PHYSICAL AND VIRTUAL: TRANSFORMATION OF THE ARCHITECTURAL MODEL

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
THE MIDDLE EAST TECHNICAL UNIVERSITY

BY

ASLI ARPAK

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER OF ARCHITECTURE
IN
ARCHITECTURE

JUNE 2008

Approval of the thesis:

PHYSICAL AND VIRTUAL: TRANSFORMATION OF THE ARCHITECTURAL MODEL

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ABSTRACT

PHYSICAL AND VIRTUAL: TRANSFORMATION OF THE ARCHITECTURAL MODEL

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June 2008, 101 pages

Today the most prosperous interface of architectural design and representation has become the architectural model both in its digital and physical forms. There has been a shift in the design medium from the physical modeling processes to computer-aided design, by way of which the computational design methods have established a much more dynamic, complex, and continual design. In this process, the digital design model now accompanies the whole design as a single entity, contrary to conventional analog modeling techniques where design is compartmentalized into linear phases.

By the embracement of computer-aided manufacturing (CAM) in company of computer-aided design (CAD), physical modeling has gained another dimension in the interwoven relationship of the digital and physical. The aim of this study is to explore the novel conceptual and computational changes which mark the departure of this new mode of design from the old. There has always been a hierarchy of presence between the virtual space of representations and architecture's materiality. Within this context, the emphasis of the study is on the relationship between the virtuality of conception and modeling processes, and the materiality of construction, production and fabrication.

Keywords: Architectural modeling, physical modeling, virtuality, computational design, rapid prototyping (RP).

ÖZ

FİZİKSEL VE SANAL: MİMARİ MODELİN DÖNÜŞÜMÜ

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Yüksek Lisans, Mimarlık Bölümü
Tez Yöneticisi: Doç. Dr. Zeynep Mennan

Haziran 2008, 101 sayfa

Hem fiziksel hem de dijital biçimleri ile mimari model, bugün mimarlık tasarımının ve temsiliyetinin en başarılı ara yüzü olma özelliğini korumuştur. Fiziksel modelleme süreçlerinden bilgisayar destekli tasarıma geçiş ile tasarım ortamında bir dönüşüm meydana gelmiştir. Sayısal tasarım metotları ile, tasarım sürecinin geleneksel olarak bölümlere ayrılmış yapısına karşıt ve dijital tasarım modelinin tasarıma tek varlık olarak eşlik ettiği çok daha dinamik, karmaşık ve sürekli bir tasarım süreci kurulmuştur.

Bilgisayar destekli üretimin (BDÜ) bilgisayar destekli tasarım (BDT) beraberinde benimsenmesi ile, dijital ve fizikselin birbirine geçmiş ilişkisi içerisinde fiziksel modelleme de yeni bir boyut kazanmıştır. Bu çalışmanın amacı, tanımlanan bu yeni tasarım biçimini eskisinden ayıran kavramsal ve sayısal değişimleri araştırmaktır. Mimari temsiliyetin sanal mekanı ile mimarlığın maddesel mekanı arasında her zaman varoluşsal bir hiyerarşi bulunmaktadır. Bu bağlamda kavramsal düşünce ve modelleme süreçlerinin sanallığı ile inşa, yapım ve üretim süreçlerinin arasındaki ilişki vurgulanmaktadır.

Anahtar kelimeler: Mimari modelleme, fiziksel modelleme, sanallık, bilişimsel tasarım, hızlı prototipleme (HP).

To My Dearest Family

ACKNOWLEDGEMENTS

I would like to express my sincere appreciation to my thesis supervisor Assoc. Prof. Dr. Zeynep Mennan, for her guidance, understanding, meticulous reading, and motivating comments throughout the whole study.

I would like to present my appreciation to my jury committee, Assoc. Prof. Dr. Ayşen Savaş, Asst. Prof. Dr. Mine Özkar, Inst. Dr. Nihal Bursa, and Inst. Dr. Hakan Tong for their valuable discussions, helpful comments and criticism.

I present my honest thanks and gratitude to my family, whose love, grace, and support I always feel by my side throughout a lifetime.

I offer my sincere thankfulness to Özcan Oğuz, for his love, patience, and support in everything I do.

I am thankful to all my friends at METU for their friendship, support and enthusiasm. I would like to thank Haldun and Sevilay Sevinçli for my second home, to Nihan Karaveyisoğlu for stimulating my work in all aspects; to Başak Uçar and Hacer Yalım Keleş for sharing their knowledge and experience; and to my colleagues at the Department of Architecture, especially to Heves Beşeli, Sertuğ Tanrıverdi, Onur Özkoç, Esatcan Coşkun, Ali Yücel Özdemir, Aytül Baran and Ayşegül Akçay for their friendship and support.

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CHAPTER 1

INTRODUCTION

Architectural design ideas have been processed and represented in various media throughout architectural history. The media are composed of representational techniques such as drawing, painting, collage, photography, and modeling. Two-dimensional representation, especially the architectural drawing, is seen to have always been of great interest in architectural theory. Compared to two-dimensional representation techniques, for a long period architectural modeling has been under minor focus in the architectural discourse, though maintaining a vital position in the field. This study shares the interest in contemporarily enlivened discussions on architectural modeling which focus on the generative potentials of the architectural model within the design process. The position which recognizes the architectural model as a design tool can be said to oppose to the consideration of the model as an a posteriori representation equipment which functions in presentational purposes to explain a finalized design work. Within this context, the model is seen to serve only as an alternative representational medium to architectural drawings. In this sense, the design information produced within the drawing medium is solely translated to the model medium. The thesis controversially focuses on the model medium as a direct means to the architectural design process, rather than merely for presentation or visualization.

When the traces of the intention to integrate modeling to the very early stages of architectural design have been searched, as we understand it today, it is observed that the first declared manifestation came from the Bauhaus in the early twentieth century.[1] This was a major consideration of the influential Bauhaus education and it has had a very important role in the history of architectural education as it defined a mind shift in design procedures. However, as the Bauhaus was closed in 1933 and the Bauhaus tutors were dissipated, the educational system based on modeling was suppressed in favor of design with drawing.[2] The Bauhaus tutors were scattered around the world and many of them went to important architectural schools in the US. They tried to reconstruct a Bauhausian education within the

[1] Mark Morris. *Models: Architecture and the Miniature.* Chichester, West Sussex: Wiley Academy, 2006.

[2] *Ibid.*

American architectural education system. Their efforts throughout the twentieth century has also had a profound effect in integrating the architectural model into the design,[3] though it is mainly the changing scientific and cultural context of the late twentieth century that prepared the basis for a compulsory shift towards the extensive use of modeling within the design procedures.[4] Due to the interdisciplinary dialogue of architecture, the changes in many other disciplines in the late twentieth century have had a profound influence on architectural creation, production and representation. Some of these major disciplines that altered architectural thinking have been mathematics, science, and philosophy.

The Cartesian space and Euclidean geometry, which architecture has internalized for long, had been challenged by the studies of Karl Freidrich Gauss, Janos Bolyai, Nikolai Ivanovich Lobachevsky, and Bernard Riemann.[5] By the works of these mathematicians the space was now constructed in a curved and multi-dimensional configuration.[6] Space and time became associated, and this association brought about the studies of non-Euclidean geometries and topological structures. Within this conceptualization, "time" could be directly representable on form and this recognition gave rise to a "multiplicity."[7] Within this context, a single form could embed multiple possibilities in itself; therefore it became highly dynamic and complex.

Similarly in science, the focal inclination from simplicity to complexity found its equivalence with the studies of "complexity sciences." Their new offering has been to understand the world in its "complex, interconnected, and rapidly changing" structure.[8] John Casti notes that now a system does not have to be fragmented and studied in these isolated theories in the hope of reassembling them in the future: Instead, complexity sciences propose to study directly on the complexity of the actual system and releasing the observer from the

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[3] Albert C Smith. *Architectural Model as Machine.* Oxford: Architectural Press, 2004.

[4] Branko Kolarevic. "Digital Morphogenesis." *Architecture in the Digital Age: Design and Manufacturing.* Edited by Branko Kolarevic. New York: Taylor and Francis, 2003.

[5] Linda Dalrymple Henderson. *The Fourth Dimension and Non-Euclidean Geometry in Modern Art.* Princeton, N.J.: Princeton Architectural Press, 1983.

[6] *Ibid.*

[7] Greg Lynn. *Animate Form.* New York: Princeton Architectural Press, 1999.

[8] Irine Sanders and Judith McCabe. "The Use of Complexity Science," October 2003. p.4.
Reached at: http://www.hcs.ucla.edu/DoEreport.pdf
(Last accessed on 13.06.2008.)

"shadow of hypotheticality."[9] Therefore science is seen to be restructured in a holistic approach in which the boundaries of different research fields are blurred.[10] Within this context, complexity sciences can be observed to have promoted the interdisciplinary structure of theories and experimentation methods.

In the philosophical realm, the plurality and multiplicity that have been stimulated in mathematical and scientific discourses are seen to find their correspondent in the post-phenomenological discourse. In this scope, the philosophy of Gilles Deleuze has been highly inspirational. Indeed, the studies of Deleuze have been based on is the work of Henri Bergson, whose philosophical studies fundamentally challenged the notion of "time."[11] He introduced the notion of *durée*, which represents the "continuous lived time," as opposed to mechanical clock time.[12] This offering constituted an important shift where time was now considered as a continuity, instead of involving discrete instances; therefore it allowed multiple beings and correspondence of different situations.[13] This discussion leads to another important dimension of Bergsonian philosophy: Bergson proposes that the notion of *durée* can be explained by the notion of the "virtual." He argues that, contrary to the common conception, the "virtual" belongs to "reality," but a reality which is not "actualized."[14] In other words, the virtual can be actualized by a materializing action. Within this context, the virtual is not the antidote of the real, but the actual, and these three act in a simultaneity. In this scope, the virtual becomes a situation full of potential for future realizations, and allows a multiplicity of viewpoints and becomings. In parallel, Deleuze accepts this theoretical position, and proposes the notion of the "diagram" and the "abstract machine," which are correspondent of the virtual situation in Bergonian philosophy.[15] The Deleuzian

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[9] John L Casti. *Would-Be Worlds: How Simulation is Changing the Frontiers of Science.* New York: John Wiley and Sons, 1997. pp.34-36.

[10] "The Center for Complexity Science." Reached at: http://www.ccs.org.il/ (Last accessed on 13.06.2008.)

[11] Alexander Sthyre. "Knowledge as a Virtual Asset: Bergson's Notion of Virtuality and Organizational Knowledge," *Culture and Organization.* 9.1 (2003): 15 – 26.

[12] *Ibid.*

[13] *Ibid.*

[14] Stephen Linstead. "Organization as Reply: Henri Bergson and Causal Organization Theory." *Organization.* 9:1 (2002): 95 – 111.

[15] Gilles Deleuze. *Bergsonism.* New York: Zone Books, 1988. p.94-8.

diagrammatic abstraction is conceived as a virtual entity, which possesses a potential for multiple generations in its actualization.[16]

As observed, the twentieth century has constructed an understanding of the world in its complexity with the studies in the mathematical, scientific, and philosophical disciplines. Within this context, it can be remarked that the static and discrete conception of space, time, and form had been increasingly leaving its place to dynamism, complexity, and continuity. However, a major handicap could be noticed in this shift, where the newly recognized complexity could not be studied and experimented with the traditional models and tools. Towards the end of the twentieth century by the development of the computer technology, many disciplines have retrieved adequate tools with the affordable and high-quality computing capabilities to directly study the complex structures.[17]

The availability of computing technology is seen to compose a direct effect on all the aforementioned disciplines and inevitably on the mode of architectural design and production. In the 1950s, the computers were introduced to the architectural field; however due to their expense, they could not be fully integrated in the architectural practice.[18] In the 1970s, the computers had slowly begun to be recognized, but architects more likely used them for drafting and visualization purposes. It can be noted that this type of employment of computer tools does not go beyond the capabilities of two-dimensional representation techniques, but only an increased quality in drawing. But by the 1980s, it is seen that the computer had begun to be increasingly employed in the earlier stages of design, and the new-generative possibilities available by computing had begun to be used. The first encounter with computational methods is observed to have created an excitement among architects to recognize closely and test the new digital medium of design, and this situation led to a highly experimental process regarding architectural creation. The computer modeling can be said to have been tested to its boundaries as it proposed many novel operational procedures beyond the traditional analog modeling techniques. Meanwhile, Pittman notes that personal

[16] William Braham. "After Typology: The Suffering of Diagrams." *Architectural Design,* v. 70 n.3:9-11. June 2000.

[17] John L. Casti. *Would-Be Worlds: How Simulation is Changing the Frontiers of Science.*

[18] Nicholas Negroponte. *The Architecture Machine.* Cambridge, MA: The MIT Press, 1973.

computers were becoming more feasible and faster, and many architects have obtained the chance to be involved in the computational design processes.[19]

For nearly five decades, the computational tools have been increasingly integrated to architectural design. It can be remarked that computer-aided design (CAD) has offered extensive and versatile design procedures for architects. Firstly, the Non-Uniform Rational B-Splines (NURBS), on which many computer modeling software are based, offered architects to study with highly complex curves very fast and easily. This has been possible due to the fact that the NURBS provide an efficient form of data representation, they allow fast operations, and their algorithms are numerically stable. Piegl and Tiller summarize that on the basis of NURBS, computer modeling allows complex operations which cannot be carried in conventional analog modeling medium.[20] The novel modeling operations can be exemplified as parametrics, associative geometry, keyframe animation, morphing, genetic algorithms, and scripting.[21]

To understand the shift in design from the viewpoint of new modeling procedures, some details of the new modeling operations can be touched upon. In parametric modeling, a form can be expressed by mathematical sets of equations in addition to its geometrical expression. The alterations in the model can be acquired by the revaluing of the variables in equations, as well as the manipulation of the equations themselves. Mark Burry notes that by this feature the parametric modeling procedure has been providing architects to construct an explicit design method where the internal logic of the form becomes transparent through its mathematics.[22] Subsequently, parametric modeling is joined with associative geometry, where the association within the form is carried to a higher level in which the relationships of different geometries within a model are also determined by the equations. Therefore, when an object or a detail is altered, the others follow respectively which brings the design sequence simultaneity. Within this modeling procedure, complex forms can be generated and manipulated with ease, speed, and greater accuracy.

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[19] Jon Pittman. "Chapter 18: Building Information Modeling: Current Challenges and Future Directions." *Architecture in the Digital Age: Design and Manufacturing.* Edited by Branko Kolarevic. New York: Taylor and Francis, 2003. pp.254-8.

[20] Les Piegl and Wayne Tiller. *The NURBS Book.* Berlin: Springer, 1997.

[21] Branko Kolarevic. "Digital Morphogenesis."

[22] Mark Burry. "Paramorph: Anti-accident Methodologies." *Hypersurface Architecture II: Architectural Design AD*, West Sussex: Academy Editions, 1999.

In addition to parametric associative modeling, there are other forms of transformative operations which are either completely or partially controlled by designers. With the ability of animation, the form can be shaped by means of associating certain motion-based modeling techniques, such as dynamics, kinematics, and keyframe (or keyshape) animation.[23] In dynamics, the motion of the object and the form is processed through dynamic simulation, where the force fields are taken into account as inputs for the process, though they are external to the form. On the contrary, kinematics put emphasis on the motion of the object, which can be exemplified by the motion in the form's skeletal structure and expressed through joints and bones. In these transformative operations, when time is added to the process as a temporal dimension, the possibility is created to follow the metamorphosis of form. Kolarevic explains that the animation software interpolates the discrete states of form under transformation and creates a smooth time-coded transition in this sequence, from where designers may choose a specific state and propose to develop design further through that stage.[24] Kolarevic adds that another branch of keyshape animation has been important in design which is "morphing," where formally adverse spaces are joined to obtain hybridity, which would result in more responsive yet difficultly anticipated realizations.

In the transformations involved in animation, the evolutionary structure of morphogenesis can be expressed with sets of generative rules, and this generation can be digitally encoded. This kind of coding of the generative process is worked with "genetic algorithms," which are defined by John Frazer as "string-like" procedures and involves processes as reproduction or gene-crossover in analogy with the natural organism's mutation and variation.[25] These processes are observed to be based on parametrics, but in a more adaptive and responsive fashion as the system reacts to newly integrated data into the system and redefines and rewrites the sets of rules.[26] Therefore, the process can be inferred to have become highly dynamic, and the evolutionary structure of the process manifests the inner logic of the form in its external form. In other words, as Greg Lynn points out, the complexity of the form

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[23] Branko Kolarevic. "Digital Morphogenesis."

[24] *Ibid.*

[25] John Frazer. *Evolutionary Architecture.* London: Architectural Association, 1995.

[26] Branko Kolarevic. "Digital Morphogenesis."

does not lie at only its complex curvatures, but also its internal logic and the embedded information of its evolution.[27]

The algorithmic processes can also be represented in non-visual expressions through "scripting." Scripting is defined as writing basic command sequences or computer programs, which utilizes a set of codes and instructions to allow the control of automatic operations. Kostas Terzidis observes that scripting entails efficiency in data representation, and offers rapidness by automaton in highly iterative processes.[28] What is noteworthy in scripting considering architectural conception is its offering of a new non-visual working medium: As Mennan argues, the non-visual working medium of the script would challenge architectural vision and visuality, and liberate designers from visual constraints, formal imagery and prejudgment.[29] Scripting is also seen to bring forth the open-endedness to form as it constructs an easily adaptive nature by the manipulation of the script. As the scripting process operates on a non-visual level, it can be remarked that the design process becomes non-deterministic and emergent. Mark Burry defines this situation of open-endedness as that the final form is neither stabilized with original formal intentions, nor made possible to be foreseen from the early stages of design.[30] Scripting is seen to have become an enriching design procedure commonly utilized by designers both for its speed, and both for the freedom in switching between modes of design in geometry, mathematics, and programming.

The nearly five decades of CAD involvement has been seen to produce a wide range of new architectural design procedures and modeling techniques. The complex structures and forms have become easily generated and manipulated by the CAD development. Subsequently, it is seen that another handicap occurred at the point where the material production of this complexity became impossible with traditional fabrication and construction methods. At this

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[27] Greg Lynn. *Animate Form.*

[28] Kostas Terzidis. *Expressive Form: A Conceptual Approach to Computational Design.* London: Routledge, 2003. p.65.

[29] Zeynep Mennan. "Non Standardization Through Non-Visualization: Scripting the Dom-Ino House". *The Architecture Co-Laboratory: GameSetandMatch II, International Conference On Computer Games, Advanced Geometries and Digital Technologies,* Delft University of Technology, Faculty of Architecture, The Netherlands, 29. March- 01 April 2006.

[30] Mark Burry. "Paramorph: Anti-accident Methodologies." *Hypersurface Architecture II: Architectural Design AD*, West Sussex: Academy Editions, 1999.

point, architects embraced the computer-aided manufacturing (CAM) technologies, which is an extension of CAD in digitally-driven technology. CAM tools work with the similar form data that is stored in a CAD file, in which they read the data through CAM software and directly materialize the artifact in a variety of materials. CAM technologies involve a wide range of fabrication techniques in two-dimensional and three-dimensional production by the utilization of CNC equipment. The direct production and assembly capacity from the CAD file via the use of CAM tools has been seen to dramatically challenge the conventional construction procedures. As Mennan remarks, the representational stages of design are dissolving between conception and production,[31] and the dialogues between different disciplines involved in building industry are increased and accelerated. The use of CNC technologies has also been changing the mode of designing by providing the fabrication of physical models at early stages directly from CAD files. Mitchell notes that this new design course generates continuous feedback between two media.[32] The use of physical models constructed by CNC machines in the design process has been introduced as a new field in contemporary architectural practice, which is referred to as "rapid prototyping" (RP). Rapid prototyping has mutually altered the mode of digital design process and debased certain conventions that have already begun to take transform with CAD modeling.

It can be seen that, modeling in the CAD/CAM duality enhances and enriches the architectural conception and design development, and constructs a continual association between the digital and material, where both become more meaningful and complete with each other. These kinds of extensions as from CAD modeling to CAM modeling are needed for contemporary architectural design, because as Peter Rowe has observed, the comprehension capacity of designers strongly rely on the design world which is constructed by the design medium they have preferred to adopt.[33] Therefore, it can be commented that the more the boundaries of architectural modeling are extended, the more the design world broadens, where design might be embedded with multifarious information, therefore becomes more effective, meaningful, and successfully integrated to its context. In this sense, it can be observed that there is a mutual relationship between the practice and its tools: On

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[31] Zeynep Mennan. "Des Formes Non Standard: Un 'Gestalt Switch'." *Architectures Non Standard*. Edited by Fréderic, Migayrou, and Zeynep Mennan. Paris: Editions du Centre Pompidou, 2003. pp.34-41.

[32] William J. Mitchell. "Design Worlds and Fabrication Machines," in *Architecture in the Digital Age: Design and Manufacturing.* Edited by Branko Kolarevic. New York: Taylor and Francis, 2003.

[33] Peter G. Rowe. *Design Thinking.* Cambridge, MA: The MIT Press, 1986.

the one hand, the architectural model tries to answer to the contemporary needs to be able to process very complex and dynamic forms. On the other hand, in each improvement it opens up new possibilities for architectural production as it is experienced in the course of time.

The main goal of the thesis is to explore the potentials and limits of the architectural model as a means of "actualization" between the virtual and the real spaces of design. The study tries to cover some of the conceptual and theoretical background of the changes experienced in the late twentieth and early twenty-first centuries, via studying the architectural model as the intentions and techniques in the modeling procedures are illuminating a wide area of mathematical, scientific, technological, and philosophical settings. The main argument builds around the shifts which take place in the generative role of the architectural model both on non-digital and digital, in other words physical and virtual platforms.

In the contemporary form of design, three model making methods have become to operate in collaboration: Analog physical modeling, CAD modeling, and CAM modeling. Within this context, during this study, certain dualities have been reached from the viewpoint of architectural modeling such as: "Analog – Computer-generated," "Physical – Digital," "Visual – Numerical." The thesis claims that this spectrum of dual positions and tries to reveal that they have actually a more balanced and convergent character, rather than propelling each other as polarities. This study aims to elucidate that this convergence is originating from the very nature of representation, which constitutes the means for the creative intention from the virtual to the material. It is an inquiry to redefine an integrated notion of the architectural model which comprises the three major processes of modeling.

CHAPTER 2

ARCHITECTURAL MODEL AS A MODE OF REPRESENTATION

This chapter serves as a general framework of architectural modeling as a mode of representation. It tries to form a background in two concurrent fields: Firstly in physical modeling and the conventions that have been constructed through its history, and secondly in the situations which seem to challenge not only architectural modeling but all the representation techniques and which can be expressed as computational and complex methods. Understanding the traditions, conventions, and the background of design computing synchronously would help to understand the contemporary shifts in the realm of architectural modeling and how it transforms architectural design.[1]

In order to comprehend what "model" connotes in the architectural realm, the concept is studied in the first place. Then, the types of models are defined in a general sense for the purpose of understanding such conventions in especially physical modeling. These extensions bear importance for the sake of recognizing the positions, functions and potentials of different forms of models. Such categorizations would also clarify how designers deal with design, for what purposes they employ certain model forms, and what these models mean in the architectural realm. Although such classifications might seem highly artificial, since the boundaries between practices have been increasingly dissolving, they would still help to increase accuracy in modeling terminology.

After studying the types of models, types of architectural models are defined in a parallel manner. In this classification, it can be recognized that modeling has been highly associated with its representational mode. Such a recognition would also serve to comprehend design theory from the viewpoint of modeling. Accordingly, these theoretical positionings and functional differentiations of different types of models lead to the main discussion of the

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[1] It should be mentioned that the discussion on the function of the architectural model, as it is known today, is constructed by Leon Battista Alberti in the Renaissance. The discussion was suppressed by the emphasis on the architectural drawing up until the twentieth century. In the contemporary discourse, in both pre-digital and digital era, it has drawn strong interest and become a major field of study.

Mark Morris. *Models: Architecture and the Miniature.*

thesis: The perception and meaning of architectural modeling has been going through a major shift for the last three decades, particularly by way of the digital technologies.[2] This shift is discussed broadly with various factors and outcomes in the realm of architecture, taking into consideration its highly interdisciplinar context with philosophy, science, and technology. To achieve this, a history of architectural modeling is studied in the final section of this chapter, and this argument leads to the shift in the late twentieth century which is studied in the following chapter.

2.1. An Overview of the Modeling Culture

2.1.1. The Meaning and the Concept of "Model"

In an etymological search, it is seen that the word model is "borrowed from the Middle French word *modèle*, from Italian *modello*, from Latin *modellus*. Modellus is a diminutive of the Latin modulus, a diminutive of modus, which signifies the word measure."[3] As observed, modeling is highly associated with measuring. As Smith defines it, "model" signifies a number of situations: It can be the representational organization of an entity, not necessarily in a scaled down form. It may propose a pattern or method that serves to produce a following item.[4] It may also "offer a tentative description of a theory or system that accounts for all its known properties."[5] Architectural models work in all these fields, and it might be additionally illustrative to evaluate architectural models within the "concept of model."

