wheels System*, Human Factors, 26, 1984a.

Carroll, J. M. and Carrithers, C., *Training Wheels in a User Interface*, Communications of the ACM, Number 27, 1984b.

Carroll, J. M., "Minimalist Design for Active Users" in B. Shackle (ed.), *Proceedings of First IFIP Conference on Human-Computer Interaction: Interact '84*, 1985.

Carroll, John M. and Olson, Judith Reitman (eds.), *Mental Models in Human-Computer Interaction: Research Issues About What the User of Software Knows*, National Academy Press, Washington D. C., 1987.

Carroll, J. M., Smith-Kerker, P., Ford, J. and Mazur-Rimetz, S., *The Minimal Manual*, Human-Computer Interaction 3, 1987-1988.

Cauter, Lieven de, *The Capsular Civilization: On the City in the Age of Fear*, NAi Publishers, Rotterdam, The Netherlands, 2005.

Chen, Qiyang, *Human Computer Interaction: Issues and Challenges*, Idea Group Publishing, Hershey, USA and London, UK, 2000.

Cherif, Abour H., *Mutualism: The Forgoten Concept in Teaching Science*, The American Biology Teacher, Volume 52, Number 4, April 1990, p. 206, Retrieved April 11, 2010, from http://www.jstor.org/pss/4449085

Childe, V. G., *Piecing Together the Past: The Interpretation of Archaeological Data*, London, 1956, p. 13, cited in Michael Vickers and David Gill, *Artful Crafts: Ancient Greek Silverware and Pottery*, Clarendon Press, Oxford, UK, 1996.

Ching, Francis D.K., *Architectural Graphics*, John Wiley & Sons, Hoboken, New Jersey, 2009.

Chua, C. K., Leong, K. F. and Lim, C. S. (eds.), *Rapid Prototyping: Principles and Applications*, World Scientific Publishing Co. Pte. Ltd., Singapore, 2003.

Clements, P. C., *From Subroutines to Subsystems: Component-Based Software Development*, The American Programmer, Volume 8, Number 11, 1995.

Clements, Paul, Bachmann Felix, Bass, Len, Garlan, David, Ivers, James, Little, Reed, Nord, Robert and Stafford, Judith, *Documenting Software Architectures: Views and Beyond*, SEI Series in Software Engineering, Addison-Wesley, Pearson Education Inc., Boston, MA, First edition, 2002.

Coen, Michael, *Design Principles for Intelligent Environments*, Proceedings of the Fifteenth National Conference on Artificial Intelligence, Madison, WI, 1998.

Coenders, J.L., *Interfacing Between Parametric Associative and Structural Software*, Delft University of Technology, The Netherlands and Arup Amsterdam, The Netherlands, 2007.

Cook, Peter, *Drawing: The Motive Force of Architecture*, AD Primers, John Wiley & Sons, Chichester, 2008.

Cook, Peter and Webb, Michael, *Archigram*, Princeton Architectural Press, New York, 1999.

Compton, Denis (ed.), *Concerning Archigram*, Archigram Archives, London, 1999.

Corbusier, Le, *Towards a New Architecture*, Dover Publications, UK, 1986.

Corbusier, Le, *The Modulor: A Harmonious Scale Universally Applicable to Architecture and Mechanics*, Birkhauser, Basel, Switzerland, 2000.

Cristina, Giuseppa di (ed.), *Architecture and Science*, Wiley-Academy, Chichester, 2001.

Daston, Lorraine, "Curiosity in Early Modern Science" in *Word and Image*, Number 11, 1995 (English version of Nr. 33).

Davidson, Cynthia, (ed.), *Sanford Kwinter: Far From Equilibrium – Essays on Technology and Design Culture*, Actar, Barcelona and New York, 2007.

Davies, Colin, *High Tech Architecture*, Thames and Hudson, London, 1989.

Davis, Stanley M., *Future Perfect*, Addison-Wesley, Reading, Massachusetts, 1987 and 1996.

Dean, Penelope, *Hunch 10: Mediators*, The Berlage Institute Report, Episode Publishers, The Netherlands, 2006.

De Landa, Manuel, "Materiality: Anexact and Intense" in Lars Spuybroek, *NOX: Machining Architecture*, Thames & Hudson, London, 2004.

DeLanda, Manuel, "Deleuze and the Use of the Generic Algorithm in Architecture" in Foreign Office Architects, *Phylogenesis – Foa's Ark*, Actar, Barcelona, 2004.

De Landa, Manuel, "A Thousand Years of Non-Linear History" in Camilo Pinilla, *The Politics of Design: Designers as Transparent Mediators* and P. Healy & G. Bruyns (eds.), *De-/signing the Urban – Technogenesis and the Urban Image*, Delft School of Design Series on Architecture and Urbanism, 010 Publishers, Rotterdam, 2006.

Deleuze, Gilles and Guattari, Felix, *What is Philosophy?*, Verso, London and New York, 1994.

Deleuze, Gilles, *The Fold: Leibniz and the Baroque*, Continuum, London and New York, 2006.

Descartes, Rene, "Discourse 2 of the Dioptrics" in Stephen Gaukroger (ed.), *The World and Other Writings*, Cambridge Univesity Press, Cambridge, New York and Melbourne, 1998.

DeVore, Ronald A. and Lorentz, George G., *Constructive Approximation*, Grundlehren der mathematischen Wissenschaften (A Series of Comprehensive Studies in Mathematics), Springer – Verlag, Printed in United States, 1993.

De Wolf, Tom and Holvoet, Tom, "Emergence Versus Self-Organization: Different Concepts but Promising When Combined" in Sven A. Brueckner, Giovanna Di Marzo Serugendo, Anthony Karageorgos and Radhika Nagpal (eds.), *Engineering Self-Organizing Systems: Methodologies and Applications*, Lecture Notes in Computer Science/Lecture Notes in Artificial Intelligence, Springer-Verlag, Berlin and Heidelberg, 2005.

Dorf, Richard C. and Kusiak, Andrew (eds.), *Handbook of Design, Manufacturing and Automation*, John Wiley and Sons, New York, 1994.

Du, Timon C., “Emerging Database System Architectures” in Cornelius T. Leondes (ed.), *Database and Data Communication Network Systems: Techniques and Applications*, Volume 1, Elsevier Science, San Diego, California, USA and London, England, UK, 2002

Dunne, Anthony, *Hertzian Tales: Electronic Products, Aesthetic Experience and Critical Design*, The Royal College of Art & Anthony Dunne, London, 1999.

Eastman Charles, “Adaptive-Conditional Architecture” in Nigel Cross (ed.), *Design Participation*, Proceedings of the Design Research Society’s Conference Manchester, September 1971, Academy Editions, London, 1972.

E:cue Lighting Control, “System Overview” in *System Manual: Basic. Programmer 5.1*, e:cue control GmbH, 2009.

Edler, Jan and Edler, Tim, “Message vs. Architecture? Dynamic Media as a Continuation of Architecture” in O. Kas and F. Lukas (eds.), *Game Set and Match II*, Episode Publishers, Rotterdam, 2006.

Egenter, Nold, *The Metabolism of Form in Antique Architecture*, (paper originally read at the International Seminar 'Architettura in Pietra a Secco', 27. - 30. Sept. 1987), University of Bari, Bari, Italy, 1990.

Eglash, Ron, *African Fractals: Modern Computing and Indigenous Design*, Rutgers University Press, Piscataway, New York, 1999.

Eisenman, Peter, *Conceptual Architecture II: Double Deep Structure I*, A+U 4, Number 39, March 1974.

Eisenman, Peter, “The Houses of Memory: The Texts of Analogy” in Aldo Rosi, *The Architecture and the City*, MIT Press, Cambridge, Massachusetts, and London, England, 1984.

Eisenman, Peter, “Post-Functionalism” in Kate Nesbitt (ed.), *Theorizing a New Agenda for Architecture: Anthology of Architectural Theory, 1965-95*, Princeton Architectural Press, New York, 1996.

Eisenman, Peter, “Visions Unfolding: Architecture in the Age of Electronic Media” in Luca Garofalo (ed.), Lucinda Byatt, translator, *Digital Eisenman: An Office of the Electronic Era*, IT Revolution in Architecture, Birkhauser, Basel, Switzerland, 1999.

Engelbart, Douglas C. and English, William K., “A Research Centre for Augmenting Human Intellect” in Irene Greif (ed.), *Computer-Supported Cooperative Work: A Book of Readings*, Morgan Kaufman Publishers Inc., San Mateo, CA, USA, 1988.

