AN ASSESSMENT OF THE ARCHITECTURAL REPRESENTATION PROCESS WITHIN THE COMPUTATIONAL DESIGN ENVIRONMENT

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

BY

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

JANUARY 2006

Approval of the Graduate School of Applied and Natural Sciences

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ABSTRACT

AN ASSESSMENT OF THE ARCHITECTURAL REPRESENTATION PROCESS WITHIN THE COMPUTATIONAL DESIGN ENVIRONMENT

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January 2006, 112 pages

With the introduction of a computational design environment, architectural design and representation processes witness a radical transition from the analog to the digital medium, that may be asserted to initiate a paradigm shift affecting both. In this new design environment, extending the instrumentality of computer-aided processes to the generative use of computational tools and procedures, architectural design and representation processes are subject to mutual alterations, challenged with computational design strategies such as parametric design, associative geometry, generative diagrams, scripting and algorithmic procedures.

Computational design approaches proceed with the definition of a mathematical model based on the numeric definition of relations and equations, substituting the conventional visual/orthographic representation. This thesis aims to inquire the outcomes of assuming non-visual/numeric representation as a strategy in the therefore redefined process of architectural representation.

Through the generative logic embedded in the mathematical model, attention shifts from form to process. This emphasis on process rather than the formal outcome, aids the experimentation of a desired indeterminacy, coming forth in dynamic, non-linear design processes, blurring the boundaries between different phases of design, and of representation. The intentional search for a generative design process liberated from the visual/formal determinism of the conventional design approach, initiates a conscious delay in the definition of form, and thus of visual representation. The thesis discusses the potentials presented by generative mathematical models defined with the aid of computational design tools, and the ways in which they alter and inform architectural design and representation.

Keywords: Architectural representation, computational design, orthographic set, numeric set, mathematical model.

ÖZ

MİMARİ TEMSİL SÜRECİNİN SAYISAL TASARIM ORTAMINDA BİR DEĞERLENDİRMESİ

Uçar, Başak
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Tez Yöneticisi: Doç. Dr. Zeynep Mennan

Ocak 2006, 112 sayfa

Sayısal tasarım ortamına geçiş ile birlikte, analogdan sayısala doğru bir paradigma değişimi, gerek mimari tasarım, gerekse mimari temsil süreçlerini etkilemektedir. Bilgisayar destekli süreçlerin araçsallığını sayısal araç ve yöntemlerin üretken kullanımına genişleten bu yeni tasarım ortamında, mimari tasarım ve temsil süreçleri, parametrik tasarım, yeni geometriler, üretken diyagramlar ve algoritmik yöntem ve yazılımların desteklediği karşılıklı dönüşümler geçirmektedir.

Sayısal tasarım yaklaşımları, konvansiyonel görsel/ortografik temsilin yerine geçen, ve ilişkilerin sayısal tanımlarına dayanan matematiksel bir model tanımlarlar. Bu tez görsel olmayan/sayısal temsilin bir strateji olarak kabulünü, ve böylelikle yeniden tanımlanan mimari temsil sürecinin çıkarımlarını sorgulamayı amaçlamaktadır.

Matematiksel modelin içerdiği üretken mantık dolayısıyla, dikkat biçimden sürece kaymaktadır. Dinamik ve doğrusal olmayan tasarım süreçlerinde ortaya çıkan bu vurgu, biçimsel belirleyicilikten uzaklaştırıp, belirsizliğin deneyimlenmesine yardımcı olurken, tasarım ve temsilin farklı aşamaları arasındaki sınırları da bulanıklaştırmaktadır. Konvansiyonel tasarım yaklaşımlarındaki görsel/biçimsel belirleyicilikten hafifleyen üretken bir tasarım süreci, istemli olarak biçimsel tanımı,

ve dolayısıyla görsel temsili ertelemektedir. Bu tez, sayısal tasarım araçlarının yardımı ile tanımlanan üretken matematiksel modellerin mimari tasarım ve temsil süreçlerine getirdiği olanak ve değişimleri tartışmaktadır.

Anahtar sözcükler: Mimari temsil, sayısal tasarım, ortografik set, sayısal set, matematiksel model.

ACKNOWLEDGMENTS

I would like to express sincere appreciation to my thesis supervisor Assoc. Prof. Dr. Zeynep Mennan for her guidance, stimulating suggestions and contributions throughout this study.

I am thankful to my jury members Assoc. Prof. Dr. Ayşen Savaş, Asst. Prof. Dr. Mine Özkar, Inst. Dr. Namık Günay Erkal, and Inst. Refik Toksöz for their valuable critics and inspiring comments.

I offer sincere thanks to my family for their support and encouragement at all aspects of life. My gratitude can never be enough.

I am also grateful to all my friends for their continuous support and criticisms at all times. I want to express my special thanks to Tuba Çıngı and Güney Çıngı, who always shared my excitements and enthusiasm.

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INTRODUCTION

The changes brought about at the end of the 20th century with the beginning of the *information age* can be asserted to have led to a social and cultural revolution, where the widespread use of computers has resulted in radical shifts in many disciplines.[1] The telecommunication technology that facilitates the transfer and use of data is also fascinating the practice of architectural design. Peter Zellner, associating the paradigm shifts in architecture with the developments in technology, states that;

> At the close of our century, it is the information revolution that is metamorphosing architecture and urban design. Digital technologies are transforming the nature and the intent of architectural thinking and creativity, blurring the relationships between matter and data, between the real and the virtual and between the organic and the inorganic and leading us into an unstable territory from which rich, innovative forms are emerging.[2]

Changes in the formation, modification as well as the transformation of data, are seen to directly or indirectly affect architectural design practices because of the latter's close relation with other disciplines. The use of computational design tools and strategies in architectural design processes, which are already practiced in industries such as automotive, aerospace and shipbuilding, is defined by Branko Kolarevic as inheriting the potential of generativity, and thus extending the formal

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[1] Kolarevic, Branko. "Designing and Manufacturing Architecture in the Digital Age," Laboratorio TIPUS, http://www.tipus.uniroma3.it/Master/lezioni/AID/ Branko.html. Last accessed in November 2005.