It is fundamentally important to understand the concept of "model" with its different meanings and varying contexts, because it is used to specify different means, situations and ideals in many fields. This may help to clear some ambiguities knowing the existence of such models and such classifications, in order to draw parallels between specific model types. This would illuminate a basic knowledge on the logics and conventions of model-making. Together with the dissolving boundaries between disciplines, it becomes more complex to recognize, understand and implicate a specific model. For the sake of such a

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[2] Alfredo Andia. "Integrating Digital Design and Architecture During the Past Three Decades." *Proceedings of the Seventh International Conference on Virtual Systems and Multimedia (VSMM '01), University of California, Berkeley, CA, 2001.*

[3] Albert C. Smith. *Architectural Model as Machine.* pp.61-2.

[4] *Ibid*. p.62.

[5] "Model," *Webster's Third New International Dictionary.* Springfield, MA: C. G. Meriam Co., 1967.

commencing background, following Albert C. Smith's classification, the concept of model can be studied in five categories: (1) mathematical, (2) analog, (3) qualitative, (4) engineering, (5) theoretical (sociological and philosophical.)[6]

A "mathematical model" deals with the natural systems and studies it within formal mathematical representation.[7] For the mathematician John L. Casti, "a model means an encapsulation of some slice of the real world within the confines of the relationships constituting a formal mathematical system."[8] Following with his definition of the mathematical model;

> Thus, a model is a mathematical representation of the modeler's reality, a way of capturing some aspects of a particular reality within the framework of a mathematical apparatus that provides us with a means for exploring the properties of the reality mirrored in the model.[9]

Mathematical models play an important role in architecture, with ever increasing stress in the contemporary discussions. Following the debates in complexity sciences and the recognition of computational methods, architecture has progressively been incorporating mathematical models in its processes. Together with this new mathematical background and digital technologies to process it, computational design knowledge forms this juncture as one of the key elements in the epistemological shift in contemporary architecture which is going to be discussed more in detail in the following chapter.

"Analog models" are artificial physical representations used to test and measure specific systems.[10] Some examples of scale analogs include miniature rivers, dams, aquifers[11] for hydrologic tests, miniature ship hulls for testing in water tanks, or miniature airplanes for

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[6] Albert C. Smith. *Architectural Model as Machine.* p.xviii. In his book, Albert C. Smith conceptualizes the fifth model type as "relatively subjective models," on the basis that sociologists and philosophers rely on relatively subjective views on the nature of human and society. However in the scope of this work, these kinds of models are included as "theoretical models," which may both embody objective and subjective recognitions on a conceptual level.

[7] *Ibid*. p.xviii.

[8] John L. Casti. *Reality Rules I: Picturing the World in Mathematics.* New York: John Wiley, 1992. p.1.

[9] *Ibid.*

[10] Todd Rasmussen. *Analog Models* [Course Notes]. Retrieved March 30, 2008, from the Course's Website: http://www.hydrology.uga.edu/rasmussen/class/8740/Chap3.pdf. (Last accessed on 15.05.2008.)

[11] *Ibid*.

testing in wind tunnels.[12] Analog models aim to "demonstrate known quantitative relations among governing parameters" rather than composing a discovery.[13] They are laboratory experiments which help to conduct towards design alternatives.[14] As the use of computers has increased today, computer simulations are also widely utilized in analog modeling as well as physical experiments. The types of "qualitative models" can be listed as mock-ups, prototypes and test beds.[15] They work as simulations in a more precise domain. Examples of such qualitative models can be given as scale models of high-rise buildings or bridges exposed to smoke streamers to visualize vertex patterns; or structural scale models tested for their reactions under specific loads. [16] Architects receive consultation from experts while working in such models. Engineering models, as described by Dieterich Schuring, are "experimental models structured to mirror the true physical behavior of an original phenomenon, or a prototype."[17] Following Schuring, these types of models serve as substitutes of systems that cannot be studied at the prototype level. They provide fundamental information of the studied system, which allow predictions for prototype design.[18]

Theoretical models include the models of philosophers and sociologists, assisting to comprehend and alter the human nature and its systems.[19] They work on an exceedingly conceptual level, but both hinging upon subjective and objective values.[20] In the field of architecture, they function to strengthen the theoretical and conceptual background of a

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[12] Albert C. Smith. *Architectural Model as Machine.* p.xix.

[13] *Ibid.*

[14] Todd Rasmussen. "*Analog Models.*".

[15] Albert C. Smith. *Architectural Model as Machine.* p.xix.

[16] *Ibid.*

[17] Dieterich J. Schuring. *Scale Modeling in Engineering.* Elmsford, NY: Pergamon Pres, 1977. p.5.

[18] *Ibid.* p.7.

[19] Albert C. Smith. *Architectural Model as Machine.* p.xx.

[20] *Ibid.* p.xviii. Philosophical models can be defined as subjective theories of philosophers obtained through meditation. In sociology, it is seen that there are a number of different types of models. Circa late 1970s, a constructivist view in sociology tried to hold objective grounds. For such a purpose, on a micro scale they study "one-on-one and small group dynamics in regard to social patterns, socialization and communication." It can be observed that there is the will to the possession of objective measurement in both within the realm of philosophy and sociology; however subjective models are contemplated on more often than not. The information on sociological models is obtained from: Judy Lombardi. "Sociological Models," http://www4.vjc.edu/JudyLombardi/stories/storyReader$749. Last accessed on 30 April, 2008.

design proposal. The theoretical position of the architect is manifested in his design through such models. Theoretical models operate on many scales: While providing the unity in a single project, they also contribute to the consistency of the architect's attitude in the entirety of his practice. It can also be pondered that they share a part in the creation of paradigms in the context of an architectural community. It would not be going too far to regard the impulsive character of such theoretical models by mainstream architectural practitioners.

As observed, the "model" delineates a wide range of circumstances in many contexts. Construing the concept of model with its multi-faceted structure is essential since the architectural model operates in all these areas. It occasionally signifies an ideal, a canon, or a means to achieve a desired state. In this sense, it appears to be interchangeably used, though being in consciousness of the subtle disparities would help to provide terminological accuracy. Moreover, the multiple meanings of the concept are also reflected in the concept of the architectural model. In the realm of architecture, the "ideal" is extrapolated as the "design model" or the "diagram," the "canons" as "design conventions," and the "means" as the "physical or virtual architectural model" in the form of a thinking artifact. As the disciplinary boundaries are increasingly suspending, it is getting complicated to decipher and situate the architectural model. In this manifold study, it is detected that the architectural model is assuming numerous roles, particularly in its contemporary state more than ever.

2.1.2. The Architectural Model:

As observed from the study of types of models, the term "model" can be said to be a highly flexible term for architects with its many functions.[21] The architectural model simply refers to the physical or virtual representation of a design idea and can be basically defined as "a thinking and defining mechanism for understanding and demonstrating architectural concepts."[22] From the multiple definitions that can be put forward for the architectural model, as Albert C. Smith proposes, the French word *maquette* suggests the closest meaning to what is understood of the architectural model.[23] He explains that, "literally a *maquette* is a demonstration designed to gauge the general appearance or composition of the thing

[21] Mark Morris. *Models: Architecture and the Miniature.* p.8.

[22] Albert C. Smith. *Architectural Model as Machine.* p.vi.

[23] *Ibid*. p.2.

planned."[24] Today the architectural model is seen to have gained a much more flexible and versatile character with many facets whose field extends to a broader context where the boundaries of different types of models dissolve into each other. On this broad context of contemporary models, Morris defines that;

> Model applies to a whole gamut of real and virtual objects, running from what appear to be crumpled up wads of paper to models so highly finished that they appear as real full-scale buildings in photographs, and to a growing array of digital types that, by layers or in sequence, target a myriad of design concerns.[25]

It can be added that the models can be classified as old school or analogue models, which refer to touchable scale models and virtual models, or they can be categorized in terms of their performativity or functionality.[26] However, he is right in observing that with digitally fabricated models, which are cut by laser or routers or built by three-dimensional printers, this categorization is blurred. In addition to this, it can also be seen that the labels as analogue or digital models or classification by functionalities are also quite ambiguous within the context of contemporary modeling.

In contemporary design culture, modeling can be regarded to have succeeded in consolidating its grounds with its dynamism and versatility. When compared to the two-dimensional representation techniques, to which modeling was subordinated for centuries, it can be stated that by its very nature modeling outperforms two-dimensional techniques in a few topics. It can be observed that architectural sketching and drawing has always been favored by designers with its celerity and ease.[27] Porter and Neale detect that studying architectural concepts on paper at the initial stage of design is a well-disposed situation to generate design ideas, providing speed and enrichment in the process.[28] Be they efficient at this stage, it can be regarded that such two dimensional representations may carry a few handicaps.

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[24] *Ibid.*

[25] Mark Morris. *Models: Architecture and the Miniature.* p.8.

[26] *Ibid.*

[27] *Ibid.* pp.14-23.

[28] Tom Porter and John Neale. *Architectural Supermodels: Physical Design Simulation.* Oxford: Architectural Press, 2000.

Firstly, apart from sketching or generating initial drawings, it is common experience that producing the technical drawings required to completely represent a design work necessitates colossal time and labor. In addition, the orthographic set of drawings is a rather technical form of representation which requires professional training or extensive familiarity to understand.[29] Scale models are experienced to be much more communicative, easy and fast to interpret in this sense, both by designers and clients. Furthermore, during the course of design, modeling is seen to provide a strong form of penetration for the designer by illuminating all details of the building. At the same time, it is observed to hold more potential in offering several new design routes to be followed. In the context of generating new ideas, Porter and Neale have detected that "[i]f the graphic techniques are the sole method employed in design, alternative solutions which might exist beyond their capacity could remain hidden or even ignored."[30] Similarly, as Mark Morris observes, "[m]odels also help check deficiencies in design and in their refinement curb the effort of imagining various problems only in drawing."[31] It is clear that models form a more comprehensive working media and also serve to provoke the designer for diversities by permitting contemplation on all these dimensions as well.

On an epistemological level of discussion, concerning the perceptual procedures and process-related dynamics of design, it is not going too far to regard drawings and other image representations as fixative. Unlike the dynamism of three-dimensionality, two-dimensional representations are obtained by freezing a moment in design, capturing and framing the vision in image. It can be suggested that the whole perception of the final product is foreseen and planned by the producer of the image and the flexibility of the viewer's interpretation is limited. In the example of the orthographic set, there are conventions of such a standard graphical representation. The orthographic set is composed of plans, sections, elevations, in some cases accompanied by isometric or axonometric projections, and perspective drawings. Other images as model photographs, collages or computer renderings try to illuminate and visualize design with other motivations. The reason they preserve their fixity is that as soon as their advancement is complete, it can be noticed that all aspects which are dynamic in reality are frozen. For instance, when a model

[29] *Ibid*. p.2.

[30] *Ibid*. p.20.

[31] Mark Morris. *Models: Architecture and the Miniature.* p.9.

photograph or computer rendering is observed, the lighting conditions are prepared according to the scene, and the perspective is anchored by the camera.

As to directing attention to the architectural model, it can be clearly observed that the gaze of the viewer cannot be immobilized in such a sense as in the image. While observing a model, the perception is realized through a period of time. The movement of the body is also incorporated to the motion of the eyes.[32] If architects observing a model are visualized, it would surely be a scene in which they either handle the model or move around it, to obtain a perception from all angles. As Tom Porter and John Neale observe, other senses as of touch and smell also become a part of this observation. Unlike the image, it can be observed that the model and the viewer share the three dimensions and its tactility in the same reality. Opposing to the discreteness in the two dimensional representation, these interactions in the observation of a model provide a continuum. Concerning both the perceptual and design processes, models share a greater success in aiding the complex visual relationships. Based on this aid, the dialogue between the designers gains speed and non-professionals can penetrate into the design more easily. The role of the models in the design process is going to be extensively discussed in the following section, from the viewpoints of designer, designer dialogues and client relationships.

2.2. Different Roles of Architectural Models in Terms of Their Performativity

When studied closely, it is interesting to observe that there are various types of models which concentrate on different aspects of design works. This classification is far beyond the differences in the materials chosen to build a model, or the gestures of the model-maker. First, and probably the most important matter is the model's status in the course of design. Such categorizations would illuminate what certain models would mean in the process of design, and on a pragmatic degree they would help in the employment of models more effectively.[33] Secondly, the concepts of scaling, and therefore detailing, become integral to this discussion respectively. In this procedure, it becomes crucial to understand the specific utilization of the model type which directly signals the course of design as it is intended by designers. As Morris mentions that, "model types are used strategically, depending on the

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[32] Porter and Neale. p.104.

[33] Mark Morris. *Models: Architecture and the Miniature.* p.8.

stage of development and the problem being addressed."[34] This aspect alone may give hints on the whole attitude about how designing is comprehended, and how the path and character of design work is drawn.

2.2.1. Types of Architectural Models

Designers and design theoreticians have always been interested questions on how an architectural design process begins, how it proceeds, what means do designers employ, what such tools connote, and so on. To refer to the mental procedure before any design idea is materialized, Rudolf Arnheim offers that a form of model has already been employed as the "thought model." As interpreted by Morris, Arnheim points out that "architects think in model form, to scale."[35] As Arnheim states;

> No doubt, the architect must imagine with some degree of precision what the actual building will look like when approached from the street or seen from the inside. But much of the actual shaping must be done on thought models of the whole building, mental images that are supported sooner or later by small-scale models built at the office. […] What can be seen in imagination tends, of course, to be less detailed and more generalized, but nevertheless the handling of a mental image bears a striking resemblance to the manipulation of an actual model with one's hands.[36]

In more tactile or visual stages of architectural modeling, in other words while thinking with models in the course of design, it can be observed that designers utilize a list of model types: Conceptual models, working models, presentation models, a list which can be extended. These model types are common practice to many practitioners, and what is more, designers tend to utilize certain models in certain stages of design, which defines a deep-rooted traditional approach.[37]

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[34] *Ibid*. p.27.

[35] *Ibid*. pp.9-10.

[36] Rudolf Arnheim. *The Dynamics of Architectural Form.* Berkeley: University of California Press, 1977. p.17.

[37] Before the beginning of any materialization at the conceptual level of design, there is another form of study that many designers tend to find useful: The diagram. As van Berkel and Bos state, the general apprehension of the diagram is "a statistical or schematic image." (van Berkel and Bos, p.20.) They continue that architects have been favoring the diagram as a "proliferating machine," which forms its conventional significance today. Peter Eisenman also states that historically the diagram is understood in two forms: The "analytic," and the "generative." Eisenman's definition of the analytic and generative diagram can be said to be the equivalent of van Berkel's and Bos's definition of the conventional diagram. It should be mentioned that diagrams may be represented with various techniques, including the model-form as well. The diagram discussion owns a long

2.2.1.1. Conceptual models (Sketch Models)

Conceptual models can be defined as three dimensional initial sketches of architectural design ideas produced at the very beginning of a design process. Many architects are seen to have adopted different techniques for conceptual studying. Common techniques can be observed as sketching, modeling and even painting. Studying with models at the conceptual stage seems to be a deliberate choice which is believed to be more challenging and enriching, for the reason that conceptual modeling has the virtue of reversing the conventional design route where drafting is employed firstly and modeling at the later stages. Tom Porter and John Neale define the role of conceptual models as;

> Used as an initial working design tool by many designers who prefer to test newly forming ideas directly in the space of the idea, the conceptual model represents an intimate and embryonic sketch in three dimensions.[38]

Conceptual models are commonly experienced to be built very fast by simple construction techniques and materials, as card or clay. They are observed to be easily modifiable and alterable. It is noticeable that architects may choose mixed media, or test same ideas in various media. On the one hand, the advantage of working in the space of design helps to visualize three dimensional relationships and it is a great advantage if it is taken into consideration at the very beginning. On the other hand, it is seen to provide much greater freedom to test form, space and surfaces in three dimensions without the concern of detailing.

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history especially since the Bauhaus, but the contemporary understanding is based on the writings of Gilles Deleuze, which is discussed more in detail in Chapter 3. For the time being, since more tactile forms of models in the design development stage are discussed, the generative role of the diagram is referenced at this point.

Ben van Berkel and Caroline Bos. "Diagrams, Interactive Operation in Operation." *Any* 23 (1998): 19-23.

Peter Eisenman. "Diagram: An Original Scene of Writing." *Diagram Diarires.* Edited by Peter Eisenman. New York: Universe, 1999. pp.26-35.

[38] Porter and Neale. *Architectural Supermodels: Physical Design Simulation.*p.21.

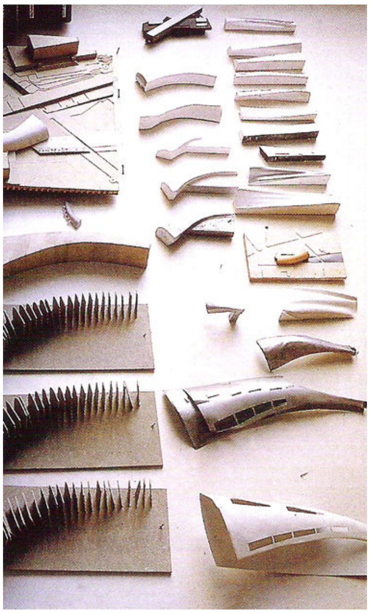

Figure 1. Concept models of Annette Goderbauer. Built for Steven Holl's Kiasma Museum of Contemporary Art, Helsinki.

Tom Porter and John Neale. *Architectural Supermodels: Physical Design Simulation*. Oxford: Architectural Press, 2000. p.22.

Conceptual models may carry an abstract language and may be scaleless as well. These choices depend on the designer's attitude in generating the initial ideas and s/he habitually makes use of the most stimulating method which would supply her/him with several outcomes. Conceptual models are deeply interesting and elementarily important in the design process due to their property of being the initial responses to a given design problem.[39] These first responses are of great interest because they crystallize the whole process and the final form. In the route of design, conceptual models can be construed as forming the foundational background of a design idea. Therefore, they serve to legitimize the architectural product by constructing the basis to lean on and the guide to follow when disoriented. Another important characteristic of conceptual models is their potential of generating various design ideas. It can be suggested that they mark the multiple outcomes of initial responses by their uttermost flexibility and versatility.

[39] *Ibid*.

2.2.1.2. Working models (Study Models, Design Development Models):[40]

Working models are the models that designers utilize in the entire design development. They can be analyzed as extensions of conceptual models, that is to say of their "conceptual predecessors."[41] They are exploration tools which unfold many underlying principles "[w]hile referring back to the design objectives," and stimulate potent future opportunities.[42] In the design process, the transition from the conceptual model to the working model might seem diffused. Working models may still act as conceptual models, but they are more delimited. They serve as tools to carry out a more detailed and specific study following the conceptual stage where initial ideas are already decided. They can be interpreted to sustain the design closer to reality gradually, incubating it until it is maturated.

Working models' constructional quality may differ in a scale of being very rough or really detailed and clean. They can be used to discuss an ongoing design between designers or with the clients if they are also involved in the process. However they are not constructed as clean as the presentation models, and they are not as representational as such. As Tom Porter and John Neale explain;

> These are not exclusively about structurally-based ideas but often about exploring different shapes, geometries or construction methods that will emerge from experimenting with form and material in different ways – and how these different approaches will ultimately affect the building process.[43]

During the course of design, many working models are built, and when an idea is tested the designers generally tend to discard them.[44] At this point, it can be commented that the discard might occur ascribable to two following situations: Either the designers may depart from the tested idea and go back to a previous stage to bring forth other ideas, or a new working model would be decided to be built based on the knowledge of the previous

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[40] Inferring to the literary survey, it is encountered that working models can be referred to by many names such as "study models" or "design development models." However, the "working model" is chosen to be used in the scope of this study.

[41] *Ibid.* p.24.

[42] *Ibid.*

[43] *Ibid.*

[44] *Ibid.*

working model. It can be detected that this procedure would construct the design as a "trial and error" process. To clarify this position, the place of design in a scientific discourse should be mentioned briefly and would be helpful in conceiving design with this perspective.

In a scientific approach, the design process has been conceptualized as a "problem solving procedure" by designers and theoreticians since the end of nineteenth century.[45] As Peter G. Rowe states, "these interpretations all seek to explain creative problem solving under the conditions of bounded rationality that are characteristic of design."[46] In the late 1950s and 1960s, "design was regarded as a series of stages characterized by dominant forms of activity."[47] The cognition of design as a "staged-process" has inspired the production of many design models,[48] one of which the most central and dominant theory have been the "information processing theory" developed by Newell, Shaw and Simon, in their paper entitled "Elements of a theory of human problem solving" published in 1957.[49] In this system, the problem-solvers' behavior is represented by a "program" which indicates "primitive information processes that account for the cognition associated with an action."[50] As Rowe explains, the general diagrammatic schema of this position is the "decision tree." In the decision tree, there are two major reference points: Firstly there are "nodes" which refer to the "decision points" or "knowledge states" in which a solution is proposed. Secondly, there are "branches of action" which represent the "generative processes, […] that allow one to take knowledge states as input, or as starting positions, and produce new knowledge states as output."[51]

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[45] Peter G. Rowe. *Design Thinking.*

[46] Peter G. Rowe. "Procedural Aspects of Design Thinking." *Design Thinking.* Cambridge, MA: The MIT Press, 1987. p.39. Rowe explains that, the mentioned "bounded rationality" here refers to the concept of "satisficing" that Herbert A. Simon has developed. To summarize Simon's argument, "satisficing" denotes the condition in which human cognition can rarely hold the capacity to consider all possible solutions to a problem, therefore settles for a satisfying solution at hand.

Herbert A. Simon. *The Sciences of the Artificial.* (Third Edition.) Cambridge, MA: The MIT Press, 1996 [1968].

[47] *Ibid.*

[48] These theories can be examplified by that of Morris Asimov's, of Hochschule für Gestaltung at Ulm and of Bruce Archer's. For further information on such design theories and cognitive studies, please see: Peter G. Rowe. "Procedural Aspects of Design Thinking."

[49] Allen J. Newell, C. Shaw and Herbert A. Simon. "Elements of a Theory of Human Problem Solving." *Psychological Review* 65.3 (1958): 151-166.

[50] Peter G. Rowe. "Procedural Aspects of Design Thinking." p.51.

[51] *Ibid.*

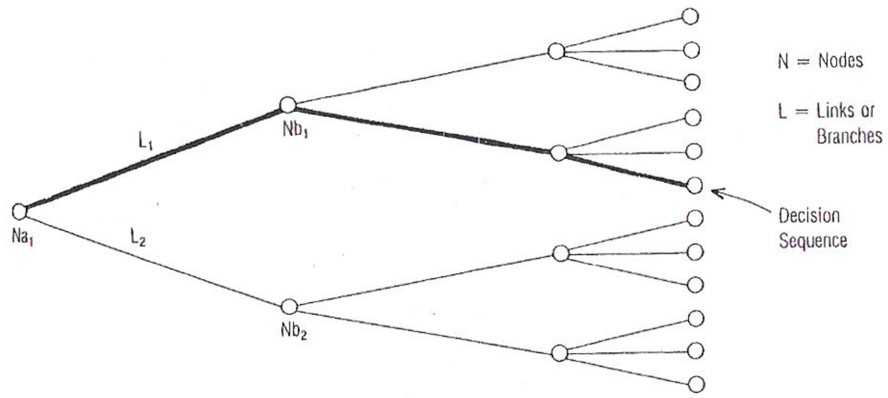

Figure 2. The general schema of the information processing theory, or the decision tree.

Peter G. Rowe. "Chapter 2: Procedural Aspects of Design Thinking," in *Design Thinking*. Cambridge, MA: The MIT Press, 1987. p.53.

With this cognitive extension, the design progression can be commented to be ensured through these tried-omitted paths and respectively successive routes. Similarly, due to their virtue of reflecting a good amount of design thinking, design process and architects' intentions as well, working models are usually preserved in the studios of architects, though discarded. Consequently, yet again in the decision tree scheme, the position of the working models in the design procedure can be formulated as that they mark the potentially weak or blocked paths. Be they crude or beautifully built, they can be commented to outline the milestones indicating the process. These milestones can be observed to be very useful to guide the architects in taking the subsequent decisions. In this very dynamic process, working models are observed to accommodate manifold design input and output. They may also carry the information or traces of information from other mediative procedures as well. For instance, these sources can be observed to be other exercises carried on at the same time (as drawing), or traces of previous assemblies, or they may reflect thought switches during the very process.

Many major design decisions seem to be made in the medium of the working models. The main discussions are stimulated for space, surface, material and structure decisions. Although the "structural models" come into prominence as another form of model in studying structural issues, the basic thinking is firstly carried in the form of the working model. After an amount of maturation, it is carried to the structural models' medium for precision. Naturally there can be observed to be many feedbacks between studying mediums, and back and forths between the models as well.

Among this variety of working models, the "block models" and "space models" are seen to be a different model form where a concentration on certain aspects of design has been developed. The block models (or mass models) are abstract models which display only the mass formation of a building without any detailing. They more likely approach the discussions of mass and surface relations. The main discussions in these models can be observed to be carried on two platforms: On a larger scale with the natural and urban context, and on the scale of the specific site. The dynamics of the contextual and local conditions provide data for positioning, orientation, form analysis and solid-void relations of the building. This form of modeling is highly abstract in terms of material choices, detailed space visualization and structural detailing. It is likely to observe them constructed completely with the same material, or painted entirely white for the most part. In some cases color-coding may be applied, with different colors or color toning.[52]

Different than block models, space models designate the spatial relations and spatial qualities of design. They function as more likely three dimensional sections, which concentrate on a central space of a certain design work. They may indicate the qualities of interior and exterior spaces, or both, as to demonstrate inside-outside relations. In this sense, they are highly associated with the outcomes of façade design as an interface, along with the quality of lighting. Interestingly, space models can be commented as the type of models where the human scale is emphasized the most. The model-maker tries to give a sense of the space by trying to take the viewer to that scale. Another situation which may support this notion would be that the photographs of space models are frequently used to accompany other presentation materials to additionally provide a sense of space. In these terms, space models are seen to be used as a platform to produce images of spaces for the design work which the designers wish to emphasize.