Engelbart, Douglas, “Augmenting Human Intellect: A Conceptual Framework” in Noah Wardrip-Fruin and Nick Montfort (eds.), *The New Media Reader*, MIT Press, Cambridge, Massachusetts and London, England, 2003.

Engeln-Müllges, Giesela and Uhlig, Frank, translated by M. Schon and F. Uhlig, *Numerical Algorithms with C*, Springer, Verlag Berlin, Heidelberg, 1996.

Engels, Friedrich, *The Condition of the Working Class in England in 1844*, Cosimo Classics, New York, 2008.

Farin, Gerald E., *NURBS for Curve and Surface Design*, A. K. Peters Ltd., Natick, Massachusetts, 1999.

Farin, G., Hoschek, J. and Kim, M.-S. (eds.), *Handbook of Computer-Aided Geometric Design*, Elsevier Science B. V., Amsterdam, The Netherlands, 2002.

Fatah, A. gen. Schieck, "Towards an Integrated Architectural Media Space", *First Monday*, Special Issue number 4: Urban Screens: Discovering the potential of outdoor screens for urban society, February 2006, Retrieved April 28, 2008, from http://firstmonday.org/issues/special11_2/fatah/index.html.

Faure, Claude, "Pen-Based Human-Computer Interaction" in M. I. Simner, C. G. Leedham and A. J. W. M. Thomassen (eds.), *Handwriting and Drawing Research: Basic and Applied Issues*, IOS Press, Amsterdam, The Netherlands, 1996

Fischer, G. and Ostwald, J., *Seeding, Evolutionary Growth and Reseeding: Enriching Participatory Design with Informed Participation*, Proceedings of the Participatory Design Conference (PDC'02), Malmö University, Sweden, 2002.

Fischer, Gerhard, "Meta-Design: Beyond User-Centred and Participatory Design" in Julie A. Jacko and Constantine Stephanidis (eds.), *Human-Computer Interaction: Theory and Practice*, Part 1, Volume 1, Lawrence Erlbaum Associates Inc., Mahwah, New Jersey, 2003.

Fischer, Gerhard, "Meta-Design: Beyond User-Centred and Participatory Design" in Julie A. Jacko and Constantine Stephanidis (eds.), *Human-Computer Interaction: Theory and Practice*, Part 1, Volume 1, Lawrence Erlbaum Associates Inc., Mahwah, New Jersey, 2003.

Focillion, Henry, *The Life of Forms in Art*, Zone Books, New York, 1996.

Foerster, Heinz von, "Ethics and Second Order Cybernetics" in *Understanding Understanding: Essays on Cybernetics and Cognition*, Springer-Verlag, New York, 2003.

Fournier, Colin, Cook, Peter, Price, Cedric, Bogner, Dieter and Pakesch, Peter, *Friendly Alien*, Hatje Cantz Books, Cologne, 2004.

Fox, Michael and Kemp, Miles, *Interactive Architecture*, Princeton Architectural Press, New York, 2009.

Frampton, Kenneth, *Modern Architecture: A Critical History*, Oxford University Press, Oxford University, UK, 1981.

Frascari, Marco, *Eleven Exercises in the Art of Architectural Drawing: Slow Food for* *the Architect's Imagination*, Routledge, New York, 2011.

Frazer, John H., *An Evolutionary Architecture*, Architectural Association Press, London, 1996.

Friedewald, Michael, “The Continuous Construction of the Computer User Models in the History of Human-Computer Interaction” in Gerhard M. Buurman (ed.), *Total Interaction: Theory and Practice of a New Paradigm for the Design Disciplines*, Birkhauser – Publishers for Architecture, Basel, Switzerland, 2005.

Friedman, Yona, *Utopies Realisables*, Editions de L'eclat, Paris, 2000.

Fuller, Buckminster, *Ideas and Integrities*, Collier Books, New York, 1963.

Fuller, Buckminster, “Prime Design” in Robert W. Marks (ed.), *Ideas and Integrities: A Spontaneous Autobiographical Disclosure*, Collier Books, New York, 1969.

Fuller, R. Buckminster, *Operating Manual for Spaceship Earth*, Pocket Books, New York, 1970.

Fuller, R. Buckminster, *Synergetics: Explorations in the Geometry of Thinking*, in collaboration with E. J. Apple-white, Macmillan Publishing Company, New York and London, 1975.

Fuller, Buckminster in “Conclusion: Functionalism and Technology” in Peter Reyner Banham, *Theory and Design in the First Machine Age*, The MIT Press, Cambridge, Massachusetts, 1980.

Fuller, R. Buckminster, *Critical Path*, St. Martin's Press, New York, 1981.

Fuller, Matthew, *Media Ecologies: Materialist Energies in Art and Technoculture*, MIT Press, Cambridge, 2005.

Fuller, Matthew, *Softness: Interrogability; General Intellect; Art Methodologies in Software*, Digital Research Unit, University of Huddersfield and The Media Centre, Huddersfield, UK, 2006.

Fuller, Matthew and Antic, Dragana, “Calculation Space”, *De Witte Raaf*, Antwerp, Belgium (Vlaams/English), 2007.

Matthew Fuller (ed.), *Software Studies: A Lexicon*, MIT Press, Cambridge, Massachusetts and London, England, 2008.

Furuya, Yasubumi, “Reasearches of Smart Actuator Materials in Japan” in Mangalgiri, P. D., Upadhya, A. R. and Selvarajan, A. (eds.), *Smart Materials, Structures and Systems – ISSS-SPIE '99*, Allied Publishers, New Delhi, 1999.

Ganti, Tibor (ed.) with commentary by James Griesemer & Eors Szathmary, *The Principles of Life*, Oxford Biology, Oxford University Press Inc., New York, 2003.

Geddes, Patrick, "Paleotechnic and Neotechnic" in Braham, William W. and Hale, Jonathan A. with Sadar, John Stanislav (eds.), *Rethinking Technology*, Routledge, Taylor and Francis Group, New York and London, 2007.

Gero, John S. and Goel, Ashok K. (eds.), "Idea Development Can Occur Using Imagery Only" in *Design Computing and Cognition 2008*, Proceedings of the Third International Conference on Design Computing and Cognition, Springer, Heidelberg, 2008.

Gerovitch, Slava, *From Newspeak to Cyberspeak: A History of Soviet Cybernetics*, MIT Press, Cambridge, Massachusetts, London, England, 2004.

Gessler, Nicholas, "Artificial Culture" in Rodney Brooks and Pattie Maes (eds.), *Artificial Life IV*, Proceedings of the Fourth International Workshop on the Synthesis and Simulation of Living Systems, MIT Press, Cambridge, 1994.

Gessler, Nicholas, "Skeuomorphs and Cultural Algorithms" in *Lecture Notes in Computer Science, Proceedings on the 7th International Conference on Evolutionary Programming VII*, Springer - Verlag, Berlin and Heidelberg, 1998.

Giannachi, Gabriella, "Performing Through Hypersurface" in *Virtual Theatres: An Introduction*, Routledge, Taylor & Francis Group, London and New York, 2004.

Gibb, Alistair G. F., *Off-Site Fabrication: Prefabrication, Pre-Assembly and Modularisation*, John Wiley & Sons Inc., New York and Toronto, 1999.

Gibson, Ian, Rosen, David W. and Stucker, Brent, *Additive Manufacturing Technologies: Rapid Prototyping to Direct Digital Manufacturing*, Springer, New York, Heidelberg, Dodrecht, London, 2009.

Gibson, James Jerome, *The Ecological Approach to Visual Perception*, Lawrence Erlbaum Associates Inc., New edition, Hillsdale, New Jersey, 1986.

Gille, Bertrand, *The Renaissance Engineers*, Lund Humphries/London, 1966.

Glassner, Andrew S., *An Introduction to Ray Tracing*, Morgan Kaufmann Publishers Inc., San Francisco, CA, USA, 1989.

Goetsch, David L., Chalk, William S., Nelson, John A. and Rickman, Raymond L., *Technical Drawing*, Drafting and Design Series, Thomson Delmar Learning, Clifton Park, New York, 1999.

Goriunova, Olga and Shulgin, Alexei, "From Art on Networks to Art on Platforms, (Case Studies: Runme.org, Micromusic.net and Udaff.com)" in Joasia Krysa (ed.), *Curating Immateriality: The Work of the Curator in the Age of Network Systems*, Autonomedia (DATA browser 03), 2006.