[2] Zellner, Peter. *Hybrid Space: New Forms in Digital Architecture*. New York: Rizzoli, 1999, p.9.

and material boundaries of architectural design.[3] Consequently, the changes defined with the use of computers and other computational design tools challenges not only the architectural design process or its manufacturing, but also the architectural representation process.

The advantages provided with the use of computers and computational design tools in the architectural design practice have gone beyond facilitating communication, drafting or visualizing, to define a departure from the conventional architectural design and representation processes. Designers have introduced new design strategies that would respond to these emerging changes and open up new grounds for the exploration of transformations. Hence, the architectural design and representation processes have been redefined in order to take full advantage of the potentials offered through computational design strategies and tools, where the aim was to define the conceptual and perceptual paradigm shifts subsequent to these changes.[4]

Within this new paradigm, computational design tools are not used as mere drafting and visualizing tools for the representation of design ideas but as generative devices defining the whole process, from the conceptualization of design ideas, to their development, representation and manufacture.[5] This also marks the importance and significance of responding to the representational challenges offered with the introduction of new computational design strategies. Therefore, the role of architectural representation in a computational design process differs from the representations produced through conventional means or

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[3] Kolarevic, Branko. "Digital Praxis: From Digital to Material,"
ERA Group, era21, http://www.erag.cz/era21/index.asp?page_id=98.
Last accessed in November 2005.

[4] Kolarevic, Branko. "Towards Non-Linearity and Indeterminacy in Design." *Cognition and Computation in Digital Design.*
The University of Sydney Faculty of Architecture, Design Computing Cognition'04, http://www.arch.usyd.edu.au/ kcdc/conferences/dcc04/workshops/workshopnotes6.pdf.
Last accessed in November 2005.

[5] Ibid.

computer-aided design techniques, redefined as a participant in all phases of the design process.

On the other hand, the changes outlined in the architectural design process as well as the representation process, also enable to work on complex situations and forms, since the technological advances and tools introduced have eased to define and calculate situations once complex for the designer.[6] Equipped with the computational design tools, the designer can execute both qualitative and quantitative researches on the definition of complex forms where s/he can also manipulate them easily. It is because design ideas can be expressed through layers of information that can be manipulated by the software used, that the designer can work on complex forms and explores the possibilities of using the computer as a generative device.

The consequence is that computational design strategies and tools have opened up the possibility for computation-based processes of form-generation, transformation and representation. Within this new realm, complex curvilinear forms are represented with the same ease as platonic solids or other cylindrical, spherical or conical forms used in many computer-aided design programs (i.e. AutoCAD, Maya, 3dsMax).[7] The complex curvilinear forms, which were once difficult to envision, modify and represent, can also be manufactured easily, since it is a same data structure that drives the production processes based on computational models. Computer numerically controlled (CNC) production processes enable the direct translation of data from the design process to the manufacturing process. As a consequence, different phases of design and manufacturing processes begin to overlap, leading to the dissolution of boundaries between phases.

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[6] Sevaldson, Birger. “Computer Aided Design Techniques,”
Oslo School of Architecture and Design, http://www.aho.no/staff/bs/phd/Computer%20aided%20design%20techniques.pdf.
Last accessed in November 2005.

[7] Kolarevic, Branko. “Digital Praxis: From Digital to Material.”

Since it is the definition process that assists the generation of each phase of design and manufacturing, in computational design approaches, attention is placed more on the definition of process rather than form. Through the identification of relations, constraints or rules of the model, a generative structure is defined that can be subjected to modifications by altering the constituents embedded within the model.[8] Therefore, the relations enabling the articulation of an internal generative logic, embedded within the computational model, extend the potentialities of computational design approaches, besides that of formal expressions.[9]

The alteration of reciprocal relations between interdependent entities constituting a model is defined by Branko Kolarevic, as structuring and organizing principles in computational design processes. Kolarevic highlights the concept of topology and states that:

> Instead of modeling an external form, designers articulate an internal generative logic, which then produces, in an automatic fashion, a range of possibilities from which the designer could choose an appropriate formal proposition for further development. The emphasis shifts away from particular forms of expression (*geometry*) to relations (*topology*) that exist between and within the proposed program and an existing site. These interdependences then become the structuring, organizing principle for the generation and transformation of form.[10]

Topological studies are thus challenged with the introduction of computational design tools, which enable the continuous transformations by way of altering the relations defined. Featured by the advantages provided with the software

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[8] Kolarevic, Branko. "Towards Non-Linearity and Indeterminacy in Design." *Cognition and Computation in Digital Design.*

[9] Ibid

[10] Kolarevic, Branko. "Digital Morphogenesis." *Architecture in the Digital Age: Design and Manufacturing.* Ed. Branko Kolarevic. London and New York: Spon Press, 2003. pg. 13.

introduced, Kolarevic identifies the new paradigm as taking part in defining the departure from the Euclidean geometry of discrete volumes represented in Cartesian space.[11] He associates this departure with the common use of topological or “rubber-sheet” geometry studies in design processes, where the computational design tools ease the definition and modification of continuous curvilinear surfaces.[12] However, the common use of topological studies in design processes is also a consequence of radical shifts in mathematics and geometry.

For centuries, the architectural design practice has been taking Euclidean geometry as the basis for the conception and expression of design ideas. This geometry consisted of five basic postulates defined by Euclid. Despite the common acknowledgement of the first four postulates, the fifth postulate of “parallelism” was considered as controversial, initiating studies on Non-Euclidean geometries.[13] Significant studies were the Lobachevskian-Bolyai geometry formulated in the 19th century, followed by “Riemannian geometry”, studying surfaces or spaces with variable curvature.[14]

On the other hand, Albert Einstein’s “*Theory of Relativity*,” referring to non-Euclidean geometry, rendered the invalidity of the concept of in-deformability associated with Euclidean conjecture, through confirming the changes in the shape and properties of a figure when it is moved.[15] The considerable interest in new geometries, together with Einstein’s *“Theory of Relativity,”* altered the conceptions about space and perception, since the three-dimensional space configuration of Cartesian space has now extended to a fourth dimension, as a

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[11] Ibid.

[12] Ibid.

[13] Henderson, Linda Dalrymple. *The Fourth Dimension and Non-Euclidean Geometry in Modern Art.* Princeton, NJ: Princeton University Press, 1983, p.5.