[52] Porter and Neale. *Architectural Supermodels: Physical Design Simulation.* p.26.

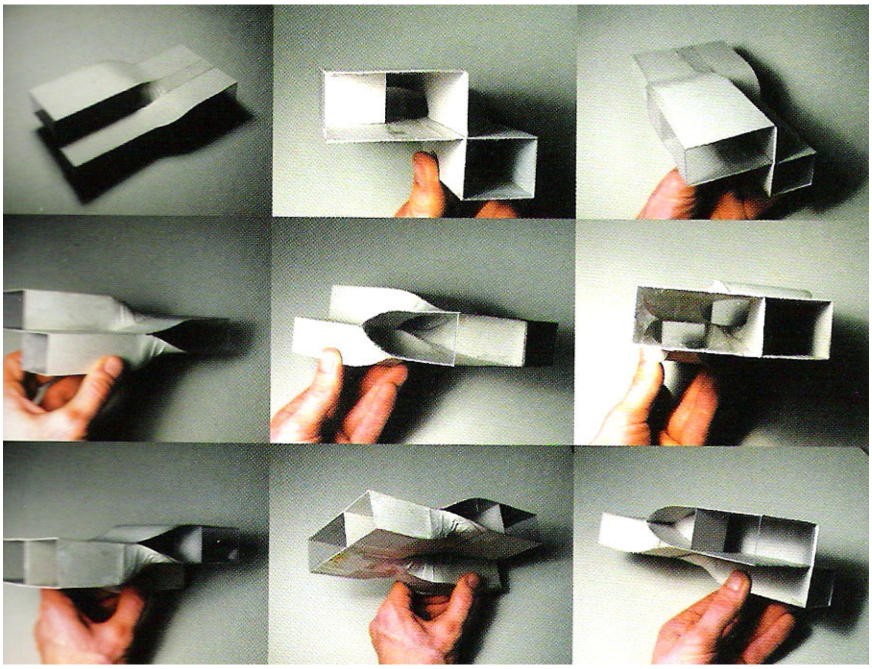

Figure 3. Working model of Ben van Berkel and Caroline Bos. Constructed for the VilLA NM, Upstate New York.

Ben van Berkel and Caroline Bos. *UN Studio: Design Models, Architecture, Urbanism, Infrastructure.* London: Thames and Hudson, 2006. p.77.

Space models are generally observed to be built fast and tend to be abstract, emphasizing on the spatial organization rather than the detailing. By their feature of rendering the interior and demonstrating the spatial quality, it can be said that they are related to the interior models and presentation models to some extent. However space models still lack this feature of being part of a "finished" design, they are still alterable and their aim is to provide a quick visualization for the spatial organization. With regards to interior models and presentation models, space models lack their level of detailing and preserve their position in the designing stage.

2.2.1.3. Structural models

Structural models are specified in terms of solving the structural system and related details for the design work. As indicated in the section of the "working models," structural models try to reveal and solidify the structural system in detail, compared to its raw stage in the working models. They may represent "isolated problems, or exist as fully developed *maquettes* that communicate a determined structural strategy.[53] The real space of the models are greatly similar to that of buildings, consequently, structural models provide a trusted field to test the decisions.[54] They can be platforms where both architects and engineers work. Structural models are significantly detailed and precise in terms of creating the objective ground for testing. As Tom Porter and John Neale observe;

> Often skeletal in nature they [structural models] avoid any display of the total external envelope in order to expose, test and demonstrate structural, construction and service systems or their assembly.[55]

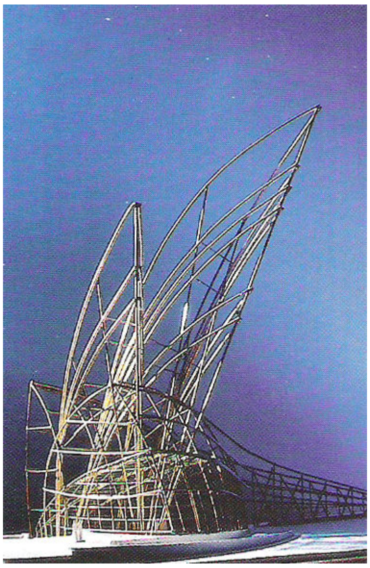

Figure 4. Structural model of National Museum of Contemporary Art, Osaka, Japan. By Cesar Pelli & Associates.

Tom Porter and John Neale. *Architectural Supermodels: Physical Design Simulation.* Oxford: Architectural Press, 2000. p.28.

[53] *Ibid.* p.28.

[54] Mark Morris. *Models: Architecture and the Miniature.*

[55] Porter and Neale. *Architectural Supermodels: Physical Design Simulation.*p.28.

In addition, they provide a vast amount of input for designers to draw the construction related boundaries. They function to carry the design closer to its materialization. But structural model making still takes place in the design process, interacting with the working models. The scales of the structural models vary immensely. Their field may extend to detail models, full scale mock-ups or full scale prototypes, but it is encountered that they mostly are realized by the building of structural units in order not to disturb the design budget. Some challenging design ideas may require the building of full scale prototypes of structural units. Parallel to the varying scales, material choice for the structural models also has a palette ranging from conventional model materials as card or balsa, to real materials as timber or metal.[56] Detail models can be categorized as a form of structural models because they concentrate on an isolated detail of the structural system. They more likely function to visualize the details and test certain structural decisions. Similar to the structural models, they are produced in the design process. Their scales may vary but some of the conventional scales are 1:10, 1:5 and 1:1. Although detail models would serve other purposes, they usually function as visualizers in terms of clarifying joints which would be perceived with difficulty.

Figure 5. Full-scale Peregrine Winery steel roof detail study model, by Architecture Workshop.

Homo Faber: Modeling Architecture Exhibition Catalogue, *Graduate Research Conference Proceedings,* Melbourne: RMIT School of Architecture and Design, 2006. p. 45. (Copyright Reserved.)

[56] *Ibid*. p.29.

2.2.1.4. Presentation models

When the subject of architectural modeling is brought into discussion, the model types that first come into mind are the presentation models. They are the models that are built to represent the final design work. They are the "complete and fully-detailed composition of an architectural solution."[57] They are seen to mark the complete ending of the design process. Presentation models are built beautifully and precisely, and they are more realistic in order to provide the exact communication with the viewers, who are other designers, peers and clients.[58] Albert C. Smith notes that presentation models are not open to interpretation in terms of design possibilities and carry the function of informing.[59] Apparently, it can be observed that the material choices for such models can be multifarious. They may be built with materials that reflect how the original building would look like. They may as well be more abstract, which may especially be the case with competition entries.[60] In such competition proposals, architects choose wide-ranging materials and techniques, and they may challenge the "realistic look."[61] For example, such abstractions can be observed in models built entirely with glass or timber blocks, painted completely white, or with the usage of other interesting materials as acrylic models. Some architects may choose strong colors to put emphasis on certain design ideas or approaches.[62]

The attitudes in the presentation models are immensely associated with the model-makers working styles and techniques, too as presentation models are generally built by professional model-makers, though some architects prefer to produce them in house.[63] The presentation models manifest the dialogue between the architect and the model-maker. Many leading

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[57] *Ibid*. p.34.

[58] *Ibid*.

[59] Albert C. Smith. *Architectural Model as Machine.*

[60] Porter and Neale. *Architectural Supermodels: Physical Design Simulation.*

[61] Porter and Neale. "Chapter 3: Models in Practice," and "Chapter 4: The Makers of the Supermodel," in *Architectural Supermodels: Physical Design Simulation.* Oxford: Architectural Press, 2000. In both chapters, Tom Porter and John Neale concentrate on how the models are incorporated in the design process, especially in competition entries. They provide the reader with various images of models as well as the process of model-making from the perspective of professional model-makers. This is very interesting in terms of learning what the designers would like to emphasize in their specific projects, why certain model materials and techniques are incorporated in their practice.

[62] *Ibid*.

[63] *Ibid*.

architects and architectural firms work with a certain model-maker. This helps to build easier communication grounds between the designers and model-makers after a certain amount of time. In addition, it can be observed from the practices of cutting-edge designers world-wide, such modeling techniques provide the architect or the firm a consistency in their presentation and even design language constructed through the presentation models. Because it is very much the case that a design work is identified with the "image" produced out of its presentation model. In this sense, such models are important for architects to form their design portfolio where most of their works are usually preserved for eternity, either the realization of their buildings takes place or not.

Figure 6. The model of Zaha Hadid's New Center for Contemporary Arts in Rome. Built by Ademir Volic. He used materials as perspex, acrylic and Urial. CNC technologies are also employed in this model.

http://www.archnewsnow.com/features/Feature60.htm (last accessed on 03.04. 2008.)

2.2.2. Design as a Staged-Process through Architectural Modeling:

As observed, when design practice is comprehended as a progression through the employment of such model types as discussed, a discreteness of actions is put forward. In other words, with the design methods terminology "knowledge states" and "branches of actions" are defined. The process of design is acknowledged to bear linearity and it is leveled in which the design is concretized and solidified as the modeling process reaches towards the end.[64] With the employment of models from conceptual to presentational aspirations, the scale enlarges and respectively details and constructional issues are resolved. In this format, it can be proposed that the design process is intrinsically acknowledged to be discrete, and on each level of design, a new model is required.

On this staging of design, it can be pointed out that the requirement of a new model in a specific design might work in two ways: Either a certain amount of design knowledge is saturated in that step and the need to building a new model occurs in order to materialize this accumulated knowledge; or the process is stopped intentionally to switch to another, probably larger scaled, model in the purpose of provoking the detail-solving process and producing design knowledge in this scale and medium. Another proof of the staging would be detected from the preferred scales of the models. It can be observed that the leveling also manifests itself in the scale. There are many conventional modeling scales incorporated by designers, although unusual scales might be chosen occasionally. The conventional scales are 1:500, 1:200, 1:100, 1:50 and 1:10. This graded sequence might be carried out until the production of 1:1 prototypes, and eventually the building itself.

In the field of physical models, many scholars as Peter Downton and Andrea Mina have been arguing that the "conceptual model" and the "working model" carry the most potential by their virtue of conceptual elasticity and design uncertainty.[65] These types of models carry the

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[64] Peter G. Rowe. "Procedural Aspects of Design Thinking."

[65] Peter Downton. "Making Dust, Acquiring Knowledge." Homo Faber: Modeling Architecture Exhibition, Melbourne: RMIT School of Architecture and Design, May 2006. Ed. Brenda Marshall. *Homo Faber: Modeling Architecture Exhibition Catalogue.* pp.8-12.

Peter Downton. "Temporality, Representation and Machinic Behaviours: Model Dialogues with the Self, Collaborators, Clients and Others." Homo Faber: Modeling Architecture Exhibition, Melbourne: RMIT School of Architecture and Design, May 2006. Ed. Brenda Marshall. *Homo Faber: Modeling Architecture Exhibition Catalogue.* pp.33-8.

Andrea Mina. "Modeling Architectural Form." Homo Faber: Modeling Architecture Exhibition, Melbourne: RMIT School of Architecture and Design, May 2006. Ed. Brenda Marshall. *Homo Faber: Modeling Architecture Exhibition Catalogue.* pp.39-41.

The inquiry on why architects do and should use models has been going on for quite a period in architectural history. The function of models in the digital age is unquestionably important; hence they are indispensable to the design process by way of computer-aided design. However the questionings on modeling had already begun in the pre-digital age, especially with the "Idea as Model Exhibition" held in Manhattan in 1976. After thirty years, the "Homo Faber, Modeling Architecture Exhibition" (Melbourne, 2006) develops similar arguments on modeling. It can be seen that both exhibitions seek to clarify and investigate modeling as a means of design and architecture. The discussions are carried on a more theoretical level, taking into considerations all forms of modeling during designing: Physical modeling, computer modeling, or processes in which both modeling forms properties of being easily built and rebuilt, and usually chosen to be built fast and rough. They carry the great potential of being open to many possibilities. These sorts of models are observed to be usually used until a satisfactory stage in design is reached. They also seem to carry the interesting attribute of transmitting the traces of previous assemblies since in most cases a single model is used to test many ideas and assemblies.[66]

Nevertheless, the new design propositions offered by the virtual environment and computational design methods are noticed to provide a much extensive level of continuity in the course of design.[67] With the recognition of these new design methods and media, architectural modeling seems to have gained the capacity to dislocate numerous design conventions and hierarchies.[68] It has been experienced that novel design procedures, performed both in virtual and physical realms, have been gaining strength from the interaction of the virtual and real through the models.

2.3. The Architectural Model in History

Morrison and Ostwald argue that the history of the architectural model is a fragmented one as very few models are preserved after the construction of the project they represent.[69] Additionally, contrary to architectural drawings and texts, the model is difficult to preserve and maintain. As Morrison and Ostwald observe further, the pre-date the twentieth century models have had symbolic or metaphoric purposes other than being design equipments.[70] Prior to the fourteenth century, beginning with the Egyptian and Greek antiquity, scholars have knowledge of scaled down representations.[71] In the Egyptian culture, the model was

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are utilized. It should be mentioned that such a perspective offers a more holistic comprehension of design and its means and processes.

66 Peter Downton. "Temporality, Representation and Machinic Behaviours: Model Dialogues with the Self, Collaborators, Clients and Others." pp.33-8.

67 William J. Mitchell. "The Poetics of Virtuality." *The Virtual Dimension.* Edited by John Beckmann. New York: Princeton Architectural Press, 1998. pp.205-17.
68 *Ibid.*

69 Tessa Morrison and Michael J. Ostwald. "Shifting Dimensions: The Architectural Model in History," in Homo Faber: Modeling Architecture Exhibition, Melbourne: RMIT School of Architecture and Design, May 2006. Edited by Brenda Marshall. *Homo Faber: Modeling Architecture Exhibition Catalogue.* pp. 102-12.

70 *Ibid.*

71 Albert C. Smith. *Architectural Model as Machine.*

associated with the divine and believed to represent the earthly and unearthly powers.[72] In Greek and Roman antiquity, models found a wide range of usage, allowing the design of very complex structures by the end of the Roman Period.[73] In Greek and Roman architecture, the models of intricate building pieces, such as the triglyphs or capitals, were modeled in 1:1 scale which guided the workers at the site, and were referred to as *paradeigma*.[74] But the model was not employed as a design tool, and this situation has been argued by the archaeologist J. J. Coulton as that the Greek and Roman architects found models "positively misleading."[75] In a parallel manner, Mario Carpo explains about the use of verbal descriptions and documentations which guides the design process as a "program," instead of a visual data transferal.[76] In the Medieval and Gothic periods, the models were utilized to celebrate the building's bearer's achievement, to be offered as a devotional gift, or represent the ownerships.[77] As observed, prior to the fourteenth century, the model was not necessarily linked to the design of a building, in other words, it was not necessarily recognized as a design tool. However, since the Renaissance, the architectural model is recognized in its two forms, as the presentation models and the working models, as we understand them today.[78]

The philosophical shift with the Renaissance humanism provided the Renaissance architects an enormous freedom in the interpretation of design and this introduced a complete novel understanding in architectural practice.[79] Smith mentions that by the sixteenth century, the architect was finally seen as the exclusive creator and controller of building design and held

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[72] Spiro Kostof. "The Practice of Architecture in the Ancient World: Egypt and Greece." *The Architect: Chapters in the History of the Profession.* Ed. Spiro Kostof, New York: Oxford University Press, 1977. p.5.

[73] William L. MacDonald. "Roman Architects." *The Architect: Chapters in the History of the Profession.* Ed. Spiro Kostof, New York: Oxford University Press, 1977. pp.14-7.

[74] Tessa Morrison and Michael J. Ostwald. "Shifting Dimensions: The Architectural Model in History."

[75] J.J. Coulton. *Ancient Greek Architects at Work: Problems of Structure and Design.* Oxford: Oxbow Books, 1995.

[76] Mario Carpo. "Drawing with Numbers: Geometry and Numeracy in Early Modern Architectural Design." *Journal of the Society of Architectural Historians* 62.4 (2003): 448-469.

[77] Albert C. Smith. *Architectural Model as Machine.* p.18.

Morrison and Ostwald. "Shifting Dimensions: The Architectural Model in History."

[78] Morrison and Ostwald. "Shifting Dimensions: The Architectural Model in History."

[79] Albert C. Smith. *Architectural Model as Machine.* p.56.

full responsibility for his practice.[80] It can be commented that, with this freedom, the Renaissance introduced a more dynamic design process and these new conceptions required the construction of scale models to visualize the architectural space. There was a much more innovative planning procedure; therefore it became common practice to fabricate models.[81]

In their models, architects used materials as wood, clay or plaster.[82] Wax models served in the study of details, a practice taken over from Roman techniques.[83] Architects used "pull-away sections and detachable roofs and floors" to demonstrate mass and space relationships and lighting qualities.[84] However, it is observed that the modeling practice in the Renaissance became more associated with communication with the clients and expert craftsmen.[85] In the sixteenth century, every building part was made to order[86] and unlike the Medieval tradition, architects were not always present at the stone yard or the building site; therefore he had to communicate with his craftsmen by means of a mediative technique. [87] At this point, it can be observed that the traditions of drawing and modeling had to be readjusted to serve such functions. Then again, As Wilkinson emphasizes, the architectural model was primarily built for the patrons, and seldom for the public. As Wilkinson observes, at this point, when the model's numerous roles gathered on one certain model type, the presentation models began to be built in extreme detail and precision.

Model-making was getting increasingly expensive and time consuming in this sense.[88] Philibert de l'Orme (1510-1570), the French Renaissance architect, complained that

[80] *Ibid*. pp.25-30. However, it should be remembered that, although the designers could get the credits for their work, as Wilkinson reminds, the profession was not yet in its modern form, which is a formation of nineteenth century.

Catherine Wilkinson. "The New Professionalism in the Renaissance." *The Architect: Chapters in the History of the Profession.* Ed. Spiro Kostof, New York: Oxford University Press, 1977.

[81] Albert C. Smith. *Architectural Model as Machine.* pp.25-30.

[82] Porter and Neale. *Architectural Supermodels: Physical Design Simulation.* p.3.

[83] Albert C. Smith. *Architectural Model as Machine.* p.25.

[84] Porter and Neale. *Architectural Supermodels: Physical Design Simulation.* p.3.

[85] Catherine Wilkinson. "The New Professionalism in the Renaissance."

[86] *Ibid*. As Wilkinson points out, this practice was altered with the Industrial Revolution.

[87] *Ibid*.

[88] Albert C. Smith. *Architectural Model as Machine.* p.25.

brilliantly crafted and painted models could mask bad design.[89] In addition, he also pointed out that for the reason that such a model had to include all major parts of a building, they were costing fortunes.[90] He nevertheless advised the patron and the architect to invest in such models because they were exceedingly valuable in the long run.[91] There was a trust and encouragement in modeling therefore the Renaissance experienced various modeling techniques.[92] In addition to the many model examples, the writings of Leon Battista Alberti (1404-1472) provide the most valuable source to illuminate the vision on modeling and the profession. In his *De Re Aedificatoria* (1452, "On the Art of Building in Ten Books,") he meticulously studies what the utilization of the model meant for the profession and how the use of model should be.[93] He states that, architectural models serve in the decision of the sizes and proportions of building pieces, producing new proposals and alterations until everything becomes satisfactory, and provide a space for examination where the whole assembly can be conceived.[94] It is clear that Alberti saw the architectural scale model as a means to study design in the sense of a *maquette*. As the models served both as design and presentation tools, Alberti felt the need to clarify the language of the models: He complained about the colored and overly dressed presentation models which would "seduce the eye of the beholder" and distance the architects' intentions on conveying the facts.[95] Instead, he proposed a plain and simple model language, where "the models are not accurately finished, refined, and highly decorated," by way of which models could now demonstrate the design

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Leopold D. Ettlinger. "The Emergence of the Italian Architect during the Fifteenth Century." *The Architect: Chapters in the History of the Profession.* Ed. Spiro Kostof, New York: Oxford University Press, 1977. p.109.

[89] Catherine Wilkinson. "The New Professionalism in the Renaissance." pp.142-3.

[90] *Ibid.*

[91] *Ibid.*

[92] There were many cases in the Renaissance where architects built full-scale wooden models of building parts situated on site so that it could be experienced in its reality. It was also common practice to build full scale models of important and repeating building parts, and also statues and reliefs, in order to place and visually test them on the actual building until they find their eternal form in stone. An example of such a full scale model was "Michelangelo's ten-foot full-scale model of the cornice for the Farnese Palace." Michelangelo was very enthusiastic about using models, particularly clay models, because he found them exceptionally demonstrative. One other reason he used models was that he did not want to use perspective drawings, extensive plans or elevations of which he thought were visualizing design from a fixed point.

Morrison and Ostwald. "Shifting Dimensions: The Architectural Model in History." p.106.

[93] Leon Battista Alberti. *On the Art of Building in Ten Books.* Translated by Joseph Rykwert, Neil Leach, and Robert Tavernor. Cambridge, MA: The MIT Press, 1988. p.33-4.

[94] *Ibid.* p.34.

[95] *Ibid*. p.35.

idea instead of the skill in fabricating the model.[96] Though the endeavor of Alberti to simplify the language of presentation models in the fifteenth century, the practice again tended to fabricate fancy and large-scale models because their effectiveness on the patrons was truly strong and helped architects to market their designs.[97]

In 1660, the foundation of the Royal Society of London was a major circumstance in defining the scientific research methods of the era.[98] Roger Pratt favored the use of models as a means to record the design process.[99] He stated that "all things both external and internal with all their divisions, connections, vanes, ornaments etc., […] there to be seen as exactly, and in their due proportion, as they can afterwards be in the work of which this is composed to be the essay."[100] Additionally, Morris reminds that architectural models became very detailed presentation models for explanatory purposes in the seventeenth century.[101] In the mid-eighteenth century, a more technical form of model began to be used as the "teaching model."[102] This model was for instructing technical students and engineers in more complex structural and constructional conditions.[103] In the attitude towards modeling, Morrison and Ostwald mention that architecture was seen genuinely akin to painting in this period. Therefore architecture became the making of the painting, or the model, in other words the visual representation. Towards the end of the eighteenth century, Gaspard Monge introduced descriptive geometry which can be defined as "the projection of three-dimensional figures on

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[96] *Ibid.*

[97] Mark Morris. *Models: Architecture and the Miniature.*

Porter and Neale. *Architectural Supermodels: Physical Design Simulation.* p.6.

[98] Morrison and Ostwald. "Shifting Dimensions: The Architectural Model in History." p.106.

[99] *Ibid.*

[100] Pratt as quoted by John Wilton Ely, "The Architectural Model: 1. English Baroque." *Apollo* October 1968: 252. Quoted in Morrison and Ostwald, *op.cit.*, p.106.

[101] Mark Morris. *Models: Architecture and the Miniature.*

One spectacular example was Sir Christopher Wren's giant model of his proposal for the new St. Paul's Cathedral which was completed in two years. When the fire damaged the cathedral, Wren was commissioned to design the new cathedral. The model of the cathedral was built in a scale of 1cm to 45cm, so allowed a person to walk in and experience the real space.

Morrison and Ostwald. "Shifting Dimensions: The Architectural Model in History." p.107. For more detailed information on Christopher Wren and the construction of St. Paul's model, please see the source.

[102] *Ibid.* p.12.

[103] *Ibid.*

the two-dimensional plan through the manipulation of angels, lengths and shape."[104] Morrison and Ostwald note that, with this method, the visual representation techniques regained their universal power.[105] Perez-Gomez explains this dramatic shift in the appreciation of the representational tools as that:

> The original architectural ideas were transformed into universal projections that could then, and only then, be perceived as reductions of buildings, creating the illusion of drawing as a neutral tool that communicates unambiguous information, like scientific prose.[106]

In the early nineteenth century, models kept their status in important design undertakes. The materials of models increased in variety: In addition to timber, other materials such as plaster, cardboard, gypsum, pasteboard and cork were also used.[107] By "the growth of the print medium, the introduction of specialized architectural drawings, virtuoso draftsmanship and especially colored artist's impressions with emotive lighting tricks and scale" the drawing seized the central role of modeling yet again.[108] There were also prominent objections to the decline of modeling. John Soane, in his lecture to the Royal Academy, stated that;

> Many of the most serious disappointments, that attend those who build, would be avoided if models were previously made of the edifices proposed to be raised. No building, at least none of considerable size or consequence, should be begun until a correct and detailed model of all its parts has been made. Such models would be of great use not only to the workmen, but to the architect likewise.[109]

Morrison and Ostwald note that in the mid-nineteenth century there were an increasing number of exhibitions and museums, and respectively there was popularity in modeling in the form of engineering models and exhibition models.[110] However as modeling was

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[104] Morrison and Ostwald. "Shifting Dimensions: The Architectural Model in History." pp.107-8.

[105] *Ibid*. p.108.

[106] Alberto Perez-Gomez. "Architecture as Drawing." *Journal of Architectural Education*, Winter 1982. pp.2-7.

[107] Porter and Neale. *Architectural Supermodels: Physical Design Simulation.* p.12.