Gorman, Michael John, *Buckminster Fuller: Designing for Mobility*, Skira, New York, (Italian translation: *Buckminster Fuller: Architettura in Movimento*, Skira Editore, Milan, Italy, 2005.)

Goulthorpe, Mark, *The Possibility of (an) Architecture, Collected Essays by Mark Goulthorpe/dECOi*, Routledge, Taylor & Francis Group, London and New York, 2008.

Graham, Stephen and Marvin, Simon, "Introduction: Networked Infrastructures, Technological Mobilities and the Urban Condition" in *Splintering Urbanism*, Routledge, London, 2001.

Graham, Steve (ed.), *The Cybercities Reader*, Routledge, Urban Reader Series, London and New York, 2003.

Gramazio, Fabio and Kohler, Matthias, *Digital Materiality in Architecture*, Lars Muller Publishers, Baden, Switzerland, 2008.

Greenfield, Adam, *Everyware: The Dawning Age of Ubiquitous Computing*, New Riders, Berkeley, CA, USA, 2006.

Grehant, Bernard, *Acoustics in Buildings*, Thomas Telford Publishing, London, 1996.

Grimm, Todd, *User's Guide to Rapid Prototyping*, Society of Manufacturing Engineers, Dearborn, Michigan, USA, 2004.

Gross, Charles G., "Claude Bernard and the Constancy of the Internal Environment" in *The Neuroscientist*, Volume 4, Issue Number 5, 1998.

Guattari, Félix, *The Three Ecologies*, Athlone, London, 2000.

Guattari, Félix, *Cartographies Schizoanalytiques*, Galilée, Paris, 1989.

Gunter, Barrie, *The Effects of Video Games on Children: The Myth Unmasked*, Sheffield Academic Press, Sheffield, England, 1998.

Hannon, Charles and Burnell, Lisa, "A Distributed Multi-Agent Framework for Intelligent Environments", *Journal of Systemics, Cybernetics and Informatics*, Volume 3, Issue Number 1, 2005, p. 1, Retrieved May 08, 2010, from http://www.iiisci.org/journal/CV$/sci/pdfs/P446593.pdf

Harper, Richard (ed.), "Inside the Smart Home: Ideas, Possibilities and Methods" in Richard Harper, *Inside the Smart Home*, Springer – Verlag, London, 2003.

Harrison, S., Tatar, D. and Sengers, P., *The Three Paradigms of HCI*, Proceedings of CHI 2007, San Jose, CA, May 2007.

Harvey, David, *The Condition of Postmodernity: An Enquiry into the Origins of Cultural Change*, Blackwell Publishing, Malden, MA, USA, Oxford, UK and Victoria, Australia, 1990.

Haque, Usman, "Architecture, Interactions, Systems", *AU: Arquitetura & Urbanismo* 149, August 2006.

Haque, Usman and Pangaro, Paul, "Paskian Environments" in Kas Oosterhuis and

Lukas Feireiss (eds.), *Game, Set and Match II*, Episode Publishers, Rotterdam, 2006.

Hayles, Katherine N., *How We Became Posthuman: Virtual Bodies in Cybernetics, Literature and Informatics*, University of Chicago Press, Chicago and London, 1999.

Hayles, Katherine, *Writing Machines*, The MIT Press, Cambridge, Massachusetts, 2002.

Hayles, Katherine (ed.), *Nanoculture: Implications of the New Technoscience*, Intellect Books, Bristol and Oregon, 2004.

Hayles, Katherine, *My Mother was a Computer: Digital Subjects and Literary Texts*, University of Chicago Press, Chicago and London, 2005.

Heims, S. J., *The Cybernetics Group*, The MIT Press, Cambridge, Massachusetts, 1991.

Hemsath, Timothy L., "Searching for Innovation Through Teaching Digital Fabrication" in Gerhard Schmitt, Ludger Hovestadt and Luc van Gool (eds.), *ECAADe 2010 Conference: Future Cities*, Proceedings of the 28th Conference on Education in Computer Aided Architectural Design in Europe, Verlag der Fachvereine Hochschulverlag AG an der ETH Zurich, Switzerland, 2010.

Henning, Michelle, "Interactives and Hands-on Science" in *Museums, Media and Cultural Theory*, Issues in Cultural and Media Studies, Open University Press, Maidenhead, Berkshire, England, 2005.

Hensel, Michael and Menges, Achim (eds.), *Morpho-Ecologies*, Architectural Association, London, 2006.

Hensel, Michael, Menges, Achim and Weinstock, Michael, *Emergent Technologies and Design: Towards a Biological Paradigm for Architecture*, Routledge, New York, 2010.

Hight, Christopher, "Modulor Residues of History" in *Architectural Principles in the Age of Cybernetics*, Routledge, Taylor and Fransis Group, New York and London, 2008.

Hippel, Eric von, *Democratizing Innovation*, The MIT Press, Cambridge Massachusetts and London, England, 2005.

Holland, John, "Outline for a Logical Theory of Adaptive Systems" in Arthur Walter Burks (ed.), *Essays on Cellular Automata*, University of Illinois Press, Urbana, Illinois, 1970.

Hunt, Gillian, "Architecture in the Cybernetic Age" in Neil Spiller (ed.), *Architects in Cyberspace II*, John Wiley & Sons, London, 1998.

Huybers, P. and Ende, van der, *Prisms and Antiprisms*, Proceedings of the International IASS Conference on Spatial, Lattice and Tension Structures, Atlanta, April 24-28, 1994

Itami, Hiroyuki, Kusunoki, Ken, Numagami, Tsuyoshi and Takeishi, Akira (eds.), *Dynamics of Knowledge, Corporate Systems and Innovation*, Springer – Verlag, Berlin and Heidelberg, 2010.

Ito, Toyo, “Architecture in a Simulated City” in K. Gerbel and P. Weibel (eds.), *Intelligent Environments*, Ars Electronica 1994, Vol. 1, PVS Verleger, Vienna, 1994.

Isozaki, Arata, “Erasing Architecture into the System” in Cedric Price, Arata Isozaki, Patrick Keiller and Hans-Ulrich Obrist, *Re:CP*, Birkhauser – Publishers for Architecture, Basel, Boston, Berlin, 2003.

Jacobs, Jane, *The Death and Life of Great American Cities*, Vintage Books, New York, 1992.

Jackson, Lesley, *Twentieth Century Pattern Design*, Princeton Architectural Press, New York, 2007.

Jencks, Charles et al, Toyo Ito, *Architectural Monographs No. 41*, Academy Editions, London, 1995.

Jencks, Charles, *The New Paradigm in Architecture: The Language of Post-modernism*, Yale University Press, New Haven and London, 2002.

Jencks, Charles and Kropf, Karl (eds.), *Theories and Manifestos of Contemporary Architecture*, Wiley-Academy, Chichester, 2006.

Johnston, George Barnett, *Drafting Culture: A Social History of Architectural Graphic Standards*, The MIT Press, Cambridge, Massachusetts and London, England, 2008.

Johnston, John, “Machinic Philosophy: Assemblages, Information, Chaotic Flow” in *Allure of Mechanic Life: Cybernetics, Artificial Life and the New AI*, MIT Press, Cambridge, 2008.

Johnson, Steven, *Interface Culture: How New Technology Transforms the Way We Create and Communicate*, Harper Collins Publisher, New York, 1997.

Jones, Steve (ed.), *Encyclopedia of New Media: An Essential Reference to Communication and Technology*, Sage Publications, Thousand Oaks, California, 2003.

Jormakka, Kari, “Liquid Architecture” in *Flying Dutchmen: Motion in Architecture*, IT Revolution in Architecture, Birkhauser – Publishers for Architecture, Basel, Switzerland, 2002.

Kahn, D. and Whitehead, G., (ed.) *Wireless Imagination: Sound, Radio and the Avant-garde*, The MIT Press, Cambridge Massachusetts, London, England, 1994.

Kaltenbacher, Brigitte, *Intuitive Interaction: Step Towards an Integral Understanding of the User Experience in Interaction Design*, Centre for Cultural Studies, Goldsmiths, University of London, London, England, 2008.

Kappraff, Jay, “A Secret of Ancient Geometry” in Catherine A. Gorini (ed.), *Geometry at Work: Papers in Applied Geometry*, Mathematical Association of America Notes

Number 53, The Mathematical Association of America (Inc.), US, 2000.

Kirschenbaum, Matthew, "The Word as Image in an Age of Digital Reproduction" in Mary E. Hocks and Michelle R. Kendricks (eds.), *Eloquent Images: Word and Image in the Age of New Media*, MIT Press, Cambridge, 2003.