[14] Ibid.

[15] Ibid.

consequence of which interactions between space and time gained great importance.[16]

Opening up new possibilities for the conception of space, the changes in mathematics, geometry and even physics can thus be claimed to have defined a radical shift from an architectural point of view. Referring to the changes in mathematics and geometry as providing a radically different conceptualization of space, Branko Kolarevic affirms that; "*An architecture of warped multidimensional space would move beyond the mere manipulation of shapes and forms into the realm of events, influences and relationships of multiple dimensions.*" [17]

Architectural design practice, altered in the light of developments in mathematics and geometry, was redefined once more with the introduction of computational design strategies and tools. The strategies used in computational design approaches such as parametric design, associative geometry, diagrammatic abstraction, algorithmic procedures and scripting, are all intended to define the desired complexity and generativity of the process, marking the departure from conventional architectural design approaches. These strategies, influenced from progresses in mathematics and geometry, depend highly on parameters and relations which define the model. Drawing attention to changes in form-making processes, Kolarevic states that:

> In a radical departure from centuries old traditions and norms of architectural design, digitally-generated forms are not designed or drawn as the conventional understanding of these terms would have it, but they are calculated by the chosen generative computational method.[18]

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[16] Ibid.

[17] Kolarevic, Branko. "Digital Morphogenesis." *Architecture in the Digital Age: Design and Manufacturing.* pg. 15.

[18] Kolarevic, Branko. "Towards Non-Linearity and Indeterminacy in Design." *Cognition and Computation in Digital Design.*

It is less form than relations and principles structuring the model defined in computational design strategies, that enable the continuous fusion of data, their simultaneous assimilation as well as their easy modifications.[19] The parametric design approach based on relations and equations, calls for the definition of a responsive and flexible model, where it is possible to define infinite solutions through altering the parameters and the equations.[20] Since in parametric design approaches, the parametric model defined can also be transferred directly to the manufacturing phase, infinite number of unique objects can be manufactured easily, which are defined by Bernard Cache as "mathematically coherent but differentiated objects"[21], in other words, "non standard" objects.[22]

Moreover, the definition of a flexible and responsive model based on associative geometry, where all elements are geometrically dependent on each other through the relations defined, also facilitates the practice of parametric design in the re-structured process.[23] Through assigning different values to the parameters defined, various outcomes can be defined, where attention is placed on relations. Another practice in parametric design approaches is that of algorithmic procedures, where the mathematical procedures are defined through the codes scripted in several steps, either by the computer program itself or by the designer. The model defined by algorithmic procedures can be controlled or redefined by altering the relations or operation sets defined by the codes.[24]

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[19] Kolarevic, Branko. "Digital Morphogenesis." *Architecture in the Digital Age: Design and Manufacturing*. pg. 17.

[20] Ibid.

[21] Cache, Bernard. *Earth Moves: The Furnishing of Territories.* Trans. Anne Boyman. Cambridge, Mass.: MIT Press, 1995.

[22] Migayrou, Fréderic and Zeynep Mennan, eds. *Architectures Non Standard*. Paris: Editions du Centre Pompidou, 2003.

[23] Burry, Mark. "Paramorph: Anti-accident methodologies." *AD: Hypersurface Architecture II.* Academy Editions: London, Vol. 69, no. 9-10, 1999. pp. 78.

[24] Kolarevic, Branko. "Digital Morphogenesis." *Architecture in the Digital Age: Design and Manufacturing.*

As a consequence of these changes, the architectural representation process can be asserted to reformulate itself in order to actively participate in a dynamic design process, enabled with the computational design strategies and tools. This marks the amendment of conventional architectural design processes, based on an orthographic set of drawings, with the numeric set that responds to the application of computational design tools. Alexander Koutamanis draws attention to the changes in the architectural representation process and states that:

> The transition from analogue to digital visualization poses questions that encompass the traditional investigation of relationships between geometric representations and built form, as well as issues such as a unified theory of architectural representation, the relationships between analysis and visualization and the role of abstraction in the structure of a representation.[25]

Hence, the role of representation as a strategy and a catalyst of the design process is interrogated within the computational design media, with a new emphasis on associative geometry, parametric design, and algorithmic procedures in design. The questioning of the ways in which new definitions of architectural representation affect the designer/user interface, as well as alter formalistic approaches relative to the altered architectural design process, seem to be of great importance.

The new design environment introduced thus enables and promotes the use of a same parametric model, that is based on relations and parameters defined by a numerical set, throughout the whole design and manufacturing processes, since it is equally responsive to every phase in the process. Through the application of computational tools, design ideas and their possible outcomes are represented non-visually, but numerically, within a set of parameters defined. Accordingly, the visual representation of design ideas is consciously delayed to define a flexible

[25] Koutamanis, Alexander. "Digital Architectural Visualisation," Vienna University of Technology, http://info.tuwien.ac.at/ecaade/proc/koutam/koutam1.htm. Last accessed in December 2004.

and non-linear design process, freed from the visual constraints. Therefore, the thesis shall analyze the substitution of visual representation in the conventional design approach with the non-visual numerical representation in computational design approach.

Apart from parametric design tools, the diagrammatic practices based on Gilles Deleuze's ideas on 'abstract machines', also support the liberation of design ideas from formal and visual constraints, and promote again the conscious delay of representation phases during the design process. However, influenced by the shifts in the new design environment defined through the introduction of computational design tools, diagrammatic practices also witness radical transformations. This thesis scrutinizes the changes in the definition of diagrams, their active role in the generation of design ideas, and their progression during the design process, as well as the ways in which they contribute to the delay of visual representation.

Considering the altered relationships between design and representation in visual, verbal, or numerical terms, one can note that the architectural design process, in its efforts to adapt to dynamic, non-deterministic processes, confronts the determinism of conventional architectural representation. These changes can be seen to have also defined fundamental changes in architectural representation processes, dislocating the well-established conventions about architectural representation. Therefore, architectural representation is recasting itself so that it actively participates in the conception of design ideas, their evolution through the design process and their manufacturing. Throughout this evolution, architectural representation processes have begun to aid the definition of an experimental design process, where new geometries, outside of the conventional Cartesian Coordinate system, are being investigated.