[108] *Ibid*.

[109] Anthony Vidler. "Introduction." *L'Architecture De C N Ledoux,* Paris: Lenoir, 1983. p.ix. Quoted in Morrison and Ostwald. "Shifting Dimensions: The Architectural Model in History." p.108.

[110] Morrison and Ostwald. "Shifting Dimensions: The Architectural Model in History." p.108.

becoming more costly, many architects did not prefer to invest in models.[111] By the late nineteenth and twentieth centuries, modeling was getting even less popular. However there were names such as Antonio Gaudi y Cornet (1852-1926), who rejected to study with drawings, but with a fascinating modeling technique in order to achieve an exceptionally complex three-dimensionality in his buildings. He employed two modeling techniques: Firstly he constructed models with white plaster; secondly, he used hanging wires, ropes and chains to study the geometry and loads.[112] It is interesting that Gaudi did not use many drawings; instead he preferred highly complex models to visualize these advanced geometric forms.[113] His models also function as engineering models to test the complex structural system of his complex forms. He chose to follow geometry and defined mathematical models in constructing his buildings and particularly employed ruled surfaces, and also referred to second order geometry.[114]

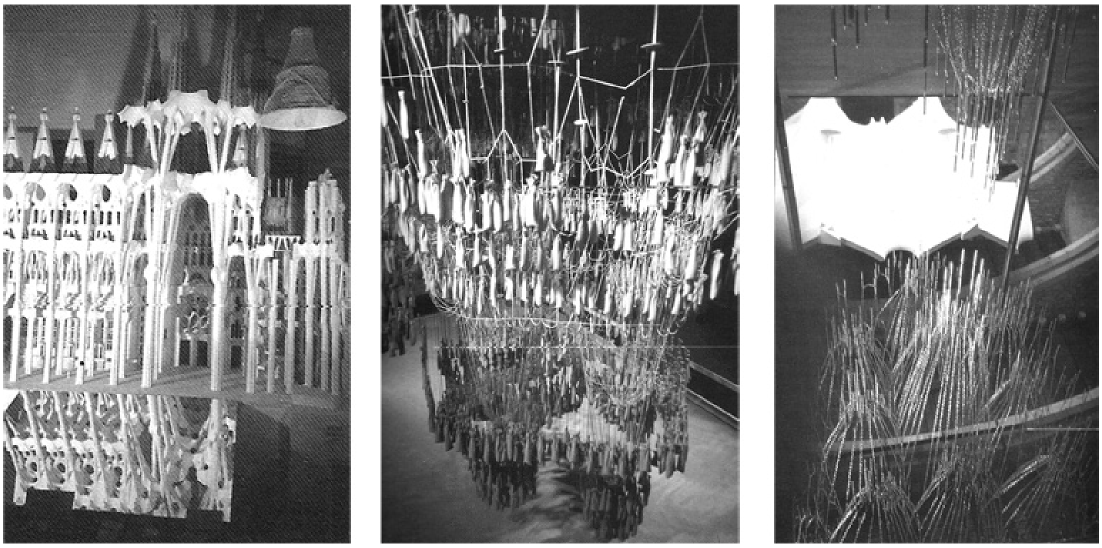

Figure 7. Three types of models which Antoni Gaudi worked with. The white plaster model (left) and hanging wires and chain model (middle), and rope model (right).

Albert C. Smith. *Architectural Model as Machine.* Oxford: Architectural Press, 2004. p.91, p.94 and p.95.

[111] *Ibid.*

[112] Albert C. Smith. *Architectural Model as Machine.* p.91.

[113] *Ibid.* p.94.

[114] Mark Burry. "Temple Sagrada Familia." Homo Faber: Modeling Architecture Exhibition, Melbourne: RMIT School of Architecture and Design May 2006. Ed. Brenda Marshall. *Homo Faber: Modeling Architecture Exhibition Catalogue.* pp.13-8. There are records from his student days in Barcelona that show that he studied descriptive geometry and this was a core study in his architectural education. He chose an exceedingly complex language which he thought would reflect the aesthetics of his system. He mostly studied with models, alongside with drawings but drafting would be highly reductionist at this level of complexity.

Unlike the embracement of modeling in Antoni Gaudi's approach, as Morris remarks, the Albertian model and its conception of three dimensional design processes were not profoundly accepted until the twentieth century.[115] The major change in architectural design and modeling was realized to a great extent by the Bauhaus education.[116] The Bauhaus introduced a revolutionary approach to reunify conception, visuality and materiality.[117] Walter Gropius and Johannes Itten arranged the curriculum of Bauhaus education with the hope of "bridging the disastrous gulf between reality and idelism."[118] In this context, the students were highly encouraged to work with models and bring their studies closer to reality, contrary to paper designs. Although the curriculum included studies of drafting and plane geometry, students were fostered to test the mass and space relationships and lighting.[119] Itten had also introduced a form of model which was a "vehicle of pure creativity."[120] Bauhaus tutors were trying to release the architectural model from its representational character, and bring it into the design. In later periods of the Bauhaus, Laszlo Moholy-Nagy introduced a partly transparent form of model, called "the space modulator," to visualize design and to relate concepts to materials.[121] The architectural model was actively used as a medium in the design process, not only for presentational aims. Architectural practice was trying to be tied to its architectonics, as it had lost it with two dimensional visualization. Although this encouraged shift was not immediately accepted,

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[115] Mark Morris. *Models: Architecture and the Miniature.*

Morris cites Colin Rowe who points that the two architectural education systems that have ever enjoyed a deep success in architectural history are The École de Beaux Arts and the Bauhaus. As Morris observes, the École de Beaux Arts strongly excluded architectural models out of the school and identified the architect with the drawing. In this sense, the material aspect of architecture was excluded and an idealism in drawing was preserved. Although the École de Beaux Arts enjoyed a wide acceptance, the Bauhaus was the school to introduce a revolutionary approach in its education on which architectural modeling is based today.

[116] Colin Rowe. Comments of the Director to the Design Faculty [attributed to Colin Rowe,] 25 May1954 (copy held in the Hoesli Archives, ETH, Zürich,) cited in Alexander Caragonne. *The Texas Rangers, Notes from an Architectural Underground.* Cambridge, MA: The MIT Press, 1995. p.155.

[117] *Ibid*.

[118] Walter Gropius. *The New Architecture and the Bauhaus.* Trans. P. Morton Shand. London: Faber&Faber, 1935. p.48. Walter Gropius took over the "Weimar School of Arts and Crafts" from Henri van de Velde in 1919. Van de Velde had already transformed the *atelier* of the French Academy to the "workshop." Gropius reorganised the Arts and Crafts School with the Academy of Fine Art, and founded the Bauhaus. Gropius tried to offer a "unification of the arts under the primacy of architecture." The revolutionary Bauhaus curriculum was created by Walter Gropius and Johannes Itten.

[119] Porter and Neale. *Architectural Supermodels: Physical Design Simulation.* p.13.

[120] Mark Morris. *Models: Architecture and the Miniature.*p.21.

[121] Porter and Neale. *Architectural Supermodels: Physical Design Simulation.*

both in the first years of the Bauhaus and among professional practitioners, the architectural model always formed a part of the Bauhaus manifesto.[122]

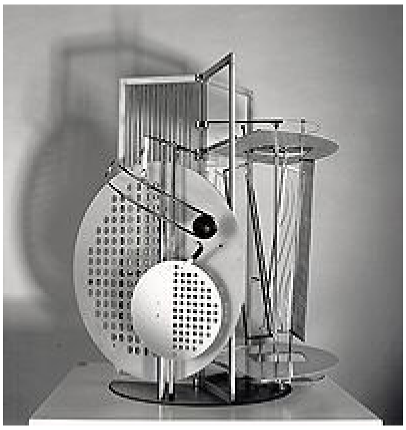

Figure 8. The "light space modulator" by Lazslo Moholy-Nagy, 1922-1930. Reconstructed in 1970.

"Bauhaus Art," Reached at: http://www.bauhaus.de/english/bauhaus1919/kunst/kunst_modulator.htm (Last accessed on 04.07.2008.)

Meanwhile, there were also symbolic usages of *maquette*-like models by Russian constructivists. For example, Vladimir Tatlin's (1885-1953) proposal for the Monument of the Third International was a centerpiece for the movement, which was also trying to define a novel reference system in a social and political context.[123] Other than Tatlin, El Lissitzky (Elaazar Markovich, 1890-1941) conceptualized a very interesting form of model in addition to his conventional models: These were his "Prouns," an acronym for "Project for the Affirmation of the New."[124] Prouns included many two and three-dimensional geometrical elements and had their own reality; for instance, they could overcome real gravitational forces and they could distortedly adjoin. [125] El Lissitzky tried to question the dimensional and

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[122] Mark Morris. *Models: Architecture and the Miniature.* Nevertheless, in addition to these studies, many mainstream architects kept the traditional modeling techniques for years, as a means to sole presentational purposes. Examplified in: Morrison and Ostwald. "Shifting Dimensions: The Architectural Model in History." p.109.

[123] Albert C. Smith. *Architectural Model as Machine.* p.98.

[124] *Ibid*. p.103.

[125] *Ibid*.

representational capacity of the traditional artistic techniques and proposed a challenging method.[126]

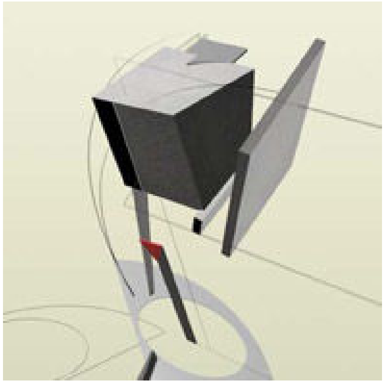

Figure 9. A model of the "Proun 5a " by El Lissitzky. Remodeled by Rob Robbers by computer modeling software.

"Prouns." Reached at: http://lava.ds.arch.tue.nl/modelshop/lissitzk/prouns_r/ (Last accessed on 04.07.2008.)

The Bauhaus successfully continued to educate with many directors[127] until it had to be closed under the Nationalist Socialist pressure.[128] The school was first moved to Chicago, but after 1937, the Bauhaus teachers migrated to various schools around the US.[129] As Morris observes, the tutors in many institutions proceeded in teaching with the Bauhaus tradition. Today the Bauhaus effects are deeply penetrated in educational systems of architectural schools in the US and it is also evident from the major number of polytechnical

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[126] Very similar to the hands-on approach of the Bauhaus, El Lissitzky had advocated: "Don't read! Take paper, block, wood pieces; build, paint, construct!" In: El Lissitzky. *About Two Squares.* 1920. Quoted in: Mark Morris. *Models: Architecture and the Miniature.* Chichester, West Sussex: Wiley Academy, 2006. p.21.

[127] Laszlo Moholy-Nagy took over the directorship from Johannes Itten in 1923. He srtengthened the school in the constructivist subjects. In 1927, the Bauhaus moved to Dessau to the building that Gropiu designed. In 1928, Hannes Meyer became the director, and Ludwig Hilberseimer owned the headship. In 1930, three years before the school was closed, Mies van der Rohe began to direct the Bauhaus.

Peter Galison. "Aufbau/Bauhaus: Logical Positivism and Architectural Modernism." *Critical Inquiry,* n. 16 (Summer 1990): 709-52.

[128] Mark Morris. *Models: Architecture and the Miniature.* p.22.

[129] After this period, Walter Gropius and Marcel Breuer went to Harvard. Mies van der Rohe moved to the Armour Institute, which later bacame the Illinois Institute of Technology. Josef and Anni Albers went to the Black Mountain College in North Carolina. Meanwhile, Philip Johnson became the director of the Department of Architecture at the Museum of Modern Art in New York. He relentlessly promoted Bauhaus and Modernist influences in the exhibition and exhibition catalogues.

Mark Morris. *Models: Architecture and the Miniature.* p.22.

schools in Europe.[130] But this success was obtained after long years of work among many schools.[131] Especially the shift in the attitude towards architectural modeling was seen only towards the end of the twentieth century. Morris mentions that, in the 1940s and 1950s, there was still a general tendency in the educational realm to use the Beaux-Arts system.[132] Students persistently relied on drawing as the main design medium. Morris adds that, in the 1960s, modeling began to be conceived as an "alternative method" to drawing, but still only found its place again in the presentation of projects; meanwhile professionals also used presentational models but even then it was seen as luxury and avoided in many cases.

In this context, the "Bauhaus" model owes its survival today to somewhere outside of the architectural school.[133] As Morris mentions, Philip Johnson had inexhaustibly advocated the Bauhaus tradition and Modernist influences in his exhibitions in Museum of Modern Art in New York.[134] Johnson, Hitchcock and Barr exhibited various models, both from the school's work and faculty's private productions, in the "Modern Architecture: International Exhibition" at the MOMA held in 1932.[135] Again in 1969, Johnson was the curator of "The New York Five" exhibition held at Museum of Modern Art.[136] These exhibitions lead to a very important one that was prepared by Peter Eisenman: The "Idea as Model" exhibition held at the Institute for Architecture and Urban Studies in 1976.[137] This was the milestone of architectural modeling, as being "the first exhibition solely devoted to the scale model as an index of process and a site for theoretical inquiry."[138]

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[130] *Ibid*. p.23.

[131] *Ibid*.

[132] *Ibid*.

[133] *Ibid*.

[134] *Ibid*.

[135] "The Museum of Modern Art, Exhibitions." Reached at: http://www.moma.org/exhibitions/exhibitions.php?id=5138 (Last accessed on 01.06.2008.)

[136] *Ibid*. "The New York Five" refers to architects whose work is chosen by Philip Johnson: Peter Eisenman, Michael Graves, Charles Gwathmey, John Hejduk and Richard Meier. The book of the exhibition was released in 1975.

[137] Mark Morris. *Models: Architecture and the Miniature.*

[138] *Ibid*.

CHAPTER 3

THE EXTENSIONS FROM THE PHYSICAL SPACE OF DESIGN TO THE VIRTUAL ENVIRONMENT

Modeling, in its many roles, is observed to be accommodating deep-rooted traditions, which are seen to be challenged in the second half of the twentieth century by the shift from the non-digital space of design to the digital space of design. The "non-digital" refers to the discussions that are predominantly carried on the "real" space of design, which refers to studies on material and tactile forms of models – in other words, the physical models. Meanwhile, the digital refers to the digitally constructed models in the "virtual" space of design, whose expansion is the computer models in most of the cases. The relationship between the "real" and the "virtual" has every so often grown to be a very problematic issue for the architects, but at the same time this tension has been feeding the architectural discourse in various fields of research for over more than thirty years.

3.1. The Extension of Design Space from the Physical to the Virtual

In the 1960s and 1970s, many architects and theoreticians were discussing about the design process in terms of "design methods."[1] One of the key themes was the "means-ends analysis," where the design tools were conceived as the means to reach a predetermined result, the ends, and another the "process-product" relation as design was related to a problem-solving process.[2] In time, these discussions grew to be an important part of design computation and the procedural and cognitive aspects of design had become the major focus.[3] A very early work, Nicholas Negroponte's book *The Architecture Machine* (1973)

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[1] Geoffrey Broadbent. "The Development of Design Methods." *Design Methods and Theories* 13(1): 41-5, 1979. Among these conferences, the "Design Methods in Architecture Symposium" held in 1967 in Portsmouth School of Architecture was an important one to gather names as Geoffrey Broadbent, Bruce Archer, Jane Abercrombie, Gordon Best, Anthony Ward, Christopher Jones, and many more. In the interdisciplinary convention, very early discussions on various fields of research had been discussed. Anthony Ward explains the main spectrum of discussion as dualities: "Subjective-Objective, Abstract-Real, Value-Fact, Process-Product, and Determinist-Existential." As observed, many themes formed early discussions on design computing.

Anthony Ward. "Introduction." *Design Methods in Architecture.* Eds. Geoffrey Broadbent and Anthony Ward. London: Lund Humphries, 1969.

[2] In the previous chapter, the scientific approach to design is discussed in the sub-section of "Working Models."

[3] *Ibid*.

discussed key stages in the relationship of computer with the design process.[4] Within the architectural community, the questioning on the architectural model was officially recognized firstly with the "Idea as Model" exhibition held in 1976.[5] The exhibition was supported by Peter Eisenman, derived by "the urge to re-think the architectural model."[6] The exhibition bears its significance by being the first exhibition that focuses solely on modeling which is recognized as a design instrument and which would work on a theoretical level.[7] The model's representational capacity was a key theme. The major purpose of the exhibition, as stated by Eisenman, was to "encourage other architects to adopt the idea of a model as a conceptual as opposed to narrative tool, as part of their design process."[8] As Morris states, this exhibition took place in a yet pre-digital environment, nevertheless he emphasizes that the architectural model had already begun to be questioned in terms of its function in both design and theory.[9] However the change in modeling towards a more complex formation was already in the air even when these discussions were carried.

In the 1980s the computer media was introduced into the realm of architecture by elementary CAD tools. These tools were firstly recognized for the purpose of drafting, serving more in the presentational phases of projects.[10] Jon Pittman explains that, one reason to the slowness in computerization was the very high expenses owning the machines.[11] He states that even major firms could afford computers to very limited numbers. Towards the end of the 1980s, by the emergence of personal computers, architects could find the

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[4] Nicholas Negroponte. *The Architecture Machine.* Cambridge, MA: The MIT Press, 1973.

[5] Morrison and Ostwald. "Shifting Dimensions: The Architectural Model in History." p.109.

[6] *Ibid.*

[7] *Ibid.*

[8] Peter Eisenman. "Preface." Eds. Kenneth Frampton and Silvia Kolbowski. *Idea as Model.* New York: Rizzoli, 1981. p.1. Quoted in: Tessa Morrison and Michael J. Ostwald. "Shifting Dimensions: The Architectural Model in History." p.109.

[9] Mark Morris. *Models: Architecture and the Miniature.* p.23. Nevertheless, Morrison and Ostwald clarify that the models in the exhibition were not working models, but were rather conceived as "completed objects in their own right." They explain further that Eisenman's major critique of the model's representational character occurred later with his "House X Project" in 1978, when he proposed the model as "a series of objects," and as a finished architectural project, not as a representation of something to be built.

Morrison and Ostwald. "Shifting Dimensions: The Architectural Model in History." p.109.

[10] Jim Glymph. "Evolution of the Digital Design Process," in *Architecture in the Digital Age: Design and Manufacturing.* Edited by Branko Kolarevic. New York: Taylor and Francis, 2003. pp.101-20.

[11] Jon Pitmann. "Building Information Modeling: Current Challenges and Future Directions."

technology at their disposal.[12] However, even in the 1990s, although many professional firms used CAD, they still employed it with the purposes of two-dimensional representation.[13] For instance, Sevaldson mentions that he got acquainted with computer modeling directly as a design tool in three dimensions and observes that although architects had inclusive abilities of three-dimensional systems then, they did not use it extensively as a design tool.[14] Pittman reminds that in the 1990s, the studies on "model-based design" had successively begun, though not with full potential.[15] Some of the mainstream architects to realize this potential of computer technologies later became the most representative figures of Computer Aided Architectural Design (CAAD.) Among these, Peter Eisenman and Frank Gehry[16] are mostly associated with CAAD in its early periods. At the beginning, it can be seen that architects tried to recognize the capacities of CAAD, its boundaries, and the possible utilizations of the upcoming design method. This period is observed to be a highly experiential one.

Pittman observes that in the 2000s the "digital architecture" has grown strong with a good number of availabilities but he still questions when this practice would become mainstream.[17] In this context, it can be said that digitalization has not been fully realized yet. Nevertheless it is a fact that computers have already become an indispensable part of architectural design and production today.[18] This shift so far can be said to have occasionally

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[12] *Ibid.*

[13] Yu-Tung Liu. (ed.) "Digital Creativity: Conversation with Birger Sevaldson / OCEANnorth." *Demonstrating Digital Architecture: 5th Far Eastern International Digital Architectural Design [FEIDAD] Award*. Basel: Birkhauser, 2005. pp. 68-73.

[14] *Ibid*. Sevaldson actively used "NURBS geometries" in his design, and he formulizes his practice in that period as "NURBS functions" as opposed to "presentational purposes."

[15] Jon Pittman. "Building Information Modeling: Current Challenges and Future Directions."

[16] As Liu explains, Gehry studied to develop a "non-rule based" architecture by "overcoming the constraints of two-dimensional matrix type models." In terms of CAAD, Frank Gehry's Guggenheim Museum Bilbao in Spain (1997) is viewed as a milestone. In this project, Gehry used a 3-D digitizing technique, where he combines physical models with virtual models. With such a process, he was able to produce a variety in his forms and spaces.

Frank Gehry. "The Search for a No Rule Architecture." *Architectural Record* 102 (1976.) In Cheng-Yuan Lin. "The Representating Capacity of Physical Models and Digital Models." In *CAADRIA 1999, Proceedings of the 4th International Conference on Computer Aided Architectural Design Research in Asia*, Shanghai: Tongji University, College of Architecture and Urban Planning. p.56.

Alejandro Zaera. "Frank O. Gehry," *El Croquis* 74-75, 1991-1995.

[17] Jon Pittman. "Building Information Modeling: Current Challenges and Future Directions."

[18] William J. Mitchell. "Antitectonics: The Poetics of Virtuality," in John Beckmann, (ed.) *The Virtual Dimension: Architecture, Representation and Crash Culture.* New York: Princeton Architectural Press, 1998. pp.205-17.

been formidable both in architectural theory and practice.[19] With the introduction of “virtual space,” there arose a highly problematic duality between the “real” and the “virtual” spaces of design. Therefore, in order to understand the many dualities that occur between the “real” and the “virtual,” it becomes crucial to define these terms and to discuss related subjects in philosophical terms.

3.2. Model In-Between the Virtual and the Real

3.2.1. Reality Versus Virtuality

In conventional usage, reality means “the state of things as they actually exist.”[20] Luigi Puglisi explains that “[t]he term reality, in its widest sense, includes everything that is, whether it is observable, comprehensible, or apparently self-contradictory by science, philosophy, or any other system of analysis. Reality in this sense may include both being and nothingness, whereas existence is often restricted to being.”[21] Therefore, it can be understood that the “real” is a term which finds its equivalent in the physical and material world, in the conditions when an entity both exists or does not exist. Something real is obliged to have a tangible characteristic. However, there is a common understanding to define the “virtual” as the antonym of the “real,” in the aim of referring to what is not real, in other words what is immaterial and intangible. Nevertheless, the meanings of these concepts bear important differences, where constructing their relationship as opposites would be overly simplifying. Additionally, within the context of computer-aided design, the term “virtual” has been overly discussed, and misleadingly came to simply refer to the “digital space” of computer modeling.[22] At this point, a thorough understanding of Gilles Deleuze’s philosophy is required in order to clearly elaborate the situations of reality and virtuality, and how they are interpreted in the contemporary architectural domain.

3.2.2. The Notions of the “Real” and the “Virtual” in Bergsonian and Deleuzian Discourses

French philosopher Gilles Deleuze is widely known as one of the main figures in post-phenomenological philosophy in the twentieth century. However, in order to understand him, it is firstly needed to understand another French philosopher, Henri Bergson, upon whom

[19] *Ibid.*

[20] Compact Oxford English Dictionary of Current English, Oxford University Press, 2005.

[21] Luigi Prestinenza Puglisi. *Hyper Architecture. Spaces in the Electronic Age.* Basel: Birkhauser , 1999. pg.79.

[22] Greg Lynn. *Animate Form.*

Deleuze further developed his ideas. Henri Bergson commences by introducing a chief notion in his thought, the notion of "*durée"*.[23] Alexander Sthyre explains that "[i]n his writings, the virtual precedes any computer-mediated human-machine interactions and is used to problematize the experience of lived time that he referred to as *durée* or *duration.*"[24] Bergson uses the notion of *durée* as opposed to the mechanical clock time: Mechanical clock time is the "abstract time", and the *durée* is the "concrete duration" which represents the time wherein time is experienced.[25] Therefore d*urée* is not made up of discrete instances but is continuous and coherent.[26] Similarly, Bergson indicates that the "human experience of real life is not a succession of clearly demarcated conscious states, progressing along some imaginary line (from sorrow to happiness, for example), but a continuous flow in which these states interpenetrate and are often unclear, being capable of sustaining multiple perspectives."[27]

In this respect, Bergson uses the idea of the virtual to explain the notion of *durée*: In his writings, the "virtual is used as an immanent state of the real, as a state of experience that is real but not actual."[28] He argues that past and future are real, the present is actual, and they are all entangled. According to him, "the past and the present are not two modalities of the present, the past receded or formed present, a present that has moved out of the limelight. Rather, the past and the present fundamentally coexist; they function in simultaneity."[29] In parallel to Bergson, Deleuze accepts the idea that "the past and the future are real without being actual; the present is actual and real."[30] The past occurred and the future will be, therefore they are real; but they are not actual in the sense that the present is. So, the future is

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[23] Alexander Sthyre. "Knowledge as a Virtual Asset: Bergson's Notion of Virtuality and Organizational Knowledge," *Culture and Organization.* 9.1 (2003): 15 – 26.

[24] *Ibid.*

[25] *Ibid.*

[26] *Ibid.*

[27] Stephen Linstead. "Organization as Reply: Henri Bergson and Causal Organization Theory." *Organization.* 9:1 (2002): 95 – 111.

[28] Alexander Sthyre. "Knowledge as a Virtual Asset: Bergson's Notion of Virtuality and Organizational Knowledge."