Klee, Paul, Des Moines Art Center, "Paul Klee: Paintings and Watercolours from the Bauhaus Years, 1921-1931", *Catalogue of an Exhibition Des Moines Art Centre*, September 18 – October 28, Des Moines Art Centre, Original from The University of California, 1973.

Knox, Paul L., *Cities and Design*, Critical Inductions to Urbanism and the City, Routledge, New York, 2010.

Koenig, Daniel T., *The Engineer Entrepreneur*, American Society of Mechanical Engineers, New York, 2003.

Kolarevic, Branko (ed.), *Architecture in the Digital Age: Design and Manufacturing*, Spon Press, Taylor and Francis, New York and London, 2003.

Kolarevic, Branko and Malkawi, Ali M. (eds.), *Performative Architecture: Beyond Instrumentality*, Spon Press, New York, 2005.

Kolarevic, Branko and Klinger, Kevin, *Manufacturing Material Effects: Rethinking Design and Making Architecture*, Routledge, London, 2008.

Kramer, Thomas R., Proctor, Frederick M., Messina, Elena, *The NIST RS274NGC Interpreter - Version 3*, Intelligent Systems Division, National Institute of Standards and Technology, Technology Administration, U.S. Department of Commerce, Gaithersburg, Maryland 20899, NISTIR 6556, August 17, 2000, Retrieved May 13, 2009, from http://www.isd.mel.nist.gov/personnel/kramer/pubs/RS274NGC_3.web/RS274NGC_33a.html#1002165

Kronenburg, Robert, *Houses in Motion: The Genesis, History and Development of Portable Building*, Wiley Academy, Chichester, 2002.

Kronenburg, Robert , Lim, Joseph and Yunn Chii, Wong, *Transportable Environments 2*, Spon Press, London, 2002.

Kronenburg, Robert and Klassen, Filiz (eds.), *Transportable Environments: Theory, Context, Design and Technology*, Taylor and Francis, New York, 2006.

Kühnel, Ernst, *The Arabesque: Meaning and Transformation of an Ornament*, translated by Richard Ettinghausen, Verlag für Sammler, Graz, Austria, 1977.

Kulkarni, Dhananjay M., Rastogi, A. P. and Sarkar, Ashoke K., *Engineering Graphics with AutoCAD*, PHI Learning Private Limited, New Delhi, 2009.

Kurokawa, Kisho, "The Origin and History of Metabolist Movement" in *Metabolism in Architecture*, Studio Vista, London, 1977.

Kurzweil, Ray, "Superintelligence and Singularity" in Susan Schneider (ed.), *Science Fiction and Philosophy: From Time Travel to Superintelligence*, Wiley-Blackwell, Oxford, UK and Malden, MA, USA, 2009.

Lally, Sean and Young, Jessica (eds.), *Softspace: From a Representation of Form to a Simulation of Space*, Routledge, Oxon and New York, 2007.

Larson Ron, Larson, Roland E. and Hostetler, Robert P., *Triginometry*, Houghton Miffin, Boston, USA, Seventh revised edition, 2006.

Latecki, Longin, *Discrete Representation of Spatial Objects in Computer Vision*, Computational Imaging and Vision, Kluwer Academic Publishers, Dordrecht, The Netherlands, 1998.

Lauer, David A. and Pentak, Stephen (eds.), *Design Basics*, Thomson Wadsworth, Boston, MA, USA, 2008

Laurel, Brenda (ed.), *The Art of Human-Computer Interface Design*, Addison – Wesley, Reading, MA, USA, 1990.

Layard, Austen Henry, "On Mosaic Decoration" in *Papers Read at the Royal Institute of British Architects*, Session 1868-1869, Printed at the rooms of the Royal Institute of British Architects, London, 1869.

Leatherbarrow, David and Mohsen Mostafi, *Surface Architecture*, MIT Press, Cambridge, Massachusetts, 2005.

Lee, Raymond L. and Fraser, Alistair B., *The Rainbow Bridge: Rainbows in Art, Myth and Science*, Pennsylvania State University Press, University Park, PA, USA, 2001.

Lee, Kunwoo, *Principles of CAD/CAM/CAE Systems*, Addison-Wesley, Reading, MA, 1999.

Lewis, Wanda J., *Tension Structures: Form and Behaviour*, Thomas Telford Ltd., London, 2003.

Lefebvre, Henri, *Production of Space*, Blackwell Publishing, Oxford, 1991.

Lefebvre, Henri, *Rhythmanalysis: Space, Time and Everyday Life*, Athlone, London, 2004.

Lin, Zhongjie, *Kenzo Tange and the Metabolist Movement: Urban Utopias of Modern Japan*, Routledge, New York, 2010.

Loos, Adolf, "Ornament and Crime" in *Ornament and Crime: Selected Essays*, trans. Michael Mitchell, Ariadne Press, Riverside, 1998.

Luhmann, Niklas and Bednarz, John, *Political Theory in the Welfare State*, Walter De Gruyter & Co., Berlin, 1990.

Lunenfeld, Peter (ed.), *The Digital Dialectic: New Essays on New Media*, MIT Press, Cambridge, Massachusetts, 2000.

Lynn, Greg, “Architectural Curvilinearity: The Folded, the Pliant and the Supple” in *AD Profile 102: Folding in Architecture*, Academy Editions, London, 1993.

Lynn, Greg, *Animate Form*, Princeton Architectural Press, New York, 1999.

Maeda, John (foreword), Reas, Casey and Fry Ben, *Processing: A Programming Handbook for Visual Designers and Artists*, MIT Press, Cambridge, Massachusetts, 2007.

Masters, Barry R., *Confocal Microscopy and Multiphoton Excitation Microscopy: The Genesis of Live Cell Imaging*, SPIE (Society of Photo-Optical Instrumentation Engineering) Press, Bellingham, WA, USA, 2006.

Massumi, Brian, *Parables for the Virtual: Movement, Affect, Sensation*, Duke University Press, USA, 2002.

Mathews, Stanley, *From Agit-prop to Free Space: The Architecture of Cedric Price*, Black Dog Publishing, London, 2007.

Mattheck, Claus, *Design in Nature:Learning From Trees*, Springer-Verlag, Berlin, Heidelberg and New York, 1998.

Maturana, Humbert R. and Varela, Francisco J., *Autpoiesis and Cognition: The Realization of the Living*, D. Reidel Publishing Company, Dordrecht, Holland, 1980.

McCleary, Peter, “Some Characteristics of a New Concept of Technology” in Jay M. Stein and K. F. Spreckelmeyer (eds.), *Classic Readings in Architecture*, McGraw-Hill Inc., Boston, US, 1999.

McCulloch, Warren S. and Walter, Pitts H., "A Logical Calculus of the Ideas Immanent in Nervous Activity" in Warren S. McCulloch, *Embodiments of Mind*, The MIT Press, Cambridge, Massachusetts, 1970

McCulloch, Warren S., "Recollections of the Many Sources of Cybernetics" in *Cybernetics and Human Knowing*, A Journal of Second Order Cybernetics, Vol. 1, No. 2/3, 1992, Retrieved April 12, 2010, from http://www.imprint.co.uk/C&HK/vol1/V1-23Fre.HTM

McCullough, Malcolm, *Abstracting Craft: The Practiced Digital Hand*, The MIT Press, Cambridge, Massachusetts and London, England, 1998.

McCullough, Malcolm, *Digital Ground*, The MIT Press, Cambridge, Massachusetts and London, England, 2005.

McLuhan, Marshal, *Undestanding Media*, Routledge, London and New York, 2001.

McQuail, Denis, *Mass Communication Theory: An Introduction*, Thousand Oaks, Sage Publications, London, 1994.

McQuail, Denis (ed.), *McQuail's Reader in Mass Communication Theory*, Sage Publications Ltd., London, 2003.

McQuire, Scott, Martin, Meredith and Niederer, Sabine, *Urban Screens Reader*, Inc Reader No.5, Institute of Network Cultures, Amsterdam, 2009.

McQuire, S., “The Politics of Public Space in the Media City” in *Urban Screens: Discovering the potential of outdoor screens for urban society*, First Monday Special Issue No 4 (February 2006), http://www.firstmonday.org, quoted in Mirjam Struppek, “Urban Screens: The Urban Potential of Public Screens for Interaction”, Intelligent Agent, Volume 6, Issue number 2, Interactive City: Urban Screens, Retrieved January 16, 2010, from http://www.intelligentagent.com/archive/Vol6_No2_interactive_city_struppek.htm

MDRDV, *KM3: Excursions on Capacities*, Actar, Barcelona, Har/DVD edition, 2005.