On the other hand, the conscious delay of visual representation, and the possible affiliation of this delay with computational design strategies and tools, are considered to pose a perceptual challenge to architectural design processes: Following Zeynep Mennan's discussion of visualization delays as "producing a perceptual deception and disorientation" in quantitative, computational design experiments, "subjecting phenomena to a numerical regime of interpretation, displacing and extending perceptual gestalt qualities to new and unfamiliar kinds of inscriptions"[26], this thesis searches for possible challenges of delaying visual representation in computational design approaches.

This thesis is an inquiry into the redefinition of digital/computational representation tools and processes, researching the ways in which they alter the architectural representation process. It investigates the transition from analogue to digital, or from orthographic to numeric representation, in order to study the effects of this transition on the changing relations between architectural representation and design processes, and the premises of such ubiquitous representation.

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[26] Mennan, Zeynep. "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.

CHAPTER 2

THE NEW DESIGN ENVIRONMENT OF COMPUTATION

2.1 Redefinition of the Architectural Representation Process within the New Design Environment

Architectural representation, not only as the definition of design ideas and depiction of architectural solutions, but also as a language using verbal, visual, and numerical means of expression, has always been a descriptive medium for designers. Delineated commonly in visual and verbal means, one's interaction with the environment initiates the representation of situations and experiences, to better understand, control and communicate. [1] Using art, literature, science, mathematics, or even cinema as tools of abstraction, it is possible to represent interactions, perceptions or thoughts.

Drawing and writing, dating back to 725 B.C., are considered as the earliest modes of architectural representation, which support and enhance the interpretation of design ideas and their legitimization.[2] Moreover, architectural drawings are said to guide and generate the architectural design process when considered as a medium of thought, rather than a simple medium of expression.[3] In this sense, architectural drawings always had a significant role in the embodiment of design ideas and in the critical relation between thought and expression.

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[1] Hewitt, Mark. "Representational Forms and Modes of Conception: An Approach to the History of Architectural Drawing." *Journal of Architectural Education. No:* 39 /2, 1985. p.2.

[2] Ibid.

[3] Ibid. pp.2-9.

The significance of drawing in architectural design is underlined by Anthony Vidler referring to Durand's words:

> Drawing serves to render account of ideas, whether one studies architecture or whether one composes projects for buildings, it serves to fix ideas, in such a way that one can examine a new at one's leisure, correct them if necessary; it serves, finally to communicate them afterwards, whether to clients, or different contractors who collaborate in the execution of buildings: one understands, after this, how important it is to familiarize oneself with it [drawing].[4]

Therefore, architectural drawings can be regarded as assisting the construction of a common medium for the expression of ideas and communication with other disciplines. Along with that, Vidler defines drawing as the natural language of architecture rather than a mere medium of expression in harmony with the ideas it represents.[5]

Hewitt notes that the discovery of scientific linear perspective construction by Brunelleschi in about 1425, assembled by Alberti in his work titled *Della Pittura*, influenced the Renaissance architects extensively.[6] As a consequence of perspective studies in the fifteenth century, the use of section perspective drawings are said to replace the orthogonal section drawings to depict the building interiors.[7] After the discovery of the linear perspective in the fifteenth century, there has been a fascination with the axonometric drawing, which had an intense

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[4] Durand cited in, Vidler, Anthony. " Diagrams of Diagrams: Architectural Abstraction and Modern Representation." *Representations.* University of California Press No.72, Fall 2000.pp 1-19

[5] Vidler, Anthony. " Diagrams of Diagrams: Architectural Abstraction and Modern Representation." pp 1-19

[6] Hewitt, Mark. "Representational Forms and Modes of Conception: An Approach to the History of Architectural Drawing." pp.2-9.

Also see Damisch, Hubert. *The Origin of Perspective*. Trans. John Goodman. Cambridge, Mass.: MIT Press, 1994.

[7] Ibid

impact in the twentieth century.[8] The use of orthographic drawing in architectural representation, altered by the expressive studies of Filippo Brunelleschi on perspective, and the introduction of axonometric drawing in Modernism, witnesses now another radical shift with the recent developments in technology, mathematics and architectural design processes. Non-Euclidean studies in mathematics, the introduction of computer-aided design and manufacturing tools, together with computational design approaches such as parametric design, associative geometry, algorithmic procedures and scripting, imposed not only a change from the analog to the digital medium, but also a change in the definition of the architectural representation process.

Therefore, digital representation tools and processes, (re)defined through these developments, are transforming and reforming the conventional architectural representation process. Raised parallel to the dynamic and responsive character of the current and near-term life-styles, architectural representation also witnesses a transformation from a static relationship between idea and image, towards a more dynamic process.[9] With a tendency to deal more with process rather than form, the altered architectural design process is numerically hosting this process in all phases of design and consciously delays its visualization.

Depending on the computational design strategies, a mathematical model of the design concept can be defined, which also inherits its representation in numeric definitions. This enables to work on a dynamic model receptive to evolution, which leads to a non-linear and open-ended design process released from the determinants of conventional design approaches, a model which will be discussed in the following chapter. [10] However, it is not only the architectural design and representation processes that are affected by technological developments, but also

[8] Ibid.

[9] Mitchell , William J.. *City of Bits: Space, Place, and the Infobahn.* Cambridge, Mass.: MIT Press, 1995, p.4.

[10] Kolarevic, Branko. "Towards Non-Linearity and Indeterminacy in Design."

the vocabulary that is scripted and generated through the computer, which revokes the visual representation of design ideas.

These changes in the architectural representation process call for a re-evaluation of the mode and the role of abstraction in design, together with a re-assessment of the altered mission of the designer. Therefore, it may be argued that, the use of digital media in architectural design in the last decades initiates a paradigm shift in architecture, where the determinism of conventional architectural representation is adapting to dynamic, non-deterministic processes tracing this shifted definition of the design process.