[29] Elizabeth Grosz. *Architecture From the Outside: Essays on Virtual and Real Spaces.* Cambridge, MA: The MIT Press, 2001. p.142.

[30] Gilles Deleuze. *Bergsonism.* p.94-8.

full of unpredictable possibilities to be realized. Therefore it becomes fluid and open-ended. As Bergson states, "the future is not ours to know but to realize."[31] Greg Lynn objects to the misunderstanding of the notion of the virtual as merely referring to the digital space of computer-aided design and its interchangeable use with the concept of "simulation."[32] Instead, referring to Deleuze, he emphasizes that virtuality is "intended as a diagram for a future possible concrete assemblage"[33] and adds that;

> Thus, use of term virtual here [in the context of computer-aided design] refers to an abstract scheme that has the possibility of becoming actualized, often in a variety of possible configurations.[34]

In a parallel manner, Lars Spuybroek explains the fluid relationship between the real and the virtual in his article "Motor Geometry:" "Why still talk about the real and the virtual, the material and the immaterial? Here, these categories are not in opposition or in some metaphysical disagreement, but more in an electroliquid aggregation, enforcing each other, as in a two-part adhesive; constantly exposing its metastability to induce animation."[35] To summarize these notions, the "real," the "actual," and the "virtual" bear such differences than being mere synonyms and antonyms. It would also be a misreading when positioning them as such isolated extremities, which in truth oppositely operate in fluid interaction with each other.

3.2.3. The Deleuzian Diagram

The discussions on the meaning of such terms lead to the notion of the "diagram," which has been introduced to the architectural realm by Gilles Deleuze.[36] In the conception of Deleuze, the "diagram" serves a similar function as the reconceptualized "future", or more extensively "time," as previously put forward. As De Landa interprets Deleuze, diagrams have "no intrinsic connection with visual representations", as opposed to their utilization by many

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[31] Anthony O'Shea. "The (r)evolution of New Product Innovation." *Organization.* 9:1 (2002): 113-25.

[32] Greg Lynn. *Animate Form.* New York: Princeton Architectural Press, 1999. p.10.

[33] *Ibid.*

[34] *Ibid.*

[35] Lars Spuybroek. "Graphs. The Sloughing of the Paradigm," in *Archilab: Radical Experiments in Global Architecture.* Edited by Frédéric Migayrou and Marie-Ange Brayer. New York: Thames & Hudson, 2001. p.10-2.

[36] Gilles Deleuze. *Foucault.* Paris: Editions de Minuit, 1986.

cognitive scientists and researchers.[37] Additionally, as De Landa explains further, they do not have to be operated by humans or robots, but "may be instantiated in even simple material and energetic systems."[38] Deleuze constructs an "abstract oscillating machine" which is actualized in all these configurations;

> An abstract machine in itself is not physical or corporeal, any more than it is semiotic; it is diagrammatic (it knows nothing of the distinctions between the artificial and the natural either). It operates by matter, not by substance; by function, not by form….The abstract machine is pure Matter-Function – a diagram independent of the forms and substances, expressions and contents it will distribute.[39]

As Manuel de Landa detects further, following the Deleuzian abstract machine, the distinction between the virtual and the actual does not engage any resemblance, therefore the diagram incorporates difference and are capable of divergent realizations. This makes the process innovative and open-ended. When a possibility is actualized, there may be multiple configurations which may not share any identity or resemblance at all. With this proposition, it is observed that Deleuze opens up a pluralistic universe.[40]

When this theoretical shift in the definition of the Deleuzian diagram combines with the introduction of CAD models in the 1980s, an experimental environment is seen to have propagated by means of both theory and technology. For three decades, new design methods have been tested by means of the new technological availabilities. Both with the technological and conceptual transformations, traditional modeling techniques and design methods are deeply challenged. It can be seen that the diagram and the virtual computer model have constructed a similar relationship with their actualization processes. The notion of the diagram has liberated architectural thinking and demanded a more comprehensive type of model able to process itself.[41] Meanwhile, the computer model improved as a highly

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[37] Manuel De Landa. "Deleuze, Diagrams and the Genesis of Form." *Any 23* (1998): 30-4.

[38] *Ibid.*

[39] Gilles Deleuze. *Foucault.* p.44.

[40] Gilles Deleuze and Félix Guattari. *A Thousand Plateaus: Capitalism and Schizophrenia.* Trans. and Foreword Brian Massumi. Minneapolis: University of Minnesota Press, 1987.

[41] Ben van Berkel and Caroline Bos. "Diagrams, Interactive Operation in Operation." *Any* 23 (1998): 19-23.

manipulative instrument for the realization of the diagram.[42] In this sense, computer models can be said to have revolutionized the design process.

3.3. New Modes of Design Organization, Process, and Modeling

In the second half of the twentieth century, with the introduction of the digital environment there has been a deep conceptual shift in architecture.[43] However, the impulse behind this shift was not only the availability of computer technology. The theoretical and philosophical background of this period has also strongly proliferated architectural thinking with themes as "multiplicity," "complexity," and "non-linearity."[44] These themes were also supported by the studies in the complexity sciences and mathematical models whose dynamism were reflected in architecture in its many aspects.[45] The novel conception of the "diagram" has also played a role in inaugurating animated and dynamic possibilities into design. Spuybroek configures "computing" as an "enhancement of the communication between diagrams, a meta-diagramming, to potentially connect all actions on matter."[46] He explains that;

> [Diagrams] are lenses, mirroring a movement: first a contraction of matter – energy onto an organizing surface, then an expansion into many new other structures.
>
> - contraction – a movement of virtualization, where information is gathered, selected, graphed, and then organized into a virtual machine: from a 3-D network towards a 2-D surface. A movement toward quality, order and organization.
> - expansion: a movement of actualization, where the organizational diagram is put inside matter, where it germinates and becomes formative: from a 2-D surface towards a 3-D structure. A movement toward quantity, matter and structure.[47]

[42] *Ibid.*

[43] Branko Kolarevic. "Digital Morphogenesis."

[44] Gilles Deleuze and Félix Guattari. *A Thousand Plateaus: Capitalism and Schizophrenia.*

[45] John L. Casti. *Would-Be Worlds: How Simulation is Changing the Frontiers of Science.* New York: John Wiley & Sons, 1997.

Bernard Cache. "Plea for Euclid."
http://architettura.supereva.com/extended/19990501/index_en.htm.
Last accessed on 24 May, 2008.

[46] Lars Spuybroek. *NOX: Machining Architecture.* New York: Thames and Hudson, 2004.

[47] *Ibid.*

He argues that this urge sourcing from the diagrammatic thinking lead the architects to embrace computer-aided design. In addition, by this change in architectural thinking in this agency, Spuybroek proposes that computer-aided conceptualization and computer-aided manufacturing should become an indispensable part of such methods.[48] As Kolarevic interprets, the Deleuzian discourse demonstrated "a multiplicity of positions from which different provisional constructions can be created, in essentially a non-linear manner, meaning that the reality and events are not organized along continuous threads, in orderly succession."[49] He summarizes that such recognition challenges the "linear causality of design thinking."[50] Both within the design process and in the nature of architecture, "non-linearity" is seen to emerge as a part of the complexity. Liu explains on "non-linear" thinking;

> In response to the internet age with all the swift changes and ever-expanding nature of information, the survival mechanism of humans in the digital era has progressed from one of single direct linear mode of thinking to that of a hybrid, multi-layer and hyper-link nature.[51]

Likewise, Ben van Berkel and Caroline Bos incorporate economic ramifications to the design models and they also denote an alteration in the architectural project; they point that "[t]he architectural project has changed, often now consisting of a multi-functional, public-private hybrid of urbanism and infrastructure."[52] Buildings are now regarded as dynamic, open-ended, and non-linear organisms which are in immense interaction with their environment.[53] In this scope, it can be observed that the boundaries and the scale of the architectural project have also changed. The building's highly interactive mode with its environment brings forth a complexity, and prevents it from becoming an isolated entity.

In the field of computer modeling, a designer is able to explore a richer domain with ostensibly limitless possibilities: As Gao explains, this new position would "expand the

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48 *Ibid.*

49 Branko Kolarevic. "Introduction." p.4.

50 *Ibid.*

51 Yu-Tung Liu. "Architecture of Tomorrow: Ecological, Digital, Pure-Artistic, and Non-Linear Thinking," in *Demonstrating Digital Architecture: 5th Far Eastern International Digital Architectural Design [FEIDAD] Award*. Basel: Birkhauser, 2005. p. 7.

52 Ben van Berkel and Caroline Bos. *UN Studio, Design models: Architecture, Urbanism, Infrastructure.* New York: Thames & Hudson, 2006. p. 13.

53 Branko Kolarevic. "Introduction." pp.2-10.

possibilities for design well beyond previous limits, leading the mind of the designer into a three-dimensional or even four-dimensional space for design concepts." [54] It can be observed that this dynamism is manifested in major aspects of design as the process, form, and space. This dynamism can be grouped into two main areas: Firstly, there is the dynamism of the design process as experienced by the designer, which comes from the capability of computer models in simulating the several states of a design work.[55] This feature makes possible the exploration of very complex procedures during design manipulation and development. Secondly, the ability of simulating "actions and reactions" premises new offerings as responsiveness, interaction, and adaptation in the architectural space.[56] Designers have become able to visualize these highly dynamic interactive sequences of such design proposals.

Virtual computer models can be said to match these intentions to the highest degree. In the traditional design process with drawings and hand made models, there were limited means of processing such complex design data; therefore a certain amount of abstraction was needed in order to continue the process. It can be said that with the computer modeling techniques, the needed amount of abstraction has dramatically decreased or fully vanished.[57] As Allen explains, with the ability to work on three-dimensions and directly on the object itself, the distance between the designer and the representation collapses. [58] Controversially Allen also argues that since the computer representations are more immaterial than conventional drawings, the distance is also increased. He builds a two-fold argument in which he proposes that computer modeling simultaneously collapses and increases the distance between the representational and real space. When the abstraction phases collapse, models have been experienced as tools which incessantly work at the background.[59] The computer's

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[54] Wan-Ping Gao. "Digital Tectonics," in *Diversifying Digital Architecture, 2003 FEIDAD Award.* Edited by Yu-Tung Liu. Basel: Birkhauser, 2004. pp.66-77.

William J. Mitchell. "Articulate Design of Free-Form Structures." *Artificial Intelligence in Structural Engineering: Information Technology for Design, Collaboration, Maintenance, and Monitoring.* Ed. Ian Smith. Berlin: Springer Verlag, 1998. pp.223-4.

[55] Wan-Ping Gao. "Digital Tectonics."

[56] *Ibid.*

[57] Stan Allen. "Terminal Velocities: The Computer in the Design Studio." Ed. John Beckmann. The Virtual Dimension: Architecture, Representation, and Crash Culture. New York: Princeton Architectural Press, 1998. p.247.

[58] *Ibid.*

[59] *Ibid.*

transformative power in the architectural design process can be said to be based on its being a direct means to design, rather than being a mere representation tool where the representation is produced after the design is finalized. When the modeling medium is enriched with such novel generative processes that computation offers, the nature of the design process can be said to be challenged significantly. As Greg Lynn explains;

> There are three fundamental properties of organization in a computer that are very different from the characteristics of inert mediums such as paper and pencil: **topology**, **time**, and **parameters**.[60]

The study will follow these three properties of organization to discuss the novel techniques introduced by computer modeling medium. Some of the many related concepts such as NURBS geometries, associative geometry, animation, algorithmic processes, motion kinematics and dynamics, force fields, and scripting are also studied under these sections.

3.3.1. Topology and Time

Computer generated form and space propose a new level of complexity with their dynamism. As Kolarevic explains, such experimentation on form and space is based on "digital generation and transformation […] that respond to complex contextual or functional influences, both static and dynamic."[61] Kolarevic observes further that the digitally generated architecture rejects any "typology."[62] At this point, "topology" is introduced into the architectural realm as opposed to typology.[63] In this context, the notion of the diagram also inspires designers in the production of dynamic forms and spaces.

Van Berkel and Bos utilize the diagram as an "instrumentalizing technique" which, in their words, would delay "topological fixation."[64] As they acknowledge, a representational

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[60] Greg Lynn. *Animate Form.* p.20.

[61] Branko Kolarevic. "Introduction." p.4.

[62] Building typology has been the dominant model of an architectural working method since the late Eighteenth century, from church typologies to Nikolaus Pevsner's *History of Building Types*. There have been either functional or formal typologies, or the reappropriated typologies generated by interchanging between the two. Braham recognizes that these typologies were indisputably fixative and representational, but he also advocates that typology had a promise as a generative tool and as a means to understand new building forms.
Braham, William. "After Typology: The Suffering of Diagrams." *Architectural Design,* v. 70 n.3:9-11. June 2000.

[63] Branko Kolarevic. "Introduction."

[64] Ben van Berkel and Caroline Bos. "Diagrams, Interactive Operation in Operation."

technique implies that the designer converges on reality from a conceptual position, therefore fixing the relationship between the idea and the form. They argue that when form and content are superimposed in this way, types emerge and architecture cannot escape existing typologies. Therefore, opposing to the reductionist, representational and fixative character of typology, they celebrate "tools against typologies."[65] In this argument, they prefer the "introduction", rather than the "superimposition" of concepts external to architecture. The diagram may feed from various sources and liberate the design from conventional assemblages which refer to typologies.[66] Correspondingly, Lars Spuybroek favors diagrammatic operations as he elucidates the diagram's emplacement into form as an "engine" which "doesn't want to impose itself on matter, but to engage in a process of continuous formation."[67] Similarly Lynn explains that;

> This concept of a discrete, ideal, and fixed prototype [typological fixity] can be subsumed by the model of the numerically controlled multi-type that is flexible, mutable, and differential. This mutli-type, or **performance envelope,** does not privilege a fixed type but instead models a series of relationships or expressions between a range of potentials. […] this concept of an envelope of potential from which a single or a series of **instances** can be taken, is radically different from the idea of a fixed prototype that can be varied.[68]

At this point, it can be suggested that topological geometries could offer a solution to the realization of diagram-like operations. Topology is the mathematical field in which the objects are studied in terms of their properties which are preserved through deformations such as twisting and stretching.[69] Cache suggests that "topology enables us to focus on

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65 *Ibid.*

Stan Allen also addresses the issue of representation, but he gives it a positive twist pointing at the necessary degree of abstraction in architectural representation. He indicates that there is a "[…] distance interposed between the thing and its representation. Design does not operate on the basis of resemblance, but on the basis of abstract codes and a complex instrumentality." He argues that this abstraction is the very reason that representation finds its power, because the architect who attempts to "work directly with that reality will be paralyzed."

Stan Allen. "Terminal Velocities: The Computer in the Design Studio." Ed. John Beckmann. The Virtual Dimension: Architecture, Representation, and Crash Culture. New York: Princeton Architectural Press, 1998. pp.242-55.

66 *Ibid.*

67 Lars Spuybroek. *NOX: Machining Architecture.* New York: Thames and Hudson, 2004.

68 Greg Lynn. *Animate Form.* pp.13-4.

69 "Topology." Reached at: http://mathworld.wolfram.com/Topology.html (Last accessed on 29.05.2008.) It should be noted that in topological transformations "tearing" or "cutting" are not allowed.

fundamental properties from which our Euclidean intuition is distracted by the metric appearances."[70] Topologically identical structures, which may be in different forms through transformative operations, are called "homeomorphic" structures.[71] As Kolarevic explains, "the quality of homeomorphism is particularly interesting, as focus is on the relational structure of an object and not on its geometry – the same topological structure could be geometrically manifested in an infinite number of forms."[72] Therefore, as Kolarevic explains further, "a single topological construct is manifestable through multiple forms."[73] In a sense, topological structures manifest the continuous transformation space where form is generated and evolving.[74]

Figure 10. The topological transformation of a coffee cup to a torus.

"Archimedes' Labaratory." http://www.archimedes-lab.org/workshoptorquato.html (Last accessed 07. 07.2008.)

Lynn acknowledges that architecture have always maintained an "ethics of statics."[75] In this approach, "[a]rchitectural form is conventionally conceived in a dimensional space of idealized stasis, defined by Cartesian fixed-point coordinates."[76] Lynn explains that in the conventional approach, the understanding of "form" and "motion" is discrete because "[a]ctual movement often involves a mechanical paradigm of multiple discrete positions."[77]

[70] Bernard Cache. "Plea for Euclid."

[71] Branko Kolarevic. "Digital Morphogenesis." p.13. Homeomorphism is also called "continuous transformation," and it means "an equivalence relation and one-to-one correspondence between points in two geometric figures or topological spaces that is continuous in both directions." Reached at: http://mathworld.wolfram.com/Homeomorphism.html (Last accessed on 29.05.2008.)

[72] *Ibid*.

[73] Branko Kolarevic. "Introduction."

[74] Guiseppa Di Cristina. "The Topological Tendency in Architecture." *Science and Architecture.* Edited by Guiseppa Di Cristina. Chicester: Wiley Academy, 2001. pp.6-13.

[75] Greg Lynn. *Animate Form.* p.9.

[76] *Ibid*. p.11.

[77] *Ibid*. p.10.

In this fashion, he continues, the motion is often understood as a sequential process, and is represented through the "cinematic model," where the sequenced snap-shots simulate the movement. The motion is not an indispensable part of the design at this point, but something reintroduced afterwards in the representation of design. Lynn offers the "ethics of dynamics" by way of "animate design" as a contrast to the "ethics of statics."[78] It is clear that the ethics of dynamics powerfully challenge the deep-rooted design conventions. While the static motion bears discreteness, "virtual movement allows form to occupy a multiplicity of possible positions continuously with the same form."[79] Lynn explains that;

> In this way, topology allows for not just the incorporation of a single moment but rather a multiplicity of vectors, and therefore, a multiplicity of times, in a single continuous surface.[80]

The recognition of this multiplicity and the emphasis on the relations and continuity of space is important in architectural conception.[81] It should be repeated that the totality of the entity, in other words the internal and external interconnections, gains importance over formal expression. As Imperiale interprets;

> The Deleuzian focus on smooth spaces, seriality, and dynamic processes seems to have found its perfect foil in the way one can design architectural form in a NURBS modeling system. There seems to be a smooth link between one and the other. However, one should be cautious against reducing one entirely to the other.[82]

With their capability of processing complex forms and topological transformations, architects have embraced three-dimensional and four-dimensional (animation) modeling techniques. The three-dimensional computer modeling software is based on NURBS (Non-Uniform

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[78] *Ibid.*

[79] *Ibid.*

[80] *Ibid.*

[81] Topological structures as the "Möbius strip" and the "Klein bottle" have drawn attentions of many architects. Many experimental studies have been carried in experimenting with these structures. Architects tried to challenge the traditional relationships and spatial organizations, especially of the interior and the exterior. However, it should be noted that such experimentations should be carried on a conceptual level to understand "relations," beyond merely imitating the geometrical forms of these topologies.

Ben van Berkel and Caroline Bos. *UN Studio: Design Models, Architecture, Urbanism, Infrastructure.*

R&Sie... architects. Corrupted Biotopes. Design Document Series_05. Korea: DAMDI, 2005.

[82] Alicia Imperiale. *New Flatness: Surface Tension in Digital Architecture.* Basel: Birkhauser, 2000. p. 42.

Rational B-Splines.)[83] Within NURBS geometries, parametric curves and surfaces can be generated and manipulated with ease. Interestingly, as Strickland states, in mathematical studies, the questions on topology are usually formulated “in terms of logic and algebra rather than geometry.”[84] At this point, in addition to the availability of the NURBS geometries and topological operations, some of the major generative processes employed in the generation of complex forms such as parametric design gain importance due to the fact that parametrics introduce a new mode of operation beyond geometrical visualization.[85] It is seen that in computational design, there has occurred a shift of emphasis from the form and space to their generation and manipulation processes. The digital architectural model is regarded to provide this shift a favorable means with its capability of incorporating and processing the required inclusive design data of complex structures. In addition to topological structures, non-Euclidean geometries should be explained at this point in order to clarify the non-Euclidean geometries' and topological structures' different relationship with time.

3.3.1.1. Non-Euclidean Geometries

In the non-digital static architectural space, the formal repertoire was propagated through the Euclidean geometry. The basic geometries were extensions of Euclidean geometry which are lines, circles, quadrilaterals, planes, etc., and basic Platonic solids, which were derived out of these primitives.[86] By the early twentieth century, Euclid's theorems and axioms had begun to be challenged in mathematics due to incomprehensibility of Euclid's *Postulate V,* or the “parallel postulate.”[87] Subsequently, this challenge led to the studies of non-Euclidean geometry and geometry of n-dimensions, together with a strong background with the works of Karl Freidrich Gauss, Janos Bolyai, Nikolai Ivanovich Lobachevsky, and Bernard Riemann.[88] With these studies, space was now conceptualized as curved and multi-dimensional, and “time” was recognized as a dimension in this multi-dimensionality.[89]

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[83] Branko Kolarevic. “Introduction.” p.6.

[84] http://neil-strickland.staff.shef.ac.uk/Wurble.html (Last accessed on 29.05.2008.)

[85] Mark Burry. “Anti-accident Methodologies.”

[86] Branko Kolarevic. “Digital Morphogenesis.”

[87] Harold Scott Macdonald Coxeter. *Non-Euclidean Geometry.* Washington, D.C.: Mathematical Association of America, 1998. p.1.

[88] Linda Dalrymple Henderson. *The Fourth Dimension and Non-Euclidean Geometry in Modern Art.*
It can be noted that there are three classes of constant curvature geometries, which are differentiated by the usage of the “parallel postulate:” “The "flat" geometry of everyday intuition is called Euclidean geometry (or parabolic

Architecture, always keeping a close relationship with mathematics, is observed to experiment in this new space and time conception with non-Euclidean geometries. However, non-Euclidean geometries should not be used synonymously with "curved surfaces." The importance of non-Euclidean geometry in architecture is the suggestion of defining forms as instances in a continuity, and the availability of mapping a form in a "sliding scale of formal complexity" within this continuity.[90] This means that Euclidean geometry is conceived as a neutral state of equilibrium where the forces of bending and folding have equal influence on the form, therefore it reaches a state of "flatness."[91] This allows architects to conceive form in different levels of complexity, and the form may possess multiple realizations in this scale. By the digital computer models, architects have gained the chance to study on topological and non-Euclidean geometries. Computer modeling, as it is based on NURBS geometries, promises to be a very effective tool to experiment on such complex surfaces.

3.3.1.2. NURBS Geometries

In the representation of Euclidean geometry, the curvilinear lines and surfaces were represented by linking "tangent circular arcs and straight line segments."[92] The computer modeling software has introduced a medium in which complex curves and surfaces could be easily modified, and the workable geometries territory has been extended into the non-Euclidean geometries.[93] As Imperiale interprets this shift, she states that "[t]his has had a liberating effect on the design process, allowing architects to work on topological surfaces with increasing levels of complexity.[94] Such a shift has been provided by the NURBS-based

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geometry), and the non-Euclidean geometries are called hyperbolic geometry (or Lobachevsky-Bolyai-Gauss geometry) and elliptic geometry (or Riemannian geometry)."

"Non-Euclidean Geometries." Reached at: http://mathworld.wolfram.com/Non-EuclideanGeometry.html (Last accessed on 29.05.2008.)

89 *Ibid*.

90 Branko Kolarevic. "Digital Morphogenesis."

91 *Ibid*. This comprehension has been constructed due to the concept of "curvature of space" in the Riemannian geometry. He defined that spaces can have positive and negative curvatures. Therefore the Euclidean geometry becomes a special geometry in the infinite scale of transformation.

92 *Ibid*.

93 Greg Lynn. *Animate Form.*

94 Alicia Imperiale. *New Flatness: Surface Tension in Digital Architecture.* p. 42.

software, known to architects through software such as Autodesk's Maya and 3DStudioMax.[95] The acronym "NURBS" refers to the "Non-Uniform Rational B-Splines."[96] Piegl and Tiller explain that the success of NURBS depends on their supplementation of "a unified mathematical basis representing both analytic shapes" and "free-form entities."[97] They add that "NURBS algorithms are fast and numerically stable."[98] Kolarevic explains that today's computer modeling software is based on NURBS, because;

> From a computational point of view, NURBS provide for an efficient data representation of geometric forms, using a minimum amount of data and relatively few steps for shape computation.[99]

From an architectural perspective, the significance of the NURBS geometries is in their easily alterable nature by the manipulation of their "control points," "weights," and "knots."[100] As Piegl and Tiller explain, the NURBS are shaped fundamentally by the location of their control points. Each control point is associated with a "weight," which regulates the extent of the control point's influence over the curve. In addition to the weight, the control point is also associated with a "polynomial equation," or in other words a "basis function" (which refers to the "B" in the acronym of the NURBS.) The "R" in the NURBS refers to the "rational B-Spline," which Kolarevic explains as;

> A rational B-Spline is defined mathematically as the ratio of two polynomial equations…Each basis function affects only the curve section in the vicinity of the associated control point, and these sections are delimited by knots. A non-uniform rational B-spline is one in which the influence of a control point on a curvature can be varied by changing the location of the knots along the control segment that links two control points.[101]

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95 "Autodesk." Reached at: http://usa.autodesk.com/ (Last accessed on 04.07.2008.)

96 Gerald E. Farin . *NURBS: From Projective Geometry to Practical Use.* Wellesley, MA: A K Peters, 1995.

97 Piegl and Tiller. *The NURBS Book.*

98 *Ibid*.