Menges, Achim, “Instrumental Geometry” in Robert Corser (ed.), *Fabricating Architecture: Selected Readings in Digital Design and Manufacturing*, Princeton Architectural Press, New York, 2010.

Merleau-Ponty, Maurice, *Phenomenology of Perception*, Routledge, London and New York, 2003.

Mitchell, William J., and McCullough, Malcolm, *Digital Design Media*, John Wiley & Sons, Inc., New York, Chichester, Weinheim, Brisbane, Singapore, Toronto, 1995.

Moggridge, Bill, *Designing Interactions*, The MIT Press, Cambridge, Massachusetts and London, England, 2007.

Moloney, J., “Designing for Time: The Case of Kinetic Skins” in Susan Roaf and A. Bairstow (eds.), *The Oxford Conference: A Re-evaluation of Education in Architecture*, WIT Press, Southampton, UK and Billerica, MA, USA, 2008.

Moore, Patricia A. (ed.), *Computer Graphic Hardware*, Harvard University, Laboratory of Computer Graphics and Spatial Analysis, 1980.

Morris, Christopher G. (ed.), *Academic Press Dictionary of Science and Technology*, Academic Press, London, 1992.

Mozer, Michael, *An Intelligent Environment Must Be Adaptive*, IEE Intelligent Systems and their Applications 14, no. 2, 1999.

Mozer, Michael, “Lessons From an Adaptive House” in Diane J. Cook and Sajal K. Das (eds.), *Smart Environments: Technologies, Protocols and Applications*, John Wiley & Sons Inc., Hoboken, New Jersey, USA, 2005.

Mueller, Mary Korstad, *Murals: Creating an Environment*, Davis Publications, Worcester, Massachusetts, 1979.

Mulder, Arjen, “The Object of Interactivity” in *NOX: Machining Architecture* by Lars Spuybroek, Thames & Hudson, London, 2004.

Munster, Anna, *Materializing New Media: Embodiment in Information Aesthetics*, Dartmouth College Press, University Press of New England, Lebanon, NH, 2006.

Negroponte, Nicholas, *Soft Architecture Machines*, The MIT Press, Cambridge, London, 1975.

Negroponte, Nicholas, *Being Digital*, Alfred A. Knopf Inc., New York, 1995.

Neufert, Ernst and Peter, *Neufert: Architect's Data,* Blackwell Science Publishers, Malden, MA, 2000.

Neumann, John Von in Arthur Walter Burks (ed.), *Theory of Self-Reproducing Automata*, University of Illinois Press, Urbana, Illinois, 1966.

Neumann, John Von, “The General and Logical Theory of Automata” in Zenon W. Pylyshyn and Liam Bannon (eds.), *Perspectives on the Computer Revolution*, Ablex Publishing Corporation, New York, 1989.

Newell, M. E., Newell, R. G. and Sancha, T. L., *A New Approach to the Shaded Picture Problem*, Proceedings of the ACM National Conference, Boston, 1972.

Noguchi, M. and Friedman, A., *Mass Custom Design System Model for the Delivery of Quality Homes: Learning from Japan's prefabricated Housing Industry*, Proceedings of International Council for Research and Innovation in Building and Construction, CIB W060-096, Syllabus Joint Conference: Measurement and Management of Architectural Value in Performance Based Building, Hong Kong, 6-10, 2002a.

Noguchi, M. and Hernandez, C., “Mass Custom Design”, Approach to Upgrading Traditional Housing Development in Mexico, *Journal of Habitat International 29*, 2005.

Noguchi, Masa, *Mass Custom Home: The Mass Custom Design Approach*, MEARU, Mackintosh School of Architecture, The Glasgow School of Art, Retrieved March 23, 2009, from http://www.masscustomhome.com/.

Nooshin, H., *Formex: Configuration Processing in Structural Engineering*, Elsevier Applied Science Publishers, London, 1984.

Nouvel, Jean, Cattani, Emmanuel et Associes, *Nouvel*, Artemis arc en reve centre d'architecture (ICA), Artemis Verlags AG, Zürich, München and London, 1992.

Novak, Marcos, “Liquid Architectures in Cyberspace” in Michael Benedikt (ed.), *Cyberspace: First Steps*, MIT Press, Cambridge, Massachusetts, 1991.

Novak, Marcos, “Cognitive Cities: Intelligence, Environment and Space” in Peter

Droege (ed.), *Intelligent Environments: Spacial Aspects of the Information Revolution*, Elsevier Science Ltd, Amsterdam, The Netherlands, 1997.

Novak, Marcos, “Transarchitectures and Hypersurfaces” in Stephen Perrella (ed.), *Hypersurface Architecture*, AD Profile 133, Academy Editions, London, 1998.

O'Connor, Johnson and Human Engineering Laboratory (US), *English Vocabulary Builder*, Volume 2, Human Engineering Laboratory, US, 1948.

Oh, Yoosoo, Schmidt, Albrecht and Woo, Woontack, *Designing, Developing and Evaluating Context-Aware Systems*, Proceedings of the 2007 International Conference on Multimedia and Ubiquitous Engineering, IEEE Computer Society, Washington DC, USA, 2007.

Oosterhuis, Kas, “A New Kind of Building”, in Arie Graafland and Leslie Jaye Kavanagh (eds.), *Crossover: Architecture, Urbanism, Technology*, 010 Publishers, Rotterdam, The Netherlands, 2006.

Oosterhuis, Kaas and Feireiss, Lukas (eds.), *Game, Set and Match II: On Computer Games, Advanced Geometries and Digital Technologies*, Episode Publishers, Rotterdam, The Netherlands, 2006.

Oswald, Patrick and Pieranski, Pawel, *Smectic and Columnar Liquid Crystals: Concepts and Physical Properties Illustrated by Experiments*, Taylor & Francis / CRC Press, London, 2005.

Pacuit, Eric, *Topics in Social Software: Information in Strategic Situations*, Doctoral dissertation, City University of New York, 2005, Retrieved April 04, 2010, from http://ai.stanford.edu/~epacuit/thesis.html

Pallasmaa, Juhani, “The Geometry of Feeling: A Look at the Phenomenology of Architecture” in Kate Nesbitt (ed.), *Theorizing a New Agenda for Architecture: Anthology of Architectural Theory 1965-1995*, Princeton Architectural Press, New York, 1996.

Pangaro, Paul, *Beyond Menus: The Rats-A-Stratz or the Bahdeens*, Harvard Computer Graphics Week, Harvard University, Graduate School of Design, 1982, Retrieved May 28, 2010, from http://www.pangaro.com/published/Beyond-Menus.html

Pangaro, Paul, *Cybernetics: A Definition,* (1990), e-book, Retrieved May 21, 2010, from http://www.pangaro.com/published/cyber-macmillan.html

Pangaro, Paul, *Cybernetics: The Centre of Science's Future*, The Philosophical Society of Washington, 1991, p. 1, Retrieved March 21, 2010, from http://www.pangaro.com/abstracts/philos-wash-cybersci.html

Papapetros, Spyros, “Aby Warburg as Reader of Gottfried Semper: Reflections on the Cosmic Character of Ornament” in Catriona MacLeod, Veronique Plesch and Charlotte Schoell-Glass (eds.), *Elective Affinities: Testing Word and Image Relationships*, Word and Image Interactions, Editions Rodopi B. V. Amsterdam and New York, 2009.

Pask, Gordon, “The Meaning of Cybernetics in the Behavioural Sciences (The Cybernetics of Behaviour and Cognition: Extending the Meaning of ’Goal’)” in J. Rose (ed.), *Progress in Cybernetics*, Volume 1, Gordon and Breach, New York, 1969.

Pask, Gordon, “A Comment, a Case History and a Plan” in Jasia Reichardt (ed.), *Cybernetics, Art and Ideas*, Studio Vista, London, 1971.

Pask, Gordon, *Conversation, Cognition and Learning: A Cybernetic Theory and Methodology*, Elsevier, Amsterdam, 1975.

Pask, Gordon and Zeeuw, Gerard de, *Interactions of Actors, Theory and some Applications_A Series of Volumes*, OOC/CICT/Universiteit Amsterdam, Volume 1 of this series, an introductory monograph Outline and Overview, Gordon Pask, Latest Edit. Nov.12.1992. Nov. 17th. 1992, latest dec 23 1992, Completed, June,1992. FiIename.Gordonsbook, in WN.2.0.