2.2 Cross-Fertilization of Mathematics, Geometry, and Computational Design

Within the context of computational design, the interaction of digital design and representation tools with other disciplines opens up new experiences and uses for the designer. Mathematics and geometry are actively used as mechanisms to guide and define both the conventional and computational architectural design processes. Mathematics enable the designer to abstract and simplify complex situations and forms, besides giving the opportunity to control them. Partitioning into grids, or defining through coordinates, is one of the chief techniques used to control and define the situations. Defined as means of measure and appropriation of space, grids serve as investigative tools for architecture and mathematics, as well as many other disciplines such as urban design or physics.[11] Daniela Bertol describes the use of grids as an interpretation of space through a relational framework, where she asserts that, defining a geometrical object through grids or with reference to coordinates, "*allows one to reduce abstract, continuous geometrical objects to discrete, numerable elements*."[12] Hence, using a coordinate system may be claimed to enable the abstraction and representation of geometrical

[11] Bertol, Daniela. "Architecture of images: An Investigation of Architectural Representations and the Visual Perception of Three Dimensional Space," *Leonardo. No:* 29/2, 1996, p.90.

[12] Ibid.

objects. Additionally, the computer-aided design software used for architectural design and visualization, such as AutoCAD, 3DsMax, MAYA, Rhinoceros, Photoshop, CorelDraw, are known to be based mainly on the Cartesian coordinate system.[13]

Despite this strict reliance on the Cartesian reference system -the grid-, such software is seen to enable the (re)modeling of relations and definition of complex situations compelling the limits of geometric expression. Working through parametric CAD software, that takes the advantage of developments in mathematics, geometry and computation, enables to define variations, deformations and topological transformations, besides controlling and reformulating relations.[14]

2.2.1 Mathematical and Geometrical Paradigm Shift

Mathematics and architecture, representing a close relation that has been constantly re-assessed since the early periods, with reference to developments and inventions in the field of mathematics, science and philosophy, may now be asserted to witness another shift with the integration of computational design tools to the architectural design process. It is not only that one is informed by the other, but also that they sometimes share the same grounds for research and theory. Of the branches of mathematics, geometry, representing the pragmatic value and the canonical relation between space and perception, may be considered to play a vital role in architecture.[15]

[13] Cache, Bernard. "Plea for Euclid,"
Objectile, http://www.objectile.net.
Last accessed in October 2005.

Also see http://www.autodesk.com, http://www.autodesk.com/3dsmax, http://www.maya.com, http:// www.rhino3d.com, http://www.adobe.com, http://www.corel.com for further information about the programs.

[14] Ibid.

[15] Evans, Robin. *The Projective Cast: Architecture and Its Three Geometries.* Cambridge, Mass.: The MIT Press, 1995.

Moreover, geometry and mathematics, besides encompassing a significant role in the theoretical foundations of perception, philosophy, science and architecture, also inform the representation processes. Studies in constructive mathematics, especially the non-standard analysis, highlight a significant change and indicate a more experimental, quasi-empirical phase for mathematics.[16] Mennan notes that the fascination with new geometries and the advent of Einstein's *"Theory of Relativity"* opened new conceptions of space and perception: Studies on non-Euclidean geometry and the geometry of n-dimensions, with their claims of the possibility of exceeding three dimensions and defining surfaces with variable curvature, altered the representations of space and objects. [17] The dominance of linear perspective since the Renaissance was challenged by new geometrical studies on curved space.[18] Therefore, by the end of the 19th century, there were already revolutionary studies aiming to respond to the deformations in the shape and properties of an object when subjected to movement or transformation.[19] These revolutionary studies aiming to conclude in an innovative system, resulted in the alteration of the means and tools of representation, altered once more with the introduction of CAD and computational design approaches, revealing a shift in the role of geometry and mathematics.

It was Euclid's theorems and axioms that directed geometrical, philosophical and perceptual studies until the 19th century, when searches for a new system have flourished.[20] Although Euclidean geometry was the only recognized geometrical system until the 19th century, there have always been counter-arguments concerning Euclid's postulates, especially the *Postulate V*. Early in that century, studies dealing with some theorems of Euclidean geometry and conflicting some

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[16] Mennan, Zeynep. "Des Formes Non Standard: Un 'Gestalt Switch'." ("Of Non Standard Forms: A 'Gestalt Switch"), *Architectures Non Standard*. Ed. Fréderic, Migayrou, and Zeynep Mennan. Paris: Editions du Centre Pompidou, 2003. pp.34-41.

[17] Ibid.

[18] Henderson, Linda Dalrymple. *The Fourth Dimension and Non-Euclidean Geometry in Modern Art.*

[19] Ibid.

[20] Cache, Bernard. "Plea for Euclid."

of its basic assumptions about parallelism, led to the definition of a new geometrical system, the non-Euclidean geometry.[21] These oppositions represented nothing less than a radical change in mathematics, one which may not be considered solely as a shift in mathematics, but also one in the conception and perception of space.

Prior to such a shift, with the belief in a finite universe, the Euclidean system was taken for granted and appreciated in theoretical and scientific works.[22] However, studies on non-Euclidean geometry and the geometry of n-dimensions were popularized in the early 20th century. Studies on the perception of space as infinite and non-Euclidean boosted with the revolutionary works of Bernhard Riemann, Karl Friedrich Gauss, Janos Bolyai and Nikolai Ivanovich Lobachevsky.[23] Impression with the idea of n-dimensions, liberation from finite space perception, fascination with the time factor and simultaneity, may all be asserted to have given way to the popularity of non-Euclidean theories. [24]

2.2.1.1 Euclid's Theorems and Euclidean Geometry

Euclidean geometry, described in Euclid's book titled *The Elements*, is the earliest geometric system referred until the 19th century, the time when some counter-arguments began to crystallize.[25] Devised as a system based on five postulates, the Euclidian system was identified in axioms, theorems and assumptions in Euclid's

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

[22] Cache, Bernard. "Plea for Euclid."

[23] Henderson, Linda Dalrymple. *The Fourth Dimension and Non-Euclidean Geometry in Modern Art.*

[24] Ibid.

[25] Heath, Thomas L..*The Thirteen Books of Euclid's Elements (* 2nd ed.). New York: Dover Publications, 1956.