99 Branko Kolarevic. "Digital Morphogenesis." p.15.

100 Piegl and Tiller. *The NURBS Book.*

101 Branko Kolarevic. "Digital Morphogenesis."

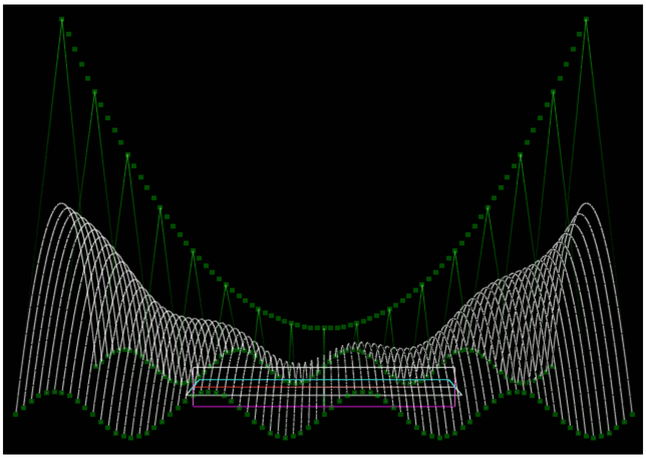

Figure 11. A spline surface generated with spline curves.

"A Spline." http://pages.cs.wisc.edu/~psilord/blog/ (Last accessed on 26.05.2008.)

The knots in the curve can be configured in unequal spacing therefore NURBS have a continually differing curvature, which separates them from the curves that used to be processed with "tangent circular arcs."[102] This continually changing curvature defines the significance of NURBS curves because this is the very property that provides the topological "multiplicity." As Piegl and Tiller explain further, as an extension of the NURBS curves, the NURBS surfaces operate very similarly.[103] There is a control lattice which connects the control points along the surface. The logic in the surfaces with the associated control points, weights, and knots operates in the same manner as in the curves. It should be clarified that NURBS geometries are situated in the three-dimensional Cartesian space, but they are also specified in a *local* parametric space.[104] However this parametric space is one-dimensional. For the NURBS curves, on a topological level, this one-dimensionality is referred to as "U," and the two-dimensionality as "V."[105] This parametric extension aids in the visualization of the NURBS geometries and offers a switching between the modes of designing.[106] In other words, one can both use the Cartesian space (X, Y, Z) and the parametric space (U, V) to modify the form. With the NURBS-based systems, architects have gained the opportunity not

[102] *Ibid.*

[103] Piegl and Tiller. *The NURBS Book.*

[104] *Ibid.*

Alicia Imperiale. *New Flatness: Surface Tension in Digital Architecture.*

[105] Greg Lynn. *Animate Form.* p.20.

[106] Piegl and Tiller. *The NURBS Book.*

only to work with very complex models but also change over modes of representation in the design process.

3.3.2. Parametrics

Pertaining to manual physical modeling, it is observed that modeling conventionally occurs during the design process which indicates and concretizes the discrete moments of design. In a linear design process, certain forms of models can be encountered as the diagram, the conceptual model, the working model and the final presentational model as discussed previously in Chapter 2. Most forms of these models are produced by stopping the design process, reading the data acquired to that extent, and materializing it. In this fashion, each design stage possesses only a certain amount of viable data, in other words the design input and output is limited.

Kolarevic notes that the models are revolutionized with the availabilities of processing complex information with novel computer hardware and software.[107] By the introduction of animation, the modeling tools have become a part of design process rather than only being used for "rendering, visualization and imaging."[108] With the recognition of the parametric modeling, it can be observed that there have been alterations in the architectural form and space in two ways: Firstly within its relational associations, secondly with its dynamism in terms of interactivity with the inhabitants. Referring to the prior, Eisenman favors the computer generated geometries as he states that the computer liberated him from "orthogonal, Platonic, Cartesian space."[109] As observed previously, parametrics provide designers with a different mode of design space other than the Cartesian coordinate system.[110] The abilities of animation in computer modeling exceed producing mere fly-throughs with sequential imaging, and makes possible to simulate the complex responsive behavior of the building.[111] Pertaining to the latter, a much more dynamic, sensitive, and

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[107] Branko Kolarevic. "Digital Morphogenesis."

[108] Greg Lynn. *Animate Form.* p.11.

[109] Michael Koch. "Interview with Peter Eisenman: Post-structural architect," *Dialogue* 9, pp.34-43.

[110] Controversially, many computer software, such as 3DSMax, Rhinoceros, Photoshop and Coreldraw, are explicitly or virtually based on Cartesian coordinate system. From an architectural point of view, Bernard Cache also criticizes the same tendency in architectural thinking in saying that "as far as technical applications are concerned, such as architecture, the digital age is still deeply Euclidean and will probably remain so." In: Bernard Cache. "Plea for Euclid."

[111] Kevin Rotherou. "A Vision for Parametric Design."
http://www.architectureweek.com/2002/0710/tools_1-2.html (Last accessed on 29.05.2008.)

adaptive concept of space has emerged. Described by Anderl and Mendgen, parametric design is an approach which "associates engineering knowledge with geometry and topology by means of constraints."[112] Concerning parametric modeling in architecture, the parametric descriptions provide a novel medium to represent and manipulate form in a completely different fashion than designing in a static Cartesian space. On parametric modeling, Rotheroe explains that;

> [P]arametric architectural software would ideally capture conceptual, three-dimensional design intent, enable the automatic parametric generation of iterative solutions throughout design development and documentation, and accommodate the accumulation of data as the computer model ultimately becomes a complete "kit of parts" representation of a building.[113]

When the reflections of the parametric modeling in architectural production are discussed, it is seen that the architectural project is also altered into a very dynamic and interactive state, where it is connected to its context through data and bits.[114] To clarify this, the interpretation of Mitchell can be useful at this point. In the realization of such projects, Mitchell offers "electronics" as the supplier of such dynamic realizations, as opposed to "tectonics."[115] He formulates this situation as architecture transforming into an "interface" as opposed to the traditional "façade."[116] He suggests that "we can recognize that inhabitation involves continuous interaction of information between a building and its inhabitants, and that the introduction of electronics requires us to rethink this interchange."[117] He adds that architects should embrace this technological shift with electronics by way of aggregating it with the architecture's material formation. Moreover, it is observable that building materials and technologies are also transforming to be able to meet the needs of such dynamism. Kolarevic even carries this argument further and notes that "[i]n the future, as buildings become more "intelligent," it will be the information the surface transmits to and from the surrounding

[112] R. Anderl and R. Mendgen. "Parametric Design and Its Impact in Solid Modeling Applications." ACM Symposium on Solid and Physical Modeling: Proceedings of the Third ACM Symposium on Solid Modeling and Applications, Salt Lake City, Utah, United States, 1995. pp.1-12.

[113] Kevin Rotherou. "A Vision for Parametric Design."

[114] William J. Mitchell. "Antitectonics: The Poetics of Virtuality."

[115] *Ibid.*

[116] *Ibid.*

[117] *Ibid*. p.215.

environment – and not its form – that will matter more.[118] Likewise, Spuybroek explains the surface is evolving from the visual towards the operational;

> In a sense, the image no longer shows the exterior of a system but must show the interior and exterior simultaneously, like an X – ray, but an abstracted X – ray in which all potential actions are contained in functions and parameters. As many others have observed, the larger cultural shift is one of surfaces towards interfaces: open, porous surfaces that are no longer images but nonetheless make use of visualization. These images aren't "seen," as in a passive recording technique, but precisely in an active way, where the seeing is permeated with acting.[119]

As observed, the architectural space has transformed into an interface between the material and electronic worlds beyond its visual and tectonic mode. The interactive architectural object would collect data from its environment, transform it into data, and process it in parametric relations to respond. It proceeds into a highly communicative state with its inhabitants in this performativity. Nevertheless, such a conceptual change is innovated firstly in the design space, through the dialogue of the model with the designers. These shifts can be viewed as an extension of the parametric modeling on the design process. The responsiveness of architecture, both in its model form and in reality, is provided by parametric processes.

In the basic logic of parametrics, it is seen that "sets of equations are used to express certain quantities as explicit functions of a number of variables, i.e. parameters, which can be independent or dependent."[120] When the variables in parametric representations are assigned different values, a limitless repertoire of objects can be generated by a pre-articulated schema. An important characteristic of parametrics is that a design is represented and declared in its parameters, and not its shape.[121] Therefore, Mark Burry notes that, a parameterized form is unstable but it has stable characteristics – which are the parameters.[122] Mark Burry adds that the equations are also determined by the designers who, in a certain

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[118] Kolarevic, Branko. "Introduction." p.7.

[119] Spuybroek, Lars. *NOX: Machining Architecture.*

[120] Branko Kolarevic. "Digital Morphogenesis." p.17. It should be noted that, as a form or an object can be represented by other "parametrization strategies," parametric representations are "non-unique."

[121] Mark Burry. "Paramorph: Anti-accident Methodologies." p.6.

[122] *Ibid*. p.5.

design process, may proceed with modifying and redefining the parametric strategy they develop, so that on a larger scale, the whole system can be said to be more flexible.

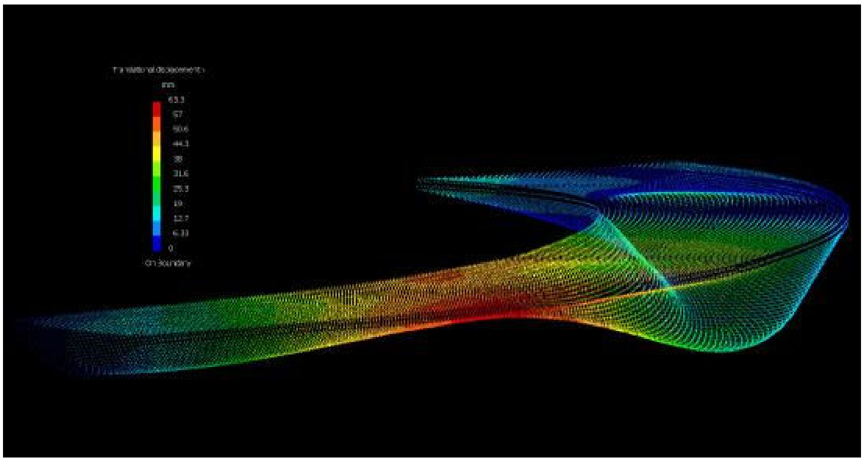

Figure 12. A caption from the research project of "the Parametric Bridge."

"Parametric Bridge: Selfridges Footbridge, Birmingham, UK."
http://www.sial.rmit.edu.au/Projects/Parametric_Bridge.php
(Last accessed on 29.05.2008.)

When a modification is made on the parametric model, the whole entity is updated according to the changed values, as Imperiale observes this feature, she explains that "[i]f you change scale in a part of the surface, the entire surface is rescaled, recalculated."[123] Therefore when a change in the model is tested, designers do not have to modify other objects in relation to the modified one, which is a highly reiterative and labor costly process.[124] As Burry explains, instead of a "reiterative erasure and remodeling" procedure, the alterations on the form can be processed and visualized simultaneously.[125] He adds that;

> Values of and relationships between parameters are stored in the graphics software database and are referred to the user through a visual representation on the screen. The size of an element is represented as a dimension that can be changed. By clicking the mouse on a particular value, for instance, it is changed interactively and the model can be regenerated in its new configuration.[126]

[123] Alicia Imperiale. *New Flatness: Surface Tension in Digital Architecture.*

[124] *Ibid.*

[125] Mark Burry. "Paramorph: Anti-accident Methodologies." p.8.

[126] *Ibid.* p.6.

This feature of parametric modeling seems to be of great value in terms of increasing the efficiency in both aesthetic and structural decisions; furthermore, it may help in predicting the economic aspects in realizing the project.[127] As Kolarevic observes parametric design often entails a procedural, algorithmic description of geometry.[128] In this sense, parametric models accommodate designers with a highly continuous process, which cannot be achieved by traditional working methods and tools. On this differentiation, Burry asserts that;

> The parametric designer can move backwards and forwards at will – a peculiar attribute to this way of working with the computer. There is no haptic equivalent, and parametric design is a rare example of a design process that is uncharacteristically linked to the computer.[129]

Even so, such a condition requires designers to be able to govern these methods as they are projected to be highly complex, emergent, and non-linear. The initial conditions and intents may lead to unexpected results intentionally or unintentionally. This might seem as a disadvantage in parametric modeling when the whole design process is considered. Burry explains that "[i]n many cases architectural design favors a linear process where design can build upon itself."[130] This might seem to be in favor of a more linear process of design, but the success of a parametric design depends on the designers' abilities in governing and comprehending the modeling technique. In such a need of turning back to a point in design, to "proceed forward in a different direction," the designers should be able to remember the transformations they employ.[131] In order to succeed in this reiterative process, the designers need to build a very successful strategy in attaining the equations and relations, in other

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[127] Kevin Rotherou. "A Vision for Parametric Design."

[128] Branko Kolarevic. "Digital Morphogenesis." p.18.

[129] Mark Burry. "Paramorph: Anti-accident Methodologies." p.7.

[130] *Ibid*. p.4. Peter G. Rowe explains that, some researchers who are interested in the design process have become involved with the "information processing theory," as discussed in Chapter 2. He continues that the information processing theory provides a basis for the designers who employ CAD, especially to guide them in the succession of "complete and hospitable design." He exemplifies the works of Nicholas Negroponte, William J. Mitchell, and Charles Eastman in this line of speculation.

Peter G. Rowe. *Design Thinking.* p.50.

William J. Mitchell. *Computer Aided Architectural Design.* New York : Petrocelli/Charter, 1977.

[131] Mark Burry. "Paramorph: Anti-accident Methodologies." p.4.

William J. Mitchell. *Computer Aided Architectural Design.*

words the parametric relations.[132] Therefore, to construct a more rigid ground in parametric modeling, and to attain a "syntax" to the unstable representations of form, parametric design through associative geometry is developed.[133]

3.3.2.1. Associative Geometry

In parametric modeling, the variables in the equations provide the generation and manipulation of form. In addition to this parametric system, mathematical equations may represent and determine the relationships between objects; then this system is referred to as the "parametric associative geometry," or as Burry defines it, "the constituent geometry that is mutually linked."[134] Burry indicates that "the ability to define, determine and reconfigure geometrical relationships is of particular value."[135] As Aish explains, "once the underlying logic and design relationships have been defined, the designer can create new options without manually building (or rebuilding) the detail design model for each scenario." [136] In other words, a parametric set is tuned to define the dependence relations, therefore objects become dependant on each other and their behavior during a transformative operation is defined. This associativity forms the core of providing the continuity in design, where a modification in an object is followed by others respectively.

In addition to the various capabilities of parametric associative models, the complete design information and history can be stored in them. As Burry explains, "the derivation of its [the parametric model's] constituent parameters can be recorded historically along with relationships between geometric entities."[137] In this sense, the architectural model can be noticed to have become exceptionally transparent. As Allen explains, the architectural object becomes "a series of projections as well as a collection of commands. Instead of a finite number of representations constructing an object (either in the mind or in the world) there is

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[132] Burry warns about the deficiency of parametric modeling at certain levels of design prediction, and argues that designers should be careful in building design strategies.

Mark Burry. "Paramorph: Anti-accident Methodologies." p.6-7.

[133] *Ibid*. p.5.

[134] *Ibid*.

[135] *Ibid*.

[136] Robert Aish. "Compter-Aided Design Software to Augment the Creation of Form." *Computers in Architecture.* Ed. Francois Penz. Harlow, UK: Longman, 1992. pp.97-104.

[137] Mark Burry. "Paramorph: Anti-accident Methodologies." p.6.

already an object (itself made up of a nearly infinite number of discrete elements) capable of generating an infinite number of representations of itself […] all in perfect transparency."[138] By the capacity of storing the complete design data, the form of information is also revolutionized. The information is digitalized and its structure is altered. As Allen adds, "the effect of working on the computer is cumulative. Nothing is lost."[139]

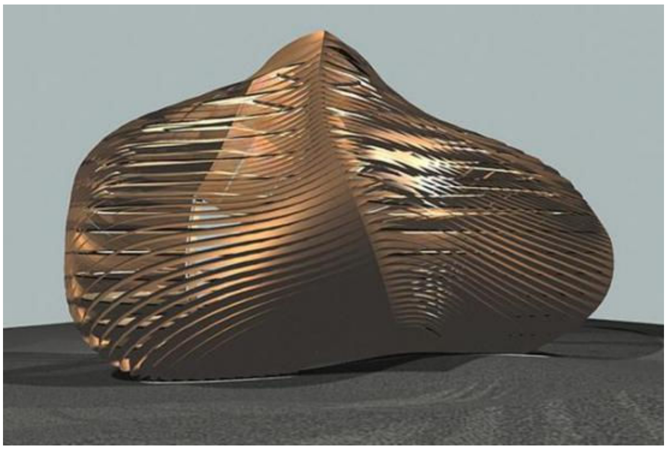

Figure 13. A Model from the "Digital Mockups."

Digital Mockups is an elective course within Architectural Technology Projects offered by Mark Burry, Andrew Maher, Jane Burry, Grant Dunlop, Gregory More (SIAL) with MIT Department of Architecture & Gehry Partners Architects, LLP (USA). It involves parametric design and associative geometry as advanced computer modelling techniques. Reached at: http://www.architecture.rmit.edu.au/Projects/Technology_Projects.php (Last accessed on 15.06.2008.)

Burry characterizes the parametric method as an "explicit" one, where the parameters have "declared values," and he explains that "in almost all CAD packages the design is explicit."[140] Some computer software, such as the *Generative Components* developed by Bentley Systems, have the capability to "capture and graphically present both design components and abstract relationships between them."[141] Additionally, as Aish explains, they provide the ability to represent design not only in graphical terms, but also enable designers

[138] Stan Allen. "Terminal Velocities: The Computer in the Design Studio." p.248.

[139] *Ibid.*

[140] Mark Burry. "Paramorph: Anti-accident Methodologies." p.5.

[141] Robert Aish. "Introduction to GenerativeComponents: A Parametric and Associative Design System for Architecture, Building Engineering and Digital Fabrication."
White paper on http://www.bentley.com.
(Last accessed on 29.05.2008.)

to work with scripting and programming.[142] This ability provides designers with an increasing level of flexibility in determining the behavior of components during possible transformations within the process.

Such transparency also functions in bridging between designers and collaborators from other disciplines. Burry and Maher have exemplified this through their “Selfridges Footbridge” located in Birmingham, UK.[143] This pedestrian bridge was designed by employing parametric associative modeling through the computer software CATIA, to analyze loads and methods for fabrication.[144] Burry and Maher explain that the team not only employed architects and engineers, but by the ability of working on a single model, mathematicians and fabricators became authoritative in the project. They conceptualize this situation through the exchange of “parameters,” as a “digital dialogue between the disciplines.”[145] This means that the representation phases are dissolving between disciplines and the architectural model is reaching an ultimate stage to embody the whole information of a building.[146]

3.3.2.2. Algorithms and Scripting

The parametric associative modeling processes, topological transformations, and the continuity in design space have led to an increasing emphasis on the process and the logic and generative process of design, rather than its visualization. As mentioned previously, computer modeling allows designers to work in various methods along a certain design process. The transformations involved in the animation, in other words the “morphogenesis,” can be expressed in its generative rules, and these rules are referred to as “genetic algorithms.” As Frazer describes, they are “string-like” procedures and they involve mutative

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142 *Ibid.*

143 “Parametric Bridge: Selfridges Footbridge, Birmingham, UK.”
http://www.sial.rmit.edu.au/Projects/Parametric_Bridge.php
(Last accessed on 29.05.2008.)

The Research team in Selfridges Bridge involves Professor Mark Burry, Andrew Maher, Jan-Peter Koppitz, Ed Clark, Alvise Simondetti, and Dr. Kristina Shea. The architects of the Selfridges store are “Future Systems.”

144 http://www.architectureweek.com/2003/1119/tools_1-1.html (Last accessed on 29.05.2008.)

145 “Parametric Bridge: Selfridges Footbridge, Birmingham, UK.”

146 Such studies have lead to the formation of a hypothetical model which is referred to as the “Building Information Model,” shortly the “BIM.” In architectural terms, Building Information Modeling refers to the ultimate model which contains all the information needed to construct a building. This term has been extensively used by Charles M. Eastman in his books and papers, but has been popularized by Jerry Laiserin.

Charles Eastman. Building Product Models: Computer Environments Supporting Design and Construction. Boca Raton, FL: CRC Pres, 1999.

processes as reproduction or gene-crossover in analogy with the natural organism's adaptation and variation.[147] In this sense, the architectural form gains an emergent character, and the generation process becomes more dynamic by the direct expression of the internal logic to the external form. In this scope, designers may use the software completely graphically, or switch to scripting, or even use programming.[148] These extensions in modeling provide an alternative to the representation of form in geometrical terms, and equip designers with non-visual numeric representation methods. As Zeynep Mennan argues, the non-visual numeric methods have been utilized by designers to prolong the experimental process with form. In this fashion, form is neither stabilized nor finalized.[149]

As Allen explains, in computer models "elements and details are continuously added, stored and filed."[150] Due to the fact that new data can be operated into the model and assimilated into design simultaneously along the design process, the final product is consciously being delayed.[151] Ali Rahim conceptualizes this as a "systematic delay," which he defines as "the temporal interstice of conceptual development between initial idea and its material form."[152] In other words, it can be said that the form tries to build up its own potential through its own internal dynamics towards a stabilized state, however this equilibrium is built by the process itself in a non-deterministic manner. Just at this point, the non-visual representation methods provide for non-determinacy by disactivating any visual stimuli to trigger deterministic

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[147] John Frazer. *Evolutionary Architecture.*

[148] Robert Aish. "Introduction to GenerativeComponents: A Parametric and Associative Design System for Architecture, Building Engineering and Digital Fabrication."

[149] Zeynep Mennan discusses the premises of non-visual representation and the estrangement from the visual modes of representation through the shift in the nature of inscriptions from visual to calculated ones. She questions the disclocation of the graphic rationality and the visual training in which architectural education is grounded in:

Zeynep Mennan. "Non Standardization Through Non-Visualization: Scripting the Dom-Ino House". In Oosterhuis, Kas and Feireiss, Lukas (eds.), 2006. *The Architecture Co-Laboratory: GameSetandMatch II, On Computer Games, Advanced Geometries and Digital Technologies* (Rotterdam: Episode Publishers) pp. 234-241.

Zeynep Mennan. "From Number to Meaning: Prospects for a Quantitative Hermeneutics at Istiklal", in Korkmaz, Tansel (ed.), 2005. *Architecture in Turkey around 2000: Issues in Discourse and Practice.* (Ankara: Chamber of Architects of Turkey) pp. 121-132.

[150] Stan Allen. "Terminal Velocities: The Computer in the Design Studio."

[151] Zeynep Mennan. "Non Standard Mimarlıklar: Bir Serginin Ardından." p.37.

[152] Ali Rahim. "Systematic Delay: Breaking the Mold." *AD: Contemporary Process in Architecture.* Academy Editions: London, 70 3 (2000): 6-8.

intuitions.[153] When design governance and control is intentionally omitted in such a fashion, the process gains a non-predictable and emergent character.[154]

In this ability of designing both in visual and parametric mediums, as Allen explains, "[a]ny element can be accessed at any time, independent on what has happened around it. Instead of proceeding always from general to specific, the designer moves from detail to whole and back again, potentially inverting traditional design hierarchies."[155] In parallel, he adds that the "parts are not necessarily integral to the whole" in the parametric model.[156] When the relation of the part and the whole is modified in such a fashion, the erosion of conventional design hierarchies would become unavoidable and a "non-linearity" is offered. On the non-linear nature of computer modeling, William Braham clarifies that;

> The real breakthrough in computer modeling comes not with the mechanization of well-defined procedures, but with the power adequately to show the results of dynamic non-linear influences. In this context, non-linear means that the influences of a particular design situation cannot be simply predicted or characterized, but only experienced or shown as a total result, either because the situation is sufficiently dynamic or the influences are too numerous and complex in their interaction.[157]

3.3.3. Towards a Unified Understanding of Modeling

The tectonic understanding of architectural materiality is detected to highly differentiate from designing in the physical space with conventional modeling procedures and digital

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[153] Zeynep Mennan. "Non Standardization Through Non-Visualization: Scripting the Dom-Ino House". In Oosterhuis, Kas and Feireiss, Lukas (eds.), 2006. *The Architecture Co-Laboratory: GameSetandMatch II, On Computer Games, Advanced Geometries and Digital Technologies* (Rotterdam: Episode Publishers) pp. 234-241.

Zeynep Mennan. "From Number to Meaning: Prospects for a Quantitative Hermeneutics at Istiklal."

[154] It should be noted that Burry is critical about the "pluralism" offered by the CAD, and proposes to rethink about a "measure" in what means success in such design productions. He questions the designers control over the process, and does not favor "accidental" happenings.

Mark Burry. "The Generation and Degeneration of Form Using CAAD: Unceratin Certainty." *Approaches to Computer Aided Architectural Composition*, Technical University of Bialystok, Bialystok, Poland, 1996. pp. 71-91.

[155] Stan Allen. "Terminal Velocities: The Computer in the Design Studio."