Pask, Gordon, *Heinz von Foerster's Self Organisation: the Progenitor of Conversation and Interaction Theories*, Systems Research, Volume 13, 1996.

Pask, Gordon, “The Architectural Relevance of Cybernetics” in Neil Spiller (ed.), *Cyber Reader: Critical Writings for the Digital Era*, Phaidon, London, 2002.

Penttilä, Hannu, “Early Architectural Design and BIM” in Andy Dong, Andrew Vande Moere and John S. Gero (eds.), *Computer-Aided Architectural Design Futures (CAAD Futures) 2007*, Proceedings of the 12th International CAAD Futures Conference, Springer, Dodrecht, The Netherlands, 2007.

Perrella, Stephen, “Hypersurface Architecture”, Second Doors of Perception conference, the Netherlands Design Institute, Amsterdam, the Netherlands, in *Mediamatic,* Volume 8, No2/3, 1994.

Perrella, Stephen (ed.), *Hypersurface Architecture II*, Architectural Design, Volume 69, Issues 9-12, John Wiley & Sons, London, 1999.

Perella, Stephen, *Hypersurface Architecture and the Question of Interface*, Interfacing Realities, 1997, Retrieved December 06, 2010, from http://www.v2.nl/archive/articles/hypersurface-architecture.

Pharr, Matt and Humphreys, Greg, *Physically Based Rendering: From Theory to Implementation*, Series in Interactive 3d Technology, Morgan Kaufmann Publishers, Elsevier, San Francisco, CA, 2004.

Pickering, Andrew, *The Cybernetic Brain: Sketches of Another Future*, Chicago University Press, Chicago and London, 2010.

Pine II, Joseph B., *Mass Customization: The New Frontier in Business Competition*, Harvard Business School Press, Boston, USA, 1993.

Plato, *Philebus*, Translator Robin H. Waterfield, Penguin Books, London, 1995.

Porter, Tom, *Archispeak: An Illustrated Guide to Architectural Design Terms*, Taylor & Francis, New York, 2004.

Powell, Kenneth (ed.), *The Lloyd's Building: Richard Rogers Partnership – Architecture in Detail*, Phaidon, London, 1994.

Price, Cedric, Isozaki, Arata, Keiller, Patrick and Obrist, Hans-Ulrich, *Re:CP*, Birkhauser – Publishers for Architecture, Basel, Boston, Berlin, 2003.

Pritchett, James, *The Music of John Cage*, Cambridge University Press, Cambridge, New York and Melbourne, 1996.

Rabeneck, Andrew, *Cybermation: A Useful Dream*, Architectural Design (AD), Volume 39, September 1969.

Randl, Chad, *Revolving Architecture: A History of Buildings That Rotate, Swivel and Pivot*, Princeton Architectural Press, New York, 2008.

Reffat, Rabee M., "Three-Dimensional CAD Models: Integrating Design and Construction" in Rick Best and Gerard de Valence (eds.), *Design and Construction: Building in Value*, Butterworth-Heinemann, Elsevier Science Limited, Oxford, UK, 2002.

Reichardt, Jasia (ed.), *Cybernetics, Art and Ideas*, Studio Vista, London, 1971.

Richards, Jonathan, *Facadism*, Routledge, London and New York, 1994.

Risatti, Howard and Trapp, Kenneth R. (foreword), *A Theory of Craft: Function and Aesthetic Expression*, The University of North Carolina Press, Chapel Hill, USA, 2007.

Rosenblueth, Arturo, Wiener, Norbert and Bigelow, Julian, "Behaviour, Purpose and Teleology" in Frank George and Les Johnson (eds.), *Purposive Behaviour and Teleological Explanations*, Studies in Cybernetics: 8, Gordon and Breach Science Publishers, New York, London, Paris, Montreux and Tokyo, 1985.

Rosheim, Mark Elling, "Leonardo's Knight" in *Leonardo's Lost Robots*, Springer – Verlag, Berlin and Heidelberg, 2006.

Rossi, Aldo, *The Architecture of the City*, The MIT Press, Cambridge, Massachusetts and London, England, 1984.

Rucker, Rudy and Walker, John, *Exploring Cellular Automata*, Autodesk, San Rafael, CA, 1989.

Rutsky, R. L., *High Techne: Art and Technology from the Machine Aesthetic to the Posthuman*, University of Minnesota Press, Minneapolis, US, 1999.

Sadler, Simon, *Archigram: Architecture Without Architecture*, The MIT Press, Cambridge, Massachusetts, 2005.

Saggio, Antonino, “The Search for an Information Space” in O. Kaas and F. Lukas (eds.), *Game Set and Match II*, Episode Publishers, Rotterdam, 2006.

Salingaros, Nikos A., *A Theory of Architecture*, Intercollegiate Studies Institute, Nikos A. Salingaros & UMBAU-VERLAG, Solingen, Germany, 2007.

Sant’Elia, Antonio and Marinetti, Filippo Tommaso, “Futurist Architecture” in Ulrich Conrads (ed.), *Programs and Manifestos on 20th Century Architecture*, The MIT Press, Cambridge Massachusetts, 1975

Schlager, Neil and Lauer, Josh (eds.), *Science and Its Times: 1950 – Present*, Volume 7: Understanding the Social Significance of Scientific Discovery, Gale Group, Farmington Hills, Michigan, 2000.

Schaik, Leon van, *Spatial Intelligence Futures for Architecture*, AD Primers, John Wiley & Sons, Ltd., Chichester, England, 2008.

Schneider, Ulrich, Speidl, Manfred and Sakamao, Hayakeyama, *Toyo Ito: Blurring Architecture 1971-2005 – Rethinking the Relationship Between Architecture and the Media*, Edizioni Charta Srl, 2000.

Schumacher, Patrik, “Parametricism: A New Global Style for Architecture and Urban Design” in Neil Leach (ed.), *AD Architectural Design – Digital Cities*, Vol 79, No 4, July/August 2009.

Schumacher, Patrik, *The Autopoiesis of Architecture: A New Framework for Architecture*, John Wiley & Sons Ltd. Publication, Chichester, West Sussex, UK, 2011.

Schwartz, Ineke (1997), “Testing Ground for Interactivity: The Water Pavilions by Lars Spuybroek and Kas Oosterhuis” in Gabriella Giannachi, *Virtual Theatres: An Introduction*, Routledge, Taylor & Francis Group, London and New York, 2004.

Sebestyen, Gyula and Pollington, Chris, *New Architecture and Technology*, Architectural Press, Elsevier Science, Oxford, England and Burlington, MA, USA, 2003.

Semper, Gottfried, *Der Stil, in den Technischen ündTektonischen Künsten: Praktische Aesthetik, Ein Handbuch für Techniker, Künstler ünd Kunstfreunde* (*The Style in the Technical and Architectural Arts, or Practical Aesthetics: A Handbook for Workman, Artist and Amateurs*), Friedrich Bruckmanns Verlag, München, 1863.

Semper, Gottfried, *Concerning the Formal Principles of Ornament and its Significance as Artistic Symbol*, The Warburg Institute Archive, London, 1856.

Semper, Gottfried in Andrew Benjamin, “Notes on the Surfacing of Walls: NOX, Kiesler, Semper” in Lars Spuybroek, *NOX: Machining Architecture*, Thames & Hudson, London, 2004.

Sennett, Richard, *The Craftsman*, Penguin Books, London and New York, 2008.

Sergio, A. and Bdeir, A., "KINET: Towards Animated Architecture Through Responsive Modular Walls" in O. Kaas and F. Lukas (eds.), *Game Set and Match II*, Episode Publishers, Rotterdam, 2006.

Shanon, Claude E. and Weaver, Warren, *The Mathematical Theory of Communication*, University of Illinois Press, Urbana, Illinois, 1949.

Sherrington, Charles, *The Integrative Action of the Nervous System*, CUP Archive, 1947.

Silver, Mike (ed.), *Programming Cultures: Art and Architecture in the Age of Software*, Architectural Design (AD), Wiley-Academy, London, July/August 2006.

Smith, Kendra Schank, *Architect's Drawings: A Selection of Sketches by World Famous Architects Through History*, PhD in History Theory Criticism and Representation, Architectural Press, Oxford, UK, 2005.

Sobolev, Sergei L., Kitov, A. I. and Lyapunov, A. A., "Osnovnie Cherti Kibernetiki" ("The Main Features of Cybernetics") in Journal *Voprosi Filosophii* (*Questions of Philosophy*), Akademia Nauk USSR Institut Filosophii, Moscow, Issue Number 4, 1955.