In the *Elements, Euclid* gathers the concepts and theorems structuring the foundation of Greek mathematics. Composed of thirteen books, the *Elements*, includes the theorems and constructions of plane geometry and solid geometry, together with the theory of proportions, incommensurables and commensurables, number theory, and a type of geometrical algebra.

book, in which he dealt with points, lines and planes. In Euclidean geometry, all the theorems are proved using the five postulates that are;

> 1-A straight line may be drawn from any one point to any other point.
> 2- A finite straight line may be produced to any length in a straight line.
> 3-A circle may be described with any centre at any distance from the centre.
> 4-All right angles are equal.
> 5- If a straight line meets two other straight line, so as to make the two interior angles on one side of it together less than two right angles, the other straight lines will meet if produced on that side on which the angles are less than two right angles."[26]

The first four postulates are recognized to be simple and comprehensible. However, the *Postulate V* known as the "parallel postulate" has been accused of being less obvious than the other four.[27] Many mathematicians assumed that it could be driven via the first four postulates and tried to prove it after them.[28] Coxeter notes that "the obscurity of the frustrated works" continued till the 19th century, when these attempts led to elliptic and hyperbolic geometry studies.[29]

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

[27] Manning, Henry Parker. *Non-Euclidean Geometry.* Boston: Ginn & Company, 1901. p.1.

[28] Coxeter, Harold Scott Macdonald. *Non-Euclidean Geometry.*, p.1.

[29] Ibid. p.vii.

Coxeter, summarizes the developments in mathematics until the 19th century and defines the three independent studies affirming self-consistent geometries, which does not aim to satisfy the parallel axiom: they were Janos Bolyai's, Carl Friedrich Gauss's and Nikolai Ivanovich Lobachevskii's studies. Of the geometric studies defined, the name non-Euclidean is used for two special kinds: hyperbolic geometry, in which all the "self-evident" postulates 1-4 are satisfied though postulate 5 is denied, and elliptic geometry, in which the traditional interpretation of Postulate 2 is modified so as to allow the total length of a line to be infinite.

A remarkable application of Euclidean space in architectural representation may be the perspective drawing. The perspective drawings by Filippo Brunelleschi in the Renaissance, were basically dependent on Euclid's studies in optics and geometry: It was the "cone of vision" - the fundamental concept from Euclid's *Optics* - that Brunelleschi adapted to his studies and envisioned as intersected by a plane surface - the "picture-plane".[30] Thus, the studies of Brunelleschi on perspective may be considered as applications of Euclidean and solid geometry, where space is assumed to extend in three dimensions.[31]

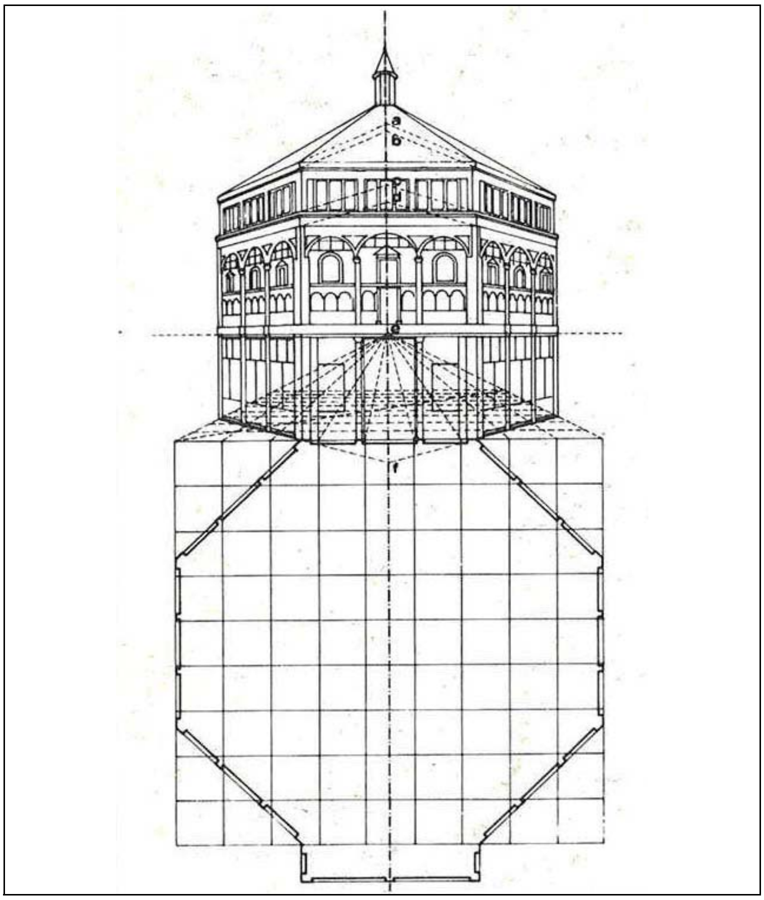

Figure 1: Schematic representation of perspective panel by Brunelleschi

Fanell, Giovanni. *Brunelleschi.* Firenze : Scala Books, 1980.p.6.

[30] Burgin, Victor. "Geometry and Abjection," *AA Files,* No: 15, 1985, pp. 35-41.

[31] Ibid.

Nonetheless, the *Postulate V* of parallel lines kept its controversial situation even in perspective studies. The belief in an infinite universe, influenced especially by Einstein's *"Theory of Relativity,"* where time is introduced as the fourth dimension to better comprehend the universe, altered the relation between geometry and space significantly.[32] Arguments on whether space is curved or not, and the desire to depict the distorted images when viewed from different angles, have then given way to projective geometry.[33] Projective geometry, called "higher geometry," or "geometry of position," or "descriptive geometry", deals with the properties and invariants of geometric figures under projection.[34] Euclidian parallelism can be said to be defeated in projective geometry, where every pair of co-planar lines is defined as a pair of intersecting lines.[35] Therefore, the studies on the Fifth Postulate and the fourth dimension may be asserted to hasten the redefinition of linear perspective drawing relative to the developments in science and mathematics. [36]

The controversy around the Fifth Postulate has led to two significant approaches, both dependent on the first four postulates: The definition of Lobachevskian-Bolyai geometry and of "Riemannian geometry".[37]

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[32] Gans, David. *An Introduction to Non-Euclidean Geometry*. New York: Academic Press, 1973, pp. 193-194.

[33] Coxeter, Harold Scott Macdonald. *Introduction to Geometry.* Washington, D.C.: Mathematical Association of America, 1961.