[156] *Ibid.*

[157] William Braham. "After Typology: The Suffering of Diagrams."

space with virtual procedures. The physics of the digital space is studied to differ from the physics of real spatial materiality. Although there is the ability to simulate and imitate the real world qualities, i.e. the gravity, within the digital model, the new generation processes are seen to operate on a much different level. As observed, the "surface geometry" of the digital form is very different than the real world of construction.[158] The understanding of tectonics is noticed to be challenged by the emphasis on the continuity of form, which is seen to attend a change in the notions of detail, joint, production and construction. A structural dynamism is perceived to govern the structural logic, therefore the detail is no longer static, but it also becomes more flexible and intricate.[159] The altered part and whole relationship is also observed to affect the constructional aspects of design; where additionally, the architectural "scale" is challenged. Designers are observed to be conceiving buildings almost on a 1:1 scale, and more significantly in real-time as their alterations are reflected simultaneously. Greg Lynn notes that, many theoreticians and critics would not favor such a "dematerialization" in computer modeling and find exert modes of organization threatening to the essence of the discipline. However, he answers to such disapproving criticisms and suggests that "an animate approach to architecture subsumes traditional models of statics into a more advanced system of dynamic organizations."[160] Such an aggregate approach would be a strengthening aspect of architectural conception and production.

In this sense, it can be said that the last decades of the twentieth century have succeeded in reaching what Liu calls an 'intricate mode of designing': As Liu explains, this means that the architect now employs a coordinated combination of drawings, physical models, and digital models in realizing design ideas.[161] In this new context, architectural modeling has become a dynamic field upon which many inquiries are carried. It can be observed that there have been at least two types of reactions in this change: Firstly, the subject area of manual physical modeling has drawn attention to itself once again, with the new perspective obtained from experiencing with the digital modeling techniques. The physical and conventional modes of designing and modeling have begun to be reconsidered. Secondly, the research on the

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[158] Wan- Ping Gao. "Digital Tectonics."

[159] *Ibid.*

[160] Greg Lynn. *Animate Form.* New York: Princeton Architectural Press, 1999. p.9-10.

[161] Yu-Tung Liu. *Understanding of Architecture in the Computer Era.* Taipei: Hu's, 1996. Paraphrased in Cheng-Yuan Lin. "The Representing Capacity of Physical Models and Digital Models." In *CAADRIA 1999, Proceedings of the 4th International Conference on Computer Aided Architectural Design Research in Asia,* Shanghai: Tongji University, College of Architecture and Urban Planning. pp.53-62.

changing nature of physical models through CAM, as it has articulated with CAD, has become a center theme of exploration. Modeling has thus obtained a new dimension. Among many studies, recently in 2006, exactly after thirty years from the first exhibition on modeling, "An Exhibition Looking at the Role of Models in the Architectural Design Process" held at RMIT School of Architecture, Melbourne has addressed both issues both in physical and digital modeling processes.[162] One of the exhibition's chief investigators, Peter Downton states that "[m]odels are a medium for communicating the design knowledge revealed through making and investigating models."[163] At this point, it can be observed that model making is recognized as a medium which reveals a considerable amount of knowledge about designing.

When the ontological need of architecture in realizing itself is considered, it can be predicted that the digital and physical models would be increasingly unified. In this sense, it can be said that today, a compromise has been developing between the real and the virtual realms. After the immensely dense experimentation period within the digital environment, architecture postulates to be connected with its materiality. Yet it seems as a certainty that the concepts of physical and virtual models have slowly been gathering under the notion of "the model." Instead of understanding these two types as polarized entities, a wholeness in the concept is improving. Within this context, the role of CAM tools in providing this link between the immateriality of the virtual and tactility of the real is investigated in the next chapter. It can be seen that the position of the architectural model between the real and the virtual has promised to be highly copious indeed. The discussions produced out of this tension have been carried through architectural modeling.

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[162] Homo Faber: Modeling Architecture Exhibition, Melbourne: RMIT School of Architecture and Design, May 2006.

[163] Peter Downton. "Making Dust, Acquiring Knowledge." Homo Faber: Modeling Architecture Exhibition, Melbourne: RMIT School of Architecture and Design, May 2006. Ed. Brenda Marshall. *Homo Faber: Modeling Architecture Exhibition Catalogue.* pp.8-12.

CHAPTER 4

THE COMPROMISE OF THE VIRTUAL AND PHYSICAL REALMS BY THE AID OF MODELING AND MANUFACTURING

The virtual space and processes of computer-aided design are seen to have revolutionarily transformed the architectural design thinking. They have brought about various new techniques and concepts that would not be possible to implement with physical modeling techniques. However, as Mitchell observes, some theoreticians, critics, and designers would find the space of digital models negatively immaterial, threatening the tectonic thinking of architecture.[1] It has been discussed that with the use of CAD, designers have reached a broad repertoire of novel design generation and manipulation techniques, but they were also feeling the urge to be able to bring their experiments into reality, in other words into the material state of architecture.

With the introduction of computer-aided manufacturing (CAM) tools into the realm of architectural design, this unison of CAD and CAM technologies propose a remarkable shift in constructing the link between the digital and real media. The need for materialization that has been felt by the designers who use CAD can be said to be answered by the CAM technologies. As discussed previously, the propulsive power of diagrams, the studies of topology, and the notion of morphogenesis have inaugurated animated and dynamic possibilities into design through parametric associative modeling processes. In this context, it can be said that finally the "virtuality" in Deleuzian terms is noticed to have found a relevant tool with CAM technologies to realize its actualization processes to the full extent. It can be suggested that CAD has been completing itself with CAM tools, both in terms of the design process, and the changing mode of architectural fabrication, production and construction.[2] Despite seemingly superseded by the computer models, the physical models have always kept their significance by being in the real medium of design, which later gave rise to

[1] William J. Mitchell. "Antitectonics: The Poetics of Virtuality."

[2] Larry Sass and Marcel Botha. "The Instant House: A Production System for Construction with Digital Fabrication." *Digital Design Fabrication Group, Department of Architecture, Massachusetts Institute of Technology.*
http://ddf.mit.edu/papers/index.html (Last accessed on 01.06.2008.)

methods such as “rapid prototyping,” where the two design environments have been brought together. Concerning the building industry, there can be argued to be major alterations by the erosion between the representation phases of design, the blurring boundaries between different disciplines involved in the design and construction, and the change in construction methods and procedures.

Beginning with the various new physical modeling opportunities, the shifts in the design process are discussed in this chapter through this field. Thereafter, the reflections in the architectural construction phases are touched upon, where the digital model is directly converted into the real architectural object. It should be remembered that, such changes have been proposed by the new available CAM technologies. It is seen that designers have been involved with computerization and digitalization since the 1960s, and it can be suggested that an initial intent has been present since, whose tools have only arrived recently with advanced CAD methods and CAM technologies.

4.1. Procedural Alteration of the Architectural Design Process through Novel Physical Modeling Techniques

In the pre-digital era, the traditional designing and building techniques were entirely based on Euclidean geometry.[3] Architects developed and utilized the necessary tools to draw, model, produce, and construct their designs primarily in this conception of space and tectonics.[4] As Kolarevic explains, “[t]he long tradition of Euclidean geometry in building brought about drafting instruments, such as the straightedge and the compass, needed to draw straight lines and circles on paper, and the corresponding extrusion and rolling machinery to produce straight lines and circles in material.”[5] In consequence, as Sass observes,

> Architects have mastered their construct as models built of wood or plastic and buildings of steel and concrete. Modern architects have demonstrated that it is possible to design and build variations of Euclidian shapes as free

[3] Greg Lynn. *Animate Form.* New York: Princeton Architectural Press, 1999.

[4] Larry Sass. “Towards a Design Science of Design and Fabrication and with Rapid Prototyping.” *Digital Design Fabrication Group, Department of Architecture, Massachusetts Institute of Technology.* p.1.
http://ddf.mit.edu/papers/index.html
(Last accessed on 01.06.2008.)

[5] Branko Kolarevic. “Digital Production.” Ed. Branko Kolarevic. *Architecture in the Digital Age: Design and Manufacturing.* New York: Taylor and Francis, 2003. p.32.

> standing or interrelated designs. However few express the ability or desire to build outside of the known Euclidean shape set.[6]

It can be observed that, there is a reciprocity between the design world and repertoire with the available means to design. This observation can be said to preserve its relevancy still today in the digital era, although the manufacturing techniques have significantly increased in variety. Computer-aided manufacturing (CAM) has been introduced to the architectural realm as an extension of computer-aided design (CAD), especially consequent to the parametric associative modeling capabilities, which resulted in highly complex and dynamic forms of architecture. As Sass characterizes these "free forms", he states that they "do embody a language beyond the traditional list of shapes constrained by the tradition of drafting and machine tooling."[7] Objects in this level of complexity in the digital representation could not be processed with manual modeling and fabrication techniques to their materiality.[8] Therefore architects have searched for relevant materializing methods and embraced CAM technologies. CAM has extended the field of new geometries by allowing the "tectonic exploration of new geometries."[9] The consequence is that again, architects need to comprehend the digital technology thoroughly and adapt its relevant fabrication equipments. As Kolarevic states;

> But as constructability becomes a direct function of computability, the question is no longer whether a particular form is buildable, but what new instruments of practice are needed to take advantage of the opportunities opened up by the digital modes of production.[10]

In this sense, the role of the architect is extended to the building construction phases as well.[11] This is because of the extended function of modeling from conception to the production phases, and as Kolarevic explains, due to the fact that architects are now creating

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[6] Larry Sass. "Towards a Design Science of Design and Fabrication and with Rapid Prototyping." p.1.

[7] *Ibid*.

[8] Branko Kolarevic. "Digital Production." p.31.

[9] *Ibid*. p.33.

[10] *Ibid*. p.31.

[11] *Ibid*. p.33. As discussed previously in Chapter 3, the role of the architects have already been broadened with the CAD technologies, as they begin to consider more material and construction related issues in their design by the capabilities of associative parametric modeling. With the introduction of CAM, this extension has gained a stronger character as architects become directly involved in the fabrication and construction.

"the information that is translated by the fabricators directly into the control data that drives the digital fabrication equipment."[12] He adds that;

> The digital age has radically reconfigured the relationship between conception and production, creating a direct link between what can be conceived and what can be constructed. Building projects today are not only born out digitally, but they are also realized digitally through "file-to-factory" processes of computer numerically controlled (CNC) fabrication technologies.[13]

So the architects have been experimenting with various manufacturing techniques which they think would fit their practice, or a specific design best. The computer-numerically controlled (CNC) technologies provide both two-dimensional and three-dimensional fabrications, together with the capabilities of assembly.[14] The computability of digital forms is made possible on the basis of new forms of data, as the mathematical and numerical data as in NURBS curves and surfaces, and they provide the relevant format for CNC machines to process.[15] The details of these fabrication methods are discussed in the following, in order to comprehend how designers construct their design strategies by the fabrication process they intend to utilize. This reciprocity may lead to the reformulation of design strategies, since there is a continuous feedback between the design and construction process.[16] This has led to the studies of "rapid prototyping" in the architectural realm, where physical models are produced with CNC technologies to cultivate more materialistic issues in design thinking. In spite of the fact that the CNC technologies have been recognized widely as production methods, they have not been fully embraced in model-making during the design process. This is due to both that the CNC technologies are expensive, and a lack of systematic approach in utilizing the machinery has not been constructed yet. Sass points to this deficiency and explains that;

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[12] *Ibid*. p.31.

[13] *Ibid*.

[14] Branko Kolarevic. "Digital Production." pp.29-54.

[15] Les A. Piegl. "Knowledge-guided NURBS: Principles and Architecture." *Computer-Aided Design & Applications*, 3.6 (2006): 719-29.

[16] Kenfield Griffith and Larry Sass. "Computing and Materializing Non-Uniform Shapes: An Evolutionary Approach to Generate and Digitally Fabricate Non-Uniform Masonry Walls," in the *Proceedings of Computer Aided Architectural Design Research in Asia*, Japan, March 30th - April 2nd 2006. pp. 227 – 35.

> Unfortunately there are few clear methods that illustrate how designers can effectively build free form shapes for design projects as scaled models. The potential of an effective scaled model is acquired information in design that will make full scale production economically feasible.[17]

In this context, after studying the basics of CNC machinery and fabrication techniques, rapid prototyping strategies are discussed to focus on the changing nature of modeling again with the CAM technologies, still with reference to the shifts that have been experienced in full scale production and construction.

4.2. Computer-Aided Manufacturing Methods

When CAM technologies are integrated to CAD, physical models are seen to be reincorporated into the design process. Architects are now experiencing a much more fluid design procedure because the representation phases are dissolving between conception and production.[18] By the availabilities of design reasoning in versatile model spaces, and direct fabrication capacities from the digital to the physical, the methods of production have metamorphosed.[19] The reasons of this succession are noticed to depend on the prosperous compatibility between various media, the speed of transmittance between these mediums, and the quality of altered digital information.[20] In this context, a variety of CAM technologies aid architects in materializing their designs. It can be observed that although these opportunities have been seriously enhancing architectural design thinking, now architects need to experiment with and acknowledge these methods and embrace the accurate technique for their practice. As there are various ways to utilize CAM technologies, some basics are discussed in the following, continuing with a more comprehensive discussion on "rapid prototyping," proven to be very promising for architectural design.

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[17] Larry Sass. "Towards a Design Science of Design and Fabrication and with Rapid Prototyping." p.1.

[18] Zeynep Mennan. "Non - Standard Mimarlıklar: Bir Serginin Ardından." *Mimarlık*. No:.321 pp.37-41.

[19] Stan Allen. "Terminal Velocities: The Computer in the Design Studio."

[20] Branko Kolarevic. "Introduction."

4.2.1. Reverse Engineering and Digital Scanning

One of the first techniques that associate the physical and the virtual realms has been "digital scanning," or referred to as "three-dimensional digitizing."[21] This method basically offers a three-dimensional scanning process by the use of a digitizing tool, creating a CAD file from the information attained from the physical model, the artifact, or the object.[22] In fact, digital scanning offers a different relationship between the physical and the digital model, which is inversely related to CAM. Therefore this methodology is also cited as "reverse engineering" in the engineering or product design terminology.[23] In the scanning process, firstly a "point cloud" is created by scanning, in other words by tracing the physical object through various points along its surface geometry.[24] This data composed of *X, Y, Z* points in space is interpreted by the "conversion software" to produce an approximate digital version of the model's geometry.[25] This transformation continues with the joining of the points and generating NURBS curves, which are later lofted to create the NURBS surfaces.[26] Three dimensional scanning can be realized in three methods: Firstly, it can be done by the "digitalizing arms," where the designer scans the object surface manually.[27] Secondly, it can be processed automatically by a coordinate measuring machine (CMM), which has a "digitizing position sensor" that is "mechanically kept in contact with the surface of the scanned object."[28] Finally, the third procedure involves a "non-contact" scanning method in which the scanners utilize laser light and digital cameras to read the object, and then this information is processed from images to the digital format.[29]

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[21] Branko Kolarevic. "Digital Production." p.31.

[22] "Applications 3D." Reached at: http://www.applications3d.com/index.html (Last accessed on 01.06.2008.)

[23] *Ibid.*

[24] "Applications 3D."

[25] Branko Kolarevic. "Digital Production.". p.31.

[26] "Applications 3D."

[27] Branko Kolarevic. "Digital Production." p.32.

[28] *Ibid.*

[29] "3D Laser Scanning." Reached at: http://www.3dlaserscanning.org/ (Last accessed on 01.06.2008.)

One of the first offices who used digital scanning was Gehry Partners.[30] Frank Gehry chose to work with physical models to begin with, in which he valued the "direct tactility of the physical model and the speed, freshness, and the energy of the freehand gesture."[31] As Mitchell explains Frank Gehry's working method;

> In Gehry's office, the process begins with the use of a very accurate three-dimensional digitizer to capture vertex, edge, and surface coordinates from a large-scale physical model. Using CATIA, mathematical curves and surfaces are then fitted as closely as possible to these digitized points. Rapid-prototyping devices, such as computer-controlled three-dimensional deposition printers and multi-axis milling machines, are then used to "build back" physical models for visual inspection and comparison with the original. The process iterates, with adjustments as necessary to the digital model, until the design team is satisfied.[32]

Gehry basically chose to design with physical modeling, where he adjusted CATIA (Computer Aided Three-dimensional Interactive Application) to function as a "translation" tool between the physical and the digital media.[33] As ascertained by Kolarevic, in Gehry's practice, "the digital technologies are not used as a medium of conception but as a medium of translation in a process that takes as its input the geometry of the physical model and produces as its output the digitally-encoded control information which is used to drive various fabrication machines."[34] This iterative mode of Gehry's practice has been interpreted by Mitchell as an ability to "transcend the limitations of traditional CAD functionality alone."[35] Similarly, Dollens favors Gehry's design process and states that it combines the "warps and wefts of one experiment with the splines and lofts of another and arrives at a third transformative structure."[36]

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[30] Branko Kolarevic. "Digital Production." p.31.

[31] William J. Mitchell. "Roll Over Euclid: How Frank Gehry Designs and Builds." Ed. Fiona Ragheb. *Frank Gehry, Architect.* New York: Guggenheim Museum Publications, 2001. p.354.

[32] *Ibid*. p.358.

[33] Branko Kolarevic. "Digital Production." p.31.

[34] *Ibid*. p.31.

[35] Timothy Lenoir and Casey Alt. "Flow, Process, Fold: Intersections in Bioinformatics and Contemporary Architecture." *History of Science Program, Stanford University.* p.15.
http://www.stanford.edu/dept/HPS/TimLenoir/Publications/Lenoir_FlowProcessFold.pdf
(Last accessed on 01.06.2008.)

[36] Dennis Dollens. "Fish, Snake, Gehry & Guggenheim." Quoted in Timothy Lenoir and Casey Alt. "Flow, Process, Fold: Intersections in Bioinformatics and Contemporary Architecture." *History of Science Program, Stanford University.* p.15. Reached at:

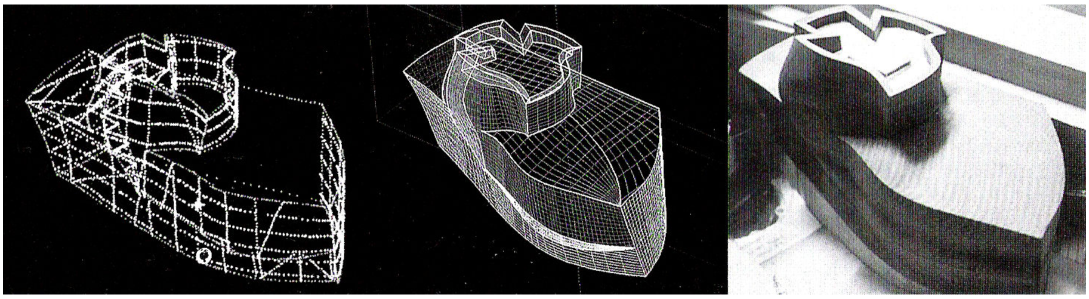

Figure 14. The translation process in Gehry's Office.

In the first image, the digitized dots are seen, which are later reconstructed into a digital surface. The model can be rematerialized by the CNC technologies. Kolarevic, Branko. "Digital Production," in *Architecture in the Digital Age: Design and Manufacturing.* Edited by Branko Kolarevic. New York: Taylor and Francis, 2003. p.31.

Although this process might seem inspiring in the first place in terms of constructing the association between the two media, it can be seen that it does not actually pursue with the generative potential of CAD indeed. As Lenoir and Alt argue, instead of engaging in "a transformative repetition of form through CATIA, he [Gehry] subjects each CATIA prototype to a process of *visual inspection and comparison with the original* and thus privileges the original physical form."[37] In this sense, digital scanning can be said to have formed an introduction with the CAD and CAM togetherness in the architectural realm. However, architects needed a different method where they could operate physical modeling more as an extension of CAD models in terms of dynamic generative and manipulative potentials. It can be suggested that only when both modeling media have a transformative role in the design, this association becomes meaningful, efficient, and productive.

4.2.2. Computer-Numerically Controlled Equipments

The most common technique of CNC technologies is the CNC cutting which works on two-dimensions.[38] It involves cutting machines such as routers and knife cutting, as well as cutting with laser-beam, plasma-arc, and water-jet.[39] The two-dimensional cutting involves two-axis motion, where the motion is realized by the movement of the cutting head, the bed,

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http://www.stanford.edu/dept/HPS/TimLenoir/Publications/Lenoir_FlowProcessFold.pdf (Last accessed on 01.06.2008.)

[37] Timothy Lenoir and Casey Alt. "Flow, Process, Fold: Intersections in Bioinformatics and Contemporary Architecture."

[38] Branko Kolarevic. "Digital Production." p.34.

[39] http://www.multicam.com/ (Last accessed on 01.06.2008.)

where the material is placed, or a combination of both.[40] In these machines, various materials can be processed, such as paper, board, clay, styrofoam, perspex, acrylic, vinyl, plastic, wood, plywood, metal, and stone.[41] However, it should be remembered that each technique would produce different results in the cleanness and accuracy of the cut, depending on the material that is being cut as well.[42] Additionally, in order to obtain cost-efficacy, the material sizes should be decided accordingly because the machines can perform on certain sizes and thicknesses of materials.[43]

4.2.2.1. Subtractive Fabrication

In three-dimensional CNC fabrication techniques, basically two types of methods can be classified: The subtractive fabrication and the additive fabrication.[44] Subtractive fabrication is based on the removal of a certain volume of material from a raw solid block.[45] A multi-axis milling process is used in this procedure, which can involve "electro-, chemically-, or mechanically-reductive" methods.[46] As Kolarevic explains, in two-axis milling routers, the rotating drill-bit moves along the *X* and *Y* axes. The three-dimensional milling works in the same logic with two-dimensional cutting, but by the extension of the ability of the drill-bit to move along the *Z* axis. In this way, volumes become available to be subtracted. However, there is an important constraint in three-axes milling, which is its incapability of

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[40] *Ibid.*

[41] *Ibid.*

Mark Morris. *Models: Architecture and the Miniature.*

Porter and Neale. *Architectural Supermodels: Physical Design Simulation.*

[42] Jennifer C.K. Seely. "Digital Fabrication in the Architectural Design Process." Master Thesis. *Master of Science in Architecture Studies at the Massachusetts Institute of Technology.* 2004.
http://ocw.mit.edu/NR/rdonlyres/Architecture/4-510Fall-2005/D031955D-02AA-4AC8-8786-6D7C8DFFBA17/0/seelythesis.pdf
(Last accessed on 01.06.2008.)

[43] Larry Sass. "Towards a Design Science of Design and Fabrication and with Rapid Prototyping." p.1.

[44] Branko Kolarevic. "Digital Production." p.34.

[45] Marshall Burns. "The Origins and Direction of the Fabricator Revolution." *Ennex Fabrication Technologies*, 1997. Reached at : http://ieeexplore.ieee.org/iel4/5230/14218/00651758.pdf?arnumber=651758 (Last accessed on 01.06.2008.)

[46] Branko Kolarevic. "Digital Production." p.34.

manufacturing the "undercuts."[47] For this purpose, four- or five-axes milling machines are required, which add the A and B axes to the motion of the drill-bit by changing its angles.[48]

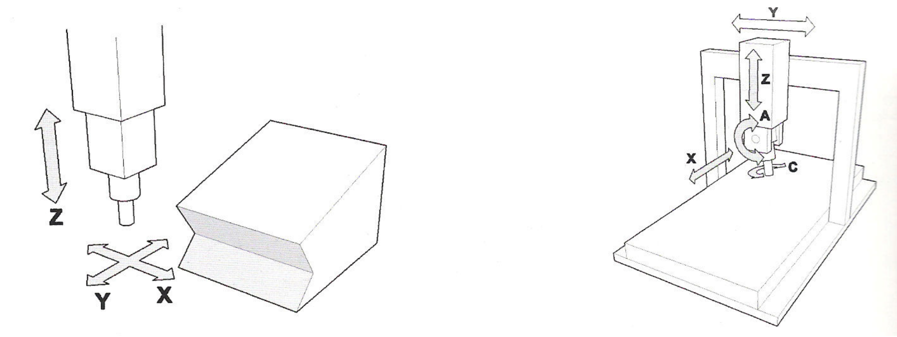

Figure 15. The motion of the drill-bit and the bed in three- and five axes milling machines.

Branko Kolarevic. "Digital Production," *Architecture in the Digital Age: Design and Manufacturing.* Edited by Branko Kolarevic. New York: Taylor and Francis, 2003.

CNC milling machines operate with post-processing software, which generates the numerically controlled information and transmits them to the machine.[49] It functions with a set of coded instructions, which create the "tool path" for the drill-bit.[50] CNC milling has been one of the oldest digital fabrication technologies. As Kolarevic explains, many large firms have been employing this technology since the 1970s to produce models and for the testing of structural decisions.[51] He adds that, since the 1980s the technology has begun to be used in full-scale construction components. These productions may involve stonework, cladding, or the fabrication of structural elements. Furthermore, CNC milling has recently begun to be used in the production of the "molds" for the components.

4.2.2.2. Additive Fabrication

The second type of three-dimensional fabrication is the additive fabrication techniques. Additive fabrication techniques can also be referred to as "layered manufacturing," "rapid prototyping (RP)," "solid free form fabrication," "stereolithography (SLA)," or "desktop

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[47] *Ibid.* pp.34-6.

[48] *Ibid.*

[49] Jennifer C.K. Seely. "Digital Fabrication in the Architectural Design Process."

[50] Paul F. Jacobs. *Rapid Prototyping and Manufacturing: Fundamentals of StereoLithography.* Dearborn: Society of Manufacturing Engineers, 1992.