Solomon, Nancy B. (ed.), *Architecture: Celebrating the Past, Designing the Future*, Commemorating 150 Years of the American Institute of Architects, Visual Reference Publications Inc., New York and Washington, USA, 2008.

Sommerer, Christa, L. C. Jain, Mignonneau, Laurent, *The Art and Science of Interface and Interaction Design*, Studies in Computational Intelligence, Springer – Verlag, Berlin and Heidelberg, 2008.

Spiller, Neil (ed.), *Cyber Reader: Critical Writings for the Digital Era*, Phaidon, London, 2002.

Spiller, Neil (ed.), *Visionary Architecture: Blueprints of the Modern Imagination*, Thames & Hudson, London, 2006.

Spuybroek, Lars, *NOX: Machining Architecture*, Thames & Hudson, London, 2004.

Steiner, A. Hadas, *Beyond Archigram: The Structure of Circulation*, Routledge, New York and London, 2009.

Stiny, George, "What Designers Do That Computers Should" in Malcolm McCullough, William J. Mitchell and Patrick Purcell (eds.), *The Electronic Design Studio: Architectural Knowledge and Media in the Computer Era*, MIT Press, Cambridge, Massachusetts, 1990.

Steenson, Molly Wright, *Cedric Price's Generator*, Retrieved March 22, 2010, from http://www.activesocialplastic.com/2007/08/cedric_prices_generator.html

Sterk, Tristan d´Estrée, *Building Upon Negroponte: A Hybridized Model of Control for Responsive Architecture*, Graz 2003, Retrieved February 13, 2010, from http://www.orambra.com/papers/negroponte/sterkECAADE_03.pdf.

Sterk, Tristan d'Estrée, "Responsive Architecture: User-centered Interactions within the Hybridized Model of Control", in O. Kaas and F. Lukas (eds.), *Game Set and Match II*, Episode Publishers, Rotterdam, 2006.

Sterk, Tristan d'Estrée, *Shape Control in Responsive Architectural Structures: Current Reasons and Challenges*, paper for 4th World Conference on Structural Control and Monitoring, 2006.

Stocker, Gerfried, Sommerer, Christa and Mignonneau, Laurent (eds.), "Media Façades as Architectural Interfaces" in *Interactive Art Research*, Springer, Vienna and New York, 2009.

Struppek, Mirjam, "Urban Screens: The Urban Potential of Public Screens for Interaction", Intelligent Agent vol.6 no.2, *Interactive City – Urban Screens*, Retrieved January 16, 2010, from http://www.intelligentagent.com/archive/Vol6_No2_interactive_city_struppek.htm

Sutherland, Ivan, *Structure in Drawings and the Hidden Surface Problem*, Petrocelli, New York, 1975.

Sutherland, Ivan Edward, *Sketchpad: A Men-Machine Graphical Communication System*, Technical Report No 574, University of Cambridge, Computer Laboratory, September 2003.

Sutherland, Ivan Edward, "Sketchpad: A Man-Machine Graphical Communication System" in Noah Wardrip-Fruin and Nick Montfort (eds.), *The New Media Reader*, MIT Press, Cambridge, Massachusetts and London, England, 2003.

Terzidis, Kostas, *Algorithmic Architecture*, Architectural Press, Elsevier, Heidelberg, London, New York, Oxford, Paris, San Diego, San Francisco, Singapore, Sydney, Tokyo, 2006.

Thomas, Michael (ed.), *Handbook of Research on Web 2.0 and Second Language Learning*, Information Science Reference, Hershey, PA, 2009.

Thompson, D' Arcy Wentworth, *On Growth and Form*, Cambridge University Press, Cambridge, UK, New York, USA, Melboune, Australia, Madrid, Spain and Cape Town, South Africa, 1961.

Thrift, Nigel, "Movement-space: the Changing Domain of Thinking Resulting From the Development of New Kinds of Spatial Awareness", in *Economy and Society*, Volume 33, Issue number 4, November 2004.

Toffler, Alvin, *Future Shock*, Bantam Books, USA, 1984.

Toy, Maggie and Jencks, Charles, *Ecstatic Architecture: The Surprising Link*, From a debate of the Academy International Forum at Royal Academy of Arts, John Wiley and Sons, London, 1999.

Trilling, James, *Ornament: A Modern Perspective*, University of Washington Press, Washington, USA, 2003.

Turing, Alan M., *On Computable Numbers, With an Application to the Entscheidungsproblem*, Proceedings of the London Mathematical Society, 1936, p. 2, Retrieved April 12, 2010, from http://www.thocp.net/biographies/papers/turing_oncomputablenumbers_1936.pdf

Turner, Whitted, "The Hacker's Guide to Making Pretty Pictures" in *Image Rendering Tricks*, Course Notes 12 for Siggraph '85, New York, July 1985.

Venturi, Robert, Brown, Denise Scott and Izenour, Steven, *Learning from Las Vegas*, The MIT Press, Cambridge, Massachusetts and London, England, revised edition, 1977.

von Foerster, Heinz, "Ethics and Second Order Cybernetics" in *Understanding Understanding: Essays on Cybernetics and Cognition*, Springer – Verlag, New York, 2002.

von Neumann, John, "The General and Logical Theory of Automata" in Zenon W. Pylyshyn and Liam Bannon (eds.), *Perspectives on the Computer Revolution*, Ablex Publishing Corporation, Norwood, New Jersey, 1989.

Voordt, D. J. M. van der and Wegen, H. B. R. van, *Architecture in Use: An Introduction to the Programming, Design and Evaluation of Building*s, Architectural Press, Elsevier, Oxford, UK and Delft, The Netherlands, 2005.

Waltenegus, Dargie, *Context-Aware Computing and Self-Managing Systems*, Chapman & Hall/CRC Studies in Informatics Series, CRC Press, Taylor & Francis Group, A Chapman & Hall Book, Boca Raton, London, New York, 2009.

Wardrip-Fruin, Noah and Montfort, Nick (eds.), *The New Media Reader*, MIT Press, Cambridge, Massachusetts and London, England, 2003.

Wark, McKenzie, *A Hacker Manifesto*, Harvard University Press, Cambridge, Massachusetts, 2005.

Waters, John Kevin, "Biological Thinking" in *Blobitecture: Waveform Architecture and Digital Design*, Rockport Publishers Inc. Gloucester, Massachusetts, USA, 2007.

Wigginton, Michael and Harris, Jude, *Intelligent Skins*, Elsevier, Architectural Press, Amsterdam, Boston, Heidelberg, London, New York, Oxford, Paris, San Diego, San Francisco, Singapore, Sydney, Tokyo, 2002.

Weiser, Mark, *The Computer for the 21st Century*, Scientific American, September 1991.

Weiser, Mark, *Some Computer Science Issues in Ubiquitous Computing*, Communications of the ACM, July 1993.

Weiser, Mark and Brown, John Seely, *Designing Calm Technology*, Xerox PARC, December 21, 1995, p. 1, Retrieved April 24, 2010, from http://nano.xerox.com/weiser/calmtech/calmtech.htm

Weiner, Norbert, *Cybernetics: Or Control and Communication in the Animal and the Machine*, MIT Press, Cambridge, Massachusetts, 1948 and 1961.

Wiener, Norbert, *The Human Use of Human Beings*, Sphere Books Ltd., London 1968.

Weiss, Jason and Caiger, Philip, "Ubiquitous Computing" in *The Industrial-Organizational Psychologist* (TIP), Volume 39, Number 4, April 2002.

Wigginton, Michael and Harris, Jude, *Intelligent Skins*, Architectural Press, Elsevier, Oxford and Woburn, MA, 2002.

Wittkower, Rudolf, "The Architectural Principles of the Modulor" in Christopher Hight, *Architectural Principles in the Age of Cybernetics*, Routledge, Taylor and Fransis Group, New York and London, 2008.

Wolf, Tom De and Holvoet, Tom, "Emergence Versus Self-Organization: Different Concepts but Promising When Combined" in Sven A. Brueckner, Giovanna Di Marzo Serugendo, Anthony Karageorgos and Radhika Nagpal (eds.), *Engineering Self-Organizing Systems: Methodologies and Applications*, Lecture Notes in Computer Science/Lecture Notes in Artificial Intelligence, Springer-Verlag, Berlin and Heidelberg, 2005.

Wolfram, Stephen, *A New Kind of Science*, Wolfram Media Inc., Champaign, IL, 2002.

Wren, Christopher R., Sparacino, Flavia, Azarbayejani, Ali J., Darrell, Trevor J., Starner, Thad E., Kotani, Akira, Chao, Chloe M., Hlavac, Michal, Russell, Kenneth B. and Pentland, Alex P., *Perceptive Spaces for Performance and Entertainment: Untethered Interaction using Computer Vision and Audition*, MIT Media Laboratory, Perceptual Computing Section Technical Report Number 372, Appears in Applied Artificial Inteligence (AAI) Journal, Vol 11, Number 4, June 1997, Retrieved May 02, 2010, from http://alumni.media.mit.edu/~flavia/Papers/perceptiveSpaces.pdf

Wyatt, William E., *General Architectural Drafting*, The University of Michigan, C. A. Bennett Co., Peoria, IL, USA, 1976.

Wylie, Chris, Romney, Gordon, Evans, David C. and Erdahl, Alan, *Half-tone Perspective Drawings by Computer*, Computer Science, Information Processing Systems, University of Utah, Salt Lake City, USA, 1968.

Websites:

Academic Dictionaries and Encyclopedias, “Technocrats”, Definition by Gunnar K. A. Njalsson, Retrieved May 15, 2009, from http://dic.academic.ru/dic.nsf/enwiki/658051

Adobe Web Tech Curriculum, Retrieved March 30, 2009, from http://www.adobe.com/education/webtech/CS2/unit_graphics1/gb_bitmap_id.htm

Autodesk, Autodesk Revit Architecture, Retrieved April 05, 2010, from http://www.autodesk.co.uk/adsk/servlet/pc/index?siteID=452932&id=14645193

Bentley, Generative Components, Retrieved November 30, 2009, from http://www.bentley.com/en-US/promo/flash/GenerativeComponents.htm

Bio Mapping, Retrieved May 16, 2009, from http://biomapping.net/

Blinkenlights Project, Retrieved September 18, 2010, from http://blinkenlights.net/

Brocker, Stijn, “Transformation of Luxurious Department Store in Seoul, Korea”, Retrieved May 11, 2008, from http://www.xilver.nl/gallaria.php

Codermind team, Retrieved March 05, 2009, from http://www.codermind.com/articles/Raytracer-in-C++-Introduction-What-is-ray-tracing.html.

Collected Papers of Eric von Hippel, Section 3: Open Information / Intellectual Property / Information Trading, Retrieved March 20, 2011, from http://web.mit.edu/evhippel/www/papers/evh-03.htm

Creative Review, Retrieved May 24, 2008, from http://www.creativereview.co.uk/crblog/dexia-tower-and-the-light-fantastic/

Daniel Lee's website, “Manimals”, Retrieved September 07, 2009, from http://www.daniellee.com/RecentWk.htm

Daniel Lee's website, “Manimals”, Retrieved September 07, 2009, from http://www.daniellee.com/Manimal.htm

Educational Software for Micromachines and Related Technologies (eSMART), “Smart Materials”, Retrieved March 28, 2009, from http://www.cs.ualberta.ca/~database/MEMS/sma_mems/smrt.html.Educational Software for Micromachines and Related Technologies (eSMART), “Smart Materials”, Retrieved March 28, 2009, from http://www.cs.ualberta.ca/~database/MEMS/sma_mems/smrt.html

Fuller, Matthew, “The Human Cellular Automata”, performed at Software Summer School, TechNiks, London and 2000 Wisards of OS 2, Berlin, 2001, Retrieved January 29, 2009, from http://www.spc.org/fuller/projects/the-human-cellular-automata/

Greg Lynn “Form”, Retrieved August 15, 2008, from http://www.glform.com/

"GUI Definition – Brief History", Retrieved November 09, 2009, from at http://www.linfo.org/gui.html

e-architect, "Seoul Building: Galleria Hall West", Retrieved October 26, 2009, from http://www.e-architect.co.uk/korea/galleria_department_store_seoul.htm

Intelligent Building Dictionary, Retrieved February 28, 2010, from http://www.intelligent-building-dictionary.com/words.php/t/Active%20Faade/

Interview with Jakob Nielsen, Retrieved May 16, 2009, from http://news.bbc.co.uk/1/hi/technology/3171376.stm.

Interview with Michael Bull, Retrieved May 16, 2009, from http://agents.sci.brooklyn.cuny.edu/scp50/papers/prof-ipod-25feb04.pdf.

Interview with Peter Cook, "Peter Cook RA and the Friendly Alien", at Royal Academy of Arts, Retrieved February 21, 2010, from http://www.royalacademy.org.uk/architecture/interviews/peter-cook-ra-and-the-friendly-alien,211,AR.html.

Interview with Stelarc, Retrieved May 17, 2009, from http://www.ctheory.net/articles.aspx?id=71.

Kinetic Design Group, Retrieved February 05, 2010, from http://www.robotecture.com/kdg/project.html

Loop.pH, "Hyper Surphace Theory – Aegis", Retrieved October 19, 2009, from http://loop.ph/bin/view/Openloop/HyperSurfaceTheory#Aegis

National Institute of Standards and Technology (NIST), Engineering Laboratory, Retrieved May 13, 2009, from http://www.isd.mel.nist.gov/personnel/kramer/pubs/RS274NGC_3.web/RS274NGC_33a.html#1002165

Media Architecture Group (MAG), Retrieved May 24, 2008, from http://www.mediaarchitecture.org/galleria-department-store/

MIT CROMA, "CROMA: Organic Interactive Facade: Concept and Development", Retrieved February 28, 2010, from http://vimeo.com/8126613

Parliamentary Office of Science and Technology, Retrieved March 28, 2009, from http://www.parliament.uk/documents/upload/postpn299.pdf

realities:united, Retrieved February 19, 2010, from http://www.realities-united.de/#SHOWINFO,1,1

Renzo Piano Building Workshop, Retrieved February 12, 2008, from www.rpbw.r.ui-pro.com

RIBA, Minimum Design Standards, Retrieved March 12, 2009, from http://www.architecture.com/NewsAndPress/News/PolicyNews/Press/2009/RIBAWelcomesMinimumDesignStandardsPolicy.aspx

Shirky, Clay, “It's Not Information Overload. It's Filter failure” lecture for Web 2.0 Expo NY, January 2009 at blip.tv, Retrieved February 12, 2010, from http://web2expo.blip.tv/file/1277460/.

Stanford Encyclopedia of Philosophy, Retrieved March 16, 2009, from http://plato.stanford.edu/entries/conceptual-art/#ConArtWhaIt

Stanford Encyclopedia of Philosophy, “Turing Machines”, First published September 14, 1995; substantive revision November 5, 2004, Retrieved April 12, 2010, from http://plato.stanford.edu/entries/turing-machine/#Definition

STEALTH.unlimited, Retrieved May 13, 2009, from http://www.stealth.ultd.net/stealth/12_cutforpurpose.html

Studio Roosegaarde, Retrieved August 15, 2008, from http://www.studioroosegaarde.net/

The Adaptive House, Retrieved April 24, 2010, from http://www.cs.colorado.edu/~mozer/house/

“The Demo”, MouseSite, Stanford University, Retrieved July 30, 2010, from http://sloan.stanford.edu/MouseSite/1968Demo.html

The Linux Information Project (LINFO), Retrieved April 19, 2009, from http://www.linfo.org/bit.html.

Top Solid, Retrieved August 15, 2008, from http://www.topsolid.com/products/plm/

Translocation_New Media/Art, "Modernity at Large", Interview with Arjun Appadurai by Anette Baldauf and Christian Hoeller, Retrieved January 22, 2010, from http://www.appadurai.com/interviews_baldauf.htm

UN studio, Retrieved October 26, 2009, from http://www.unstudio.com/nl/unstudio/projects/galleria-department-store

Urban Tapestries / Social Tapestries – Public Authoring and Civil Society in the Wireless City, Retrieved May 16, 2009, from http://urbantapestries.net/

Waag Society, “Amsterdam RealTime”, Retrieved May 16, 2009, from http://www.waag.org/project/realtime

Weiser, Mark, “Ubiquitous Computing”, 1996, Retrieved April 15, 2009, from http://www.ubiq.com/hypertext/weiser/UbiHome.html.

WolframMathWorld, “Singularity”, Retrieved May 15, 2009, from http://mathworld.wolfram.com/Singularity.html

WolframMathWorld, “Degenerate”, Retrieved May 15, 2009, from http://mathworld.wolfram.com/Degenerate.html

Xilver, Retrieved February 22, 2010, from http://www.xilver.nl/Xilver-winner-in-Seoul.aspx