[34] Cremona, Luigi. *Elements of Projective Geometry.* Oxford: Clarendon Press, 1983, p.5.

[35] Coxeter, Harold Scott Macdonald. *Introduction to Geometry.*, p.230.

[36] Coxeter, Harold Scott Macdonald. *Projective Geometry.* New York: Blaisdell Publishing Co., 1964, p.3.

[37] Henderson, Linda Dalrymple. *The Fourth Dimension and Non-Euclidean Geometry in Modern Art.* p.5.

2.2.1.2 Non-Euclidean Geometries

The possibility of thinking through other geometries opened up new grounds to explore the perception of space and its representation. Non-Euclidean geometries, though differing from the Euclidean geometry in their opposition to the Fifth Postulate, are analogous to each other, and defined as "metric geometries", which means that the line segments and angles may be measured and compared.[38] Of the alternative studies that attempted to prove the contradiction of the Fifth Postulate, the two consistent geometrical studies were the "hyperbolic geometry" of Lobachevsky known as the Lobachevskian-Bolyai geometry, and the "elliptic geometry" by the German mathematician Bernhard Riemann (1826-1866), who based his studies on curvatures using differential geometry to define and calculate curvature. [39]

Russian mathematician Nikolai Ivanovich Lobachevsky (1792-1856), and Hungarian mathematician Janos Bolyai (1802-1860), put forward that "*through a point not lying on a given line one can draw in the plane determined by this point and line at least two lines which do not have a point of intersection with the given line*"; an affirmation in which case the Fifth Postulate looses its validity. [40] In Lobachevskian-Bolyai geometry, the commonly accepted first four postulates are

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[38] Shirokov, Petr Alekseevich. *A Sketch of the Fundamentals of Lobachevskian Geometry*. Groningen, 1964, p.19.

[39] Henderson, Linda Dalrymple. *The Fourth Dimension and Non-Euclidean Geometry in Modern Art.* p.5.

[40] Ibid. p.12.

It should be mentioned that, simultaneously with Lobachevski yet independent of him, the Hungarian mathematician Janos Bolyai (1802-1860) defined similar conceptions with Nikolai Ivanovich Lobachevsky in his work *Appendix scientiam spatii absolute veram exhibens* in 1832. On the other hand, German mathematician Karl Friedrich Gauss (1777-1855) came up with the idea of non-Euclidean geometry earlier than Lobachevsky and Bolyai. Since he never published his ideas, the studies on non-Euclidean geometry are titled as Lobachevskian-Bolyai (or hyperbolic) geometry.

The historical remarks about the non-Euclidean geometry studies are cited from; Borsuk, Karol. Foundations of Geometry: Euclidean and Bolyai-Lobachevskian geometry. Projective Geometry. Amsterdam: North Holland Publication Co., 1960.

satisfied with the exception of the Fifth. This has led to Lobachevsky-Bolyai geometry, a non-Euclidean geometry also known as hyperbolic geometry. [41]

The "elliptic geometry" of Riemann and the "hyperbolic geometry" of Lobachevsky's differ from Euclidean geometry in the *Postulate V*, but both assume the first four postulates as the basis and bifurcate through it.[42] Referring to the *Postulate V* of Euclid's theorems, Riemann puts forward the impossibility of infinite extension of a line in finite space, where he assumes space as unbounded and finite on a spherical surface. [43] Defining lines as circles intersecting at the poles, the spherical geometry ensures that the line is unbounded but still of finite length.[44] Therefore, the parallel lines defined in the Fifth Postulate of Euclid do not exist in Riemannian geometry.

The attempts to define metric geometries gave way to studies on physical space, where the universe is considered referring to the geometric systems used. Moreover, studies on n-dimensions, along with Einstein's *"Theory of Relativity"* guided the four-dimensional perception of universe, instead of a three-dimensional one, where time is now considered as the fourth-dimension.[45] Einstein's "*Theory of Relativity"* that prompted the idea of a fourth-dimension is

[41] Coxeter, Harold Scott Macdonald. *Non-Euclidean Geometry.* pp. 1-11.

[42] Gans, David. *An Introduction to Non-Euclidean Geometry*. pp. 193-194.

Lobachevsky pointed out that "formulae he defined for a triangle that led to a familiar formulae for a spherical triangle when the sides *a. b. c* are replaced with *ia, ib, ic*." Stating that "any inconsistency in the new geometry could be "translated" into an inconsistency in spherical geometry", Lobachevsky established the independence of Euclid's Postulate V.

The information about the Lobachevskian geometry is obtained from; Coxeter, Harold Scott Macdonald. *Non-Euclidean Geometry.* Washington, D.C.: Mathematical Association of America, 1998.

[43] Henderson, Linda Dalrymple. *The Fourth Dimension and Non-Euclidean Geometry in Modern Art.* p.5.

[44] Coxeter, Harold Scott Macdonald. *Introduction to Geometry.* p.230.

[45] Henderson, Linda Dalrymple. *The Fourth Dimension and Non-Euclidean Geometry in Modern Art.* p.xix.

based on the theory that space is curved. [46] In Einstein's theory it is asserted that matter and energy distort space, and these distortions affect the motions of matter and energy.[47] Taking into consideration the statements of the "*Theory of Relativity"* based on non-Euclidean geometry, it may be concluded that it is the Euclidean geometry that failed to represent the curvature of space. [48]

On the other hand, studies on new geometries and the consideration of time as the fourth-dimension are asserted to have fascinated not only mathematics, but also art and photography from the 19th century onwards.[49] Henri Poincaré, with his definitive statements, was responsible for the "popularization of non-Euclidean geometry" in Paris during the first decade of 20th century.[50] The introduction of the time factor, and of photography, enabled to capture simultaneous movements, which stood for the liberation from the static notion of representation. The developments in mathematics, geometry and physics stimulate the expression of the fourth dimension and the simultaneity of internal and external movements, where motion is regarded as the generator of vision and insight into the ideas.[51] The impressive studies of Etienne Jules Marey, Laszlo Moholy-Nagy and Gyorgy Kepes, attempting to introduce movement and dynamic image of life into action, gave way to artistic works that alter static images. [52]

[46] Born, Max. *Einstein's Theory of Relativity*. Dover Publications, New York, 1965.

[47] Ibid.

[48] Kolarevic, Branko. "Digital Morphogenesis." *Architecture in the Digital Age: Design and Manufacturing.* p.14.

[49] Henderson, Linda Dalrymple. *The Fourth Dimension and Non-Euclidean Geometry in Modern Art.* p.10.

[50] Ibid. p.11.

[51] Kepes, Gyorgy. *The Nature and Art of Motion.* Ed. Gyorgy Kepes. London: Studio Vista Ltd., 1965, p.41.

[52] Moholy-Nagy, László. *The New Vision 1928 Forth Revised Edition 1947 and Abstract of an Artist.* New York: George Wittenborn Inc., 1947, p.6.

For further information about Etienne Jules Marey and his works see Dagognet, François. *Etienne-Jules Marey : A Passion for the Trace.* Cambridge, Mass.: The MIT Press, 1992.

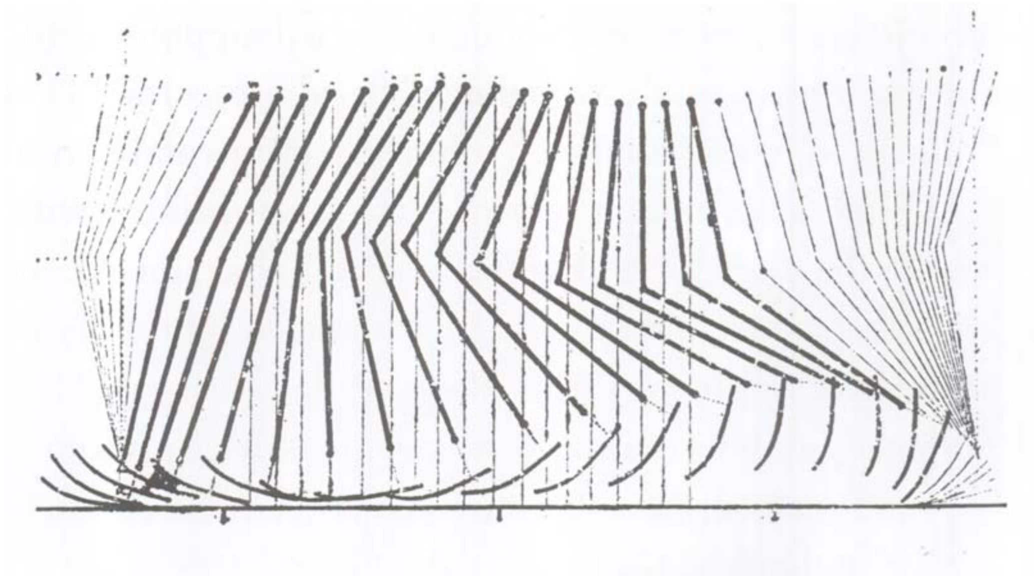

Figure 2: Motion study of human movement by Etienne Jules Marey.

Dagognet, François. *Etienne-Jules Marey : A Passion for the Trace.* Cambridge, Mass.: The MIT Press, 1992.

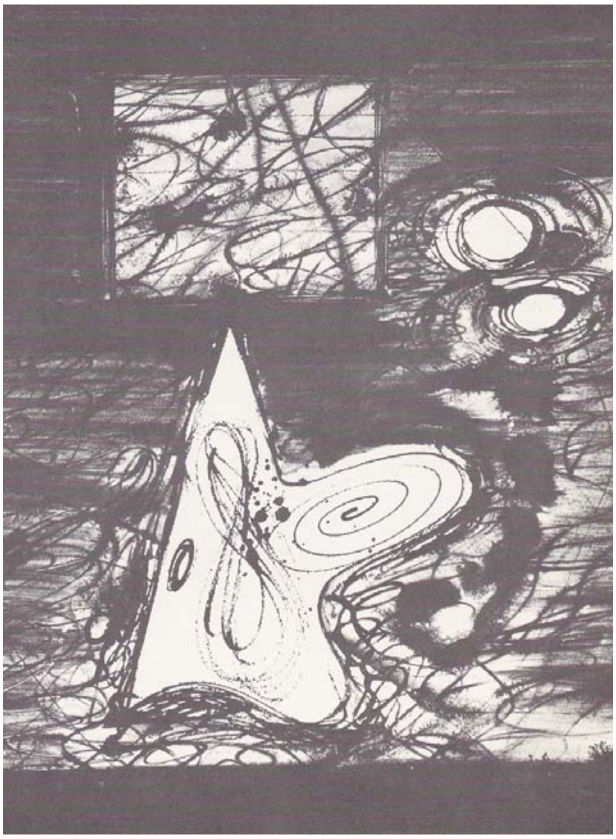

Figure 3: Drawing by Gyorgy Kepes.

Kepes, Gyorgy. *The Nature and Art of Motion.* Ed. Gyorgy Kepes. London: Studio Vista Ltd., 1965, p.5.

2.2.1.3 Cartesian Coordinate System

In mathematics, any point in space, in a plane or on a curve can be expressed through Cartesian coordinates, which enables to describe geometric concepts in terms of numbers.[53] The technique called the 'coordinate method' thus specifies the position of a point through the coordinates (the numbers) of the point. [54]

The invention of the coordinate method is credited to René Descartes (1596-1650) in his dissertation published in 1637, where he describes the coordinate method and its application to the solution of geometric problems. The *Cartesian Coordinate System,* named after Descartes, facilitates the solution and definition of geometric problems, by transcribing them into a coordinate language, where any point in the drawing plane is described with reference to its coordinates.[55]

The use of two or three-dimensional Cartesian Coordinates enables to define the position of a point, line, plane or curve on the coordinate system along x-y-z axis. The grid created through the *Cartesian Coordinate System,* called the *Cartesian grid,* also defines the basis of computer programs. A *Cartesian grid* is generated through the software used in the programs that require a dense flow of information and computation. Since the computer-aided design programs, such as 3DsMax, Rhinoceros, AutoCAD, MAYA, Adobe Photoshop, CorelDraw and Photopaint, all make use of virtual computational grids dependent on the *Cartesian grid,* it may be stated that, most of the computer-aided design programs still depend on Euclidean geometry, despite developments in non-Euclidean geometry.[56]

[53] Gelfand