[51] Branko Kolarevic. "Digital Production." p.33-4.

manufacturing."[52] These methods are basically referred to the automatic materialization of data that is constructed in CAD, through the use of CNC technologies which are used in three-dimensional production. In all these procedures, fundamentally the digital model is analyzed and sliced into two-dimensional layers by the related software.[53] Then it is sent to the SLA machine which employs a computer controlled laser to treat a photo-sensitive resin (a polymer) in a layer by layer fashion, producing the 3D artifact.[54] This process is proved to be very effective and fast, in which an artifact is materialized in a few hours.[55]

In the building industry, additive fabrication processes are applied in the production of "components in series, such as steel elements used in light truss structures."[56] An interesting method has recently begun to be used in full scale manufacturing of large scale components, which is called "contour crafting (CC)."[57] This system promises the production of highly finished building parts directly from the digital data.[58] Additionally, as Kolarevic and Mitchell mention, the digital fabrication can offer effective solutions within budget which would be very high if traditional manufacturing techniques are used.[59] Mitchell adds that, in this way, the construction would also becomes "global," without the restriction of local manufacturing traditions.[60]

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[52] *Ibid*. p.36-7. All these methods can be gropued under the name "rapid prototyping." However, it should be noted that there are some different treatments of machines on the model which are actually different procedures. To exemplify some chief techniques, there are stereolithography (SL), fused deposition modeling (FDM), three-dimensional printing (3DP), multiJet modeling (MJM), and laminated object modeling (LOM). For the details on these procedures and the materials they can process, please see: Jennifer C.K. Seely "Digital Fabrication in the Architectural Desgin Process."

[53] Branko Kolarevic. "Digital Production." p.36-7.

[54] Paul F. Jacobs. *Rapid Prototyping and Manufacturing: Fundamentals of StereoLithography.*

[55] "Industrial Laser Solutions." Reached at: http://www.industrial-lasers.com/articles/article_display.html?id=219985 (Last accessed on 01.06.2008.)

[56] Branko Kolarevic. "Digital Production." p.36-7.

[57] "Contour Crafting." Reached at : http://www.pathnet.org/sp.asp?id=7364 (Last accessed on 01.06.2008.) Contour crafting (CC) is developed by Behrokh Khoshnevis, as the Principal Investigator and Yan Xiao, as the Co-Principal Investigator at University of Southern California.

[58] *Ibid.*

[59] Branko Kolarevic. "Digital Production." p.33.

[60] William J. Mitchell. "Antitectonics: The Poetics of Virtuality," in John Beckmann, (ed.) *The Virtual Dimension: Architecture, Representation and Crash Culture.* New York: Princeton Architectural Press, 1998.

Figure 16. The stereolithography process.
"Stereolithography." Reached at: http://www.stereolithography.com (Last accessed on 16.06.2008.)

In the model making procedures, three-dimensional production has pioneered a vastly versatile field for architects to experiment with, which is discussed in the following section in detail. In the scope of this thesis, the three-dimensional additive fabrication is favored to be referred to as "rapid prototyping" in general to provide for terminological accuracy with the relevant sources.

4.3. Rapid Prototyping

Over the last three decades architects have been meticulously practicing with CAD. It has been discussed that the first years of this encounter resulted in a highly experimental and explorative period, which was also very immaterialist and abstract in conception. In time, architects are in need of the means to realize and concretize the outcome of their projects. This urge can be defined by the tectonic aspect of architecture, and as Giedion points out to this repulse, he explains that the structure and materials impel architecture to become a reality.[61] In the building industry, this search has found its answer with the CAM technologies. Meanwhile, there is also the fact that various computer-generated design work remain in the digital form of models and image format. Sass criticizes this situation and states that;

[61] Sigfried Giedion. *Space, Time, and Architecture: The Growth of a New Tradition.* Cambridge: Harvard University Press, 1967.

> Over the past 10 years many architects have focused on the production of free form designs as computer generated images and less as physical products (models or building). Both magazine and design books have graced their covers with curvy almost sensual images of free form designs. These images almost ignore the complexities of construction or any potential as a materialized construct.[62]

Sass suggests that the digital free form needs to be tested in its material form before it is realized as a building, concerning many aspects of design ranging from structure to economy.[63] Considering this need, he suggests that "for creative design fields an effective means to produce free form models has been rapid prototyping."[64] In architectural terms, Sass adds that, not only in the realizations of complex forms, but in all its configurations, physical models preserve their importance for designing. He explains that physical models do not only supply information on structure and construction, but also "provide design incite on lighting, structure and the relationship of architectural spaces."[65] He strictly recommends that architects should consider rapid prototyping, as an integral tool in design.

Rapid prototyping provides architects with the feedback that comes from the materialization of digitally generated design. Griffith and Sass acknowledge that there is a "continual design intention to experiment with more provocative forms," but these experiments need to be completed with the production of artifacts to obtain a reflection of the practice.[66] Hence there is a need to evaluate the physicality of design at an early stage. In this context, the physical architectural model is reintegrated to the design process. By appointing physical models together with the digital models, it is made possible to "redesign based on changes found while exploring the design."[67] This "evolutionary process" is introduced by Griffith and Sass as "[a]n alternative approach to typical evolutionary design by considering manufacturing as

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[62] Larry Sass. "Towards a Design Science of Design and Fabrication and with Rapid Prototyping." p.1.

[63] *Ibid.*

[64] Kenneth Cooper. *Rapid Prototyping Technology: Selection and Application.* New York: Marcel Decker, 2001. Paraphrased in Larry Sass. "Towards a Design Science of Design and Fabrication and with Rapid Prototyping." *Digital Design Fabrication Group, Department of Architecture, Massachusetts Institute of Technology.* p.1. http://ddf.mit.edu/papers/index.html
(Last accessed on 01.06.2008.)

[65] Larry Sass. "Towards a Design Science of Design and Fabrication and with Rapid Prototyping." p.2.

[66] Griffith and Sass. "Computing and Materializing Non-Uniform Shapes: An Evolutionary Approach to Generate and Digitally Fabricate Non-Uniform Masonry Walls." P.228.

[67] *Ibid.*

part of the generative process versus virtual evolution and final output."[68] Therefore the manufacturing process is perceived to be utilized as a constraint generator in the course of design. It can be observed that the fluidity in design process and production phases is solidified by the versatile character of the architectural model. The architectural model can be commented to have become a problem-solving tool and offers to realize design with ease and accuracy by allowing testing at a very early stage.

> Physical models empower designers to demonstrate and study the details of space, light and form. However the difficulty in working with physically large models is that manufacturing components and assembly require many hours of labor in translating information from drawing to physical materials. In return the process illuminates many properties at full scale construction with the benefit of physical reasoning within the design space.[69]

It can be observed that, rapid prototyping greatly help to generate strategies in CAD modeling by cultivating questions about the fabrication-related issues. In other words, it directly brings the decisions that are ought to be taken in the materialization phases to the medium of design. Additionally, rapid prototyping may "inform full scale production" by testing the structure and detailing of the project.[70] Maxwell, putting the emphasis on the tectonic aspect, observes that "no building, however abstract its forms, is able to set up an ideal world without accounting for the penetration of its idea space by real space."[71] Although it might be conceptualized that there has been an inclination either towards digitalization, in other words what has been conceived by some theoreticians as "dematerialization,"[72] or towards physicality, it can be observed that neither of them is completely relevant to the contemporary condition. Instead, it can be strongly argued that there is a "convergence" between these two media. The virtual conceptions of modeling and contemporaneous physical modeling offered by rapid prototyping are becoming increasingly integrated and indispensable. With the implementations of rapid prototyping, the correlation between the virtual and the real has

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[68] *Ibid.* p.229.

[69] *Ibid.* p.228.

[70] Larry Sass. "Towards a Design Science of Design and Fabrication and with Rapid Prototyping." p.1.

[71] Robert Maxwell. *Sweet Disorder and the Carefully Careless Theory and Criticism in Architecture.* New York: Princeton University Press, 1993.

[72] William J. Mitchell. "Antitectonics: The Poetics of Virtuality." p.208. Mitchell explains that some theoreticians are troubled by this dematerialization and might claim that "these are things of another kind, and that their production and consumption belongs to a different and incompatible discourse." However Mitchell doubts that such a sharp distinction can be sustained, since "the material now appropriates from the virtual, and the virtual from the material."

been reconstructed. However, it is clear that more time is needed to achieve maturity in using both methods effectively as designers still need to fully comprehend, command and embrace rapid prototyping tools to integrate them as a common and frequently used method while designing.

4.3.1. Rapid Prototyping Challenges and Modeling Strategies

As discussed previously in the subchapter about the CNC equipments, each machine and technique bring about their own constraints. The major constraint in this field seems to be the executable object size depending on the machine type. Scale models which are small in size can be directly materialized with three-dimensional fabrication tools. However, a chief question arises regarding the "scale" of a model.[73] While modeling in the physical space, various scales can be considered. It can be seen that many rapid prototyping techniques involve obtaining the pieces of a model, and then the assembly is realized manually.[74] Therefore, it can be deducted that designers actually possess flexibility in deciding the scale of physical modeling. However, due to the restraining condition of the current available tools, designers need to consider and develop strategies about how a physical model can be constructed.[75]

Figure 17. The continuous link between the evolutionary stages of design by rapid prototyping.

Larry Sass and Marcel Botha propose a strategy in building "mass customized, designed housing to emergency and poverty stricken locations." Sass, Lawrence and Marcel Botha. "The Instant House: A Production System for Construction with Digital Fabrication." *Digital Design Fabrication Group, Department of Architecture, Massachusetts Institute of Technology.*
http://ddf.mit.edu/papers/index.html
(Last accessed on 01.06.2008.)

[73] Alex Selenitsch. "Small, Real, Large," in Homo Faber: Modeling Architecture Exhibition, Melbourne: RMIT School of Architecture and Design May 2006. Edited by Brenda Marshall. *Homo Faber: Modeling Architecture Exhibition Catalogue.* pp.3-6.

[74] Larry Sass. "Towards a Design Science of Design and Fabrication and with Rapid Prototyping." p.1.

[75] Griffith and Sass. "Computing and Materializing Non-Uniform Shapes: An Evolutionary Approach to Generate and Digitally Fabricate Non-Uniform Masonry Walls."

It can be seen that this situation proposes a problematic area when these two model media are joined. The "scale" in the virtual space of the model had gained another dimension. It can be said that in the virtual space, objects keep a "proportional" relationship to each other. However, when this flexibility in the virtual medium is desired to be actualized in the real space, then a more earth bound conception of "scale" is given rise.[76] This has been experienced by designers using CNC machines as the constraints of the tools, some of which can be exemplified as the workable object size and desired material usage.[77] It can be argued that such a constraining outline has always been present in physical modeling, as to referring to manual modeling techniques. Therefore this constraining condition becomes a general boundary, defined by the materiality and physicality of the real, as superposed on the virtuality of the computer model.

Many researchers contribute to the improvement of rapid prototyping techniques, though their concentration might be carried on its different aspects. As studied earlier, many three-dimensional fabrication machines produce physical artifacts by "collecting thin or thick printed layers adhered to newly produced layers many times over."[78] Therefore the model quality differs by "model strength, layer smoothness, and fabrication speed."[79] Sass explains that many researchers focus on different fields to improve the CNC machinery, software, and strategies.[80] For instance, he exemplifies Beaman, Gebhardt, and Chua, who rivet their research on "structurally effective model manufacturing," which takes into consideration various materials and details.[81] Others as Lipson try to offer advancement in reducing the cost

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[76] *Ibid.*

[77] Sass and Botha. "The Instant House: A Production System for Construction with Digital Fabrication."

[78] Larry Sass. "Towards a Design Science of Design and Fabrication and with Rapid Prototyping." p.3.

[79] *Ibid.*

[80] *Ibid.*

[81] Joseph J. Beaman. et.al. *Solid Freeform Fabrication: A New Direction in Manufacturing with Research and Applications in Thermal Laser Processing.* Norwell, MA: Kluwer Academic Publishers, 1997.

Chua Chee Kai. et. al. *Rapid Prototyping: Principles and Applications in Manufacturing.* River Edge NJ: World Scientific Publishing Company, 2003.

Andreas Gebhardt. *Rapid Prototyping.* Münich: Hanser, 2003.

of rapid prototyping to make it viable to all.[82] The software of rapid prototyping tools are studied by researchers as Gibson in the improvement of speed. Some researchers have also been trying to improve the usage of rapid prototyping in the very early stages of design.[83] This kind of modeling has begun to be used by product designers,[84] and would propose a very promising method for architectural design.

Sass also points to the portability of the physical model, and proposes a method "to generate free form designs as physical models that assemble and disassemble for transportation or design additions."[85] It can be commented that this "reassembling" and "reconfiguration" potential might be very promising on both modeling and building levels. Concerning the prior, it can be said that both digital and physical models can work unitedly as a "working model" which would be highly open to alterations. In this sense, the physical model extends its field by its dialogue with the computer generated model. Considering the building scale, this reconfigurability may promise that the formalization of a building would never be realized. It can be speculated that in the future, the morphogenetic potential of form might also be realized in this way on a full scale.

4.3.2. A New Look at the Physical Model

Architects have now been experiencing a complex form of designing with the combination of various representation techniques. In this complex mode of designing, it can be seen that model making has been employed in many stages, linking various design procedures. With the reconstruction of the relationship between the means of design, by the computer-generated models and physical models obtainable from CNC machines, the physical model has been repositioned. Respectively, due to the recognition of the rapid prototyping, the digital model has also been reevaluated.

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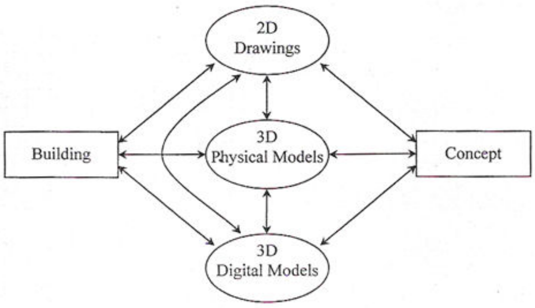
[82] Hod Lipson. "Homemade: The future of Functional Rapid Prototyping." *IEEE Spectrum*, Feature Article, May 2005. pp. 24-31.

[83] Ian Gibson. *Software Solutions for Rapid Prototyping*. Chichester, West Sussex: Wiley Academy, 2002.

[84] Bart Eisenberg. "Thinking in Prototypes." *Product Design and Develeopment.*

"Product Design." Reached at: http://www.dcontinuum.com/content/newa.php?id=149 (Last accessed on 01.06.2008.)

[85] *Ibid.*



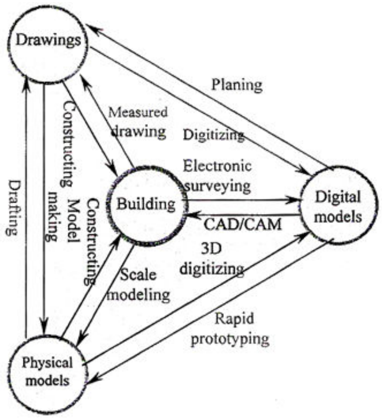


Figure 18. The schema on the left explains the design process with the utilization of 3D models and 2D drawings between the conception and construction phases. (Drawn after Yu-Tung Liu.)

Figure 19. The schema on the right shows the complex relationship between various representation techniques employed until the realization of the building is completed, and maybe even afterwards. (Drawn after William J. Mitchell.)

Cheng-Yuan Lin. "The Representing Capacity of Physical Models and Digital Models." In *CAADRIA 1999, Proceedings of the 4th International Conference on Computer Aided Architectural Design Research in Asia,* Shanghai: Tongji University, College of Architecture and Urban Planning. p.54.

However it should be noted that these new positionings would not imply a complete shift from one to another. Instead, it can be seen that it is a condition where both positions have been displaced and reconstructed through their novel relations. This relationship has become a highly incorporated one. For instance, in physical modeling with rapid prototyping, many strategies involve an algorithmic logic.[86] Meanwhile, in the generative processes of the digital model, the tectonic aspect of architecture has thoroughly been taken into consideration in ways similar to physical modeling. Furthermore, the manual physical modeling procedures are also incorporated into this context. It can be seen that the growing implementation of physical modeling is not a condition where the excessive potential of "virtuality" is weakened, but just as the opposite it has finally converged to the required tools for its materialization.[87] In this sense, the virtual forces, drives, and processes can be supposed to be heading towards unification with those of the real. Mitchell explains that, the variety in design media would provide different observations of real space; hence this condition would allow different reasonings to be made.[88] In terms of CAD, Mitchell suggests

[86] Sass and Botha. "The Instant House: A Production System for Construction with Digital Fabrication."

[87] William J. Mitchell. *The Logic of Architecture.*

[88] *Ibid.*

that in order to integrate the computer into design processes more powerfully, its boundaries should be extended into other methods where more value can be added.[89] Instead of having a completely digital-mediated or a physical-mediated design process, the freedom and flexibility to translate design information between these media, and the ability to construe one in the other's set seems to be much more promising in architectural terms.

Mitchell exemplifies this situation by analogy in two-dimensional representation. He states that "this is similar to the fact that a two-dimensional plan cannot generate the same critical language as that of a section." However, the condition experienced with CAD/CAM Technologies is obviously much more complex as they seek a "non-representationality" in their conception.

[89] William J. Mitchell. "The Virtual Studio." *ACADIA Quarterly* 16 (1997): 6-12.

CHAPTER 5

CONCLUSION

In the second half of the twentieth century, the mode of architectural design is observed to have undergone a significant shift that has been mainly consequent to the developments in computer-aided design (CAD), especially due to the designing procedures involving parametric modeling, associative geometry, keyframe animation, genetic algorithms, and scripting. The thesis has argued that such changes do not only depend on the alteration of architectural design tools as a consequence of CAD technologies, but also feeds from a novel conceptual background as architecture has always been in a highly interdisciplinary relationship with mathematics, geometry, science, and philosophy.

The alterations in the conceptions of "space," "time," and "form" based in the mathematical realm are seen to influence architecture to get acquainted with the represent the new complex structure of these concepts. In this framework, the studies on non-Euclidean geometries and topological structures have been addressed to clarify the notions of dynamism, pluralism, and multiplicity in contemporary design conceptions. The computational perspective has been highlighted by discussions on NURBS geometries, parametrics, associative geometry, algorithms, and scripting, as both related to computer programming and usage in the architectural design process. By means of the new dynamic form generation and manipulation processes of CAD modeling, the architectural model has departed from its static and deterministic mode. The design process has become non-linear, non-deterministic and capable of producing emergent forms. The dynamic, indeterministic, and non-linear behavior of the digital realizations has challenged the conventional tectonic apprehension. Procedures as scripting, have been of great value in challenging the conventional visual and tectonic thinking in architecture and introducing the emergent character of form. Additionally, as Mennan discusses, it operates on a non-visual mode, where graphic rationality and visual training is highly challenged.[1]

[1] Zeynep Mennan. "Non Standardization Through Non-Visualization: Scripting the Dom-Ino House". In Oosterhuis, Kas and Feireiss, Lukas (eds.), 2006. *The Architecture Co-Laboratory: GameSetandMatch II, On Computer Games, Advanced Geometries and Digital Technologies* (Rotterdam: Episode Publishers) pp. 234-241.

In the philosophical aspect of the discussion of changing context of architecture, the thesis put an emphasis on the duality of 'virtuality' and 'actuality.' However, as Greg Lynn has observed, "the term **virtual** has recently been so debased that it often simply refers to the digital space of computer-aided design."[2] However, it actually belongs to a much broader context of discussions. The thesis tried to emphasize the term virtual in a two fold argument: Firstly, the study tried to provide a background from the studies in post-phenomenological philosophy and to emphasize virtuality as a world of conception and representation, where virtuality constitutes the principal potential and generative authority for architectural production. The definition of the relationship between "virtuality" and "actuality" has been based on philosophical studies by Henry Bergson and Gilles Deleuze. When the virtual is formulated as a potential which may have multiple and divergent actualizations, the actualization process is seen to become pluralistic and indeterministic. The related discussions of diagrams and non-representationality have tried to be pursued in this framework. Secondly, the virtual space of representation has been referred to, in order to be able to maintain the recognition of two model worlds, both the digital and the physical, in the same representational scale.

It can be seen that for many designers the computer-generated model creates an increasing distance between the designer and the object as they belong to two different worlds. However at the same time, the digital model controversially offers an interactive and responsive mode of designing, which allows designers to work directly on the object. The capability of building digitally is also seen to empower this situation. It is true that the representational phases are dissolving, however this observation can be said to be true concerning the traditional two-dimensional orthographic set[3], or the architectural model in its function as an engineering or detail model. It can be noticed that the need for such representations to share information between architects or different disciplines involved in the construction is weakening, because these different groups are operating on the very same model during the process. In regard to that argument, the thesis tried to maintain the position that recognizes the necessity for visual and tectonic representation.

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[2] Greg Lynn. *Animate Form.* p.9.

[3] Başak Uçar. MArch Thesis. "An Assesment of the Architectural Representation Process Within the Computational Design Environment," 2006, METU.

As the tools of architectural design have answered to these conceptual shifts, architects increasingly employ computer-generated models and subsequently computer-aided manufactured physical models. Architects, in their dense involvement in CAD for many years, seem to have felt the requirement of testing their designs in the physical space before extracting them as full scale constructions. It can be detected that they demand the feedback from the physical space of design at very early stages of the process, to feed the prosperous digital model with continuous data integration from the real world. So they integrated CAM modeling into the design process where physical modeling accompanies digital modeling, which is currently referred to as rapid prototyping (RP). Within this context, the physical model is redefined and reintegrated to the design process as a digitally-generated entity, and the position of the manually-produced physical model has been rediscussed within this scope.

With the unification of the two forms of models, in their state of belonging to seemingly two different design worlds, the architectural model can be asserted to have grown to be an even more powerful design tool. With the recognition of RP, computer-aided modeling has gained more meaning as the materialization processes can now accompany its dynamism. By means of the two different design worlds, the digital and the physical, the different constrains from these environments could be processed as input data into the design work. By the ability to produce and build directly from CAD models, which is cited as a "file-to-factory" process[4], the traditional representation phases are observed to be dissolved. Similarly, the conventional staged construction of the design process has also dissolved and fused into a much more fluid state. In other words, the traditional model types, involving the conceptual, working, and presentation models, have been replaced by a single computer model which provides for continuous design conception and coordinated manipulation possibilities. Hence, a single model can function for various purposes, building on itself, and linking different designers and disciplines.[5]

Bernard Cache and Patrick Beaucé predict that by the aid of numerical manufacturing techniques, architectural design is heading towards operating in a fully-integrated

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[4] Kolarevic cites the direct process of production from CAD models to materiality by the use of CAM tools as the "file-to-factory" process. Kolarevic, Branko. "Digital Morphogenesis." *Architecture in the Digital Age: Design and Manufacturing.* Edited by Branko Kolarevic. New York: Taylor and Francis, 2003.

[5] Jim Glymph. "Evolution of the Digital Design Process." p.113.

CAD/CAM system.[6] All the more so, as the design process has extended into these new operational procedures, architects now need to adapt themselves into this new design environment. It can be observed that there are two subject fields that they need to improve: Firstly, the design process needs to be advanced into a state where the two types of models, the computer-generated digital model and the computer-generated physical model, in other words CAD and CAM technologies, should be used to their full capacity. Secondly, the CAM operations and rapid prototyping seem to require further investigation to reach a maturity in the architectural domain. Eventually, CAD has been exposed to a high interest and experimentation for nearly five decades; however CAM is respectively new in the architectural realm. In this scope, it should be remembered that CAD has also received a critical inspection in this mutual relationship. In the immediate future, CAD and CAM modeling processes can be observed to converge even more and become increasingly integrated. William J. Mitchell argues that on the one hand architects are going to seek relevant tools from other disciplines and maybe import them to the architectural domain; on the other hand they will try to reinterpret the tools they have at hand and maybe develop novel methods that would fit the current paradigm:

> Today, architects are increasingly able to take advantage of accumulated investment in code, fast computers that support complex derivation processes, and CAD/CAM fabrication machines that make it highly advantageous to invest in the production of digital information. They can exploit the resulting opportunity for more efficient exploration of familiar design worlds. Or – far more interestingly – they can seize the chance to open up new, previously inaccessible worlds.[7]

With the reduction in the expenses of fabrication methods, a multi-faceted design medium can be said to await architects with the magnification of fluidity in the design procedures and expansion into other media.[8] As rapid prototyping would serve in the continuous production line of artifacts, in due course the tools of design and modeling can be expected to change over again to respond to the needs of that moment, together with the acquired knowledge distilled from the explored design media and their potentials. In time, observing from the

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[6] Patrick Beaucé and Bernard Cache. *Objectile, Fast-Wood: A Brouillon Project.* Wien: Springer Wien, 2007. p.xi.

[7] William J. Mitchell. "Design Worlds and Fabrication Machines," in Kolarevic, Branko. (ed.) *Architecture in the Digital Age: Design and Manufacturing.* New York: Taylor and Francis, 2003. p.79.

[8] Jim Glymph. "Evolution of the Digital Design Process."

convergence of different types and media of architectural models, it can be predicted that their physical and digital modes of would increasingly merge.

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http://www.stanford.edu/dept/HPS/TimLenoir/Publications/Lenoir_FlowProcessFold.pdf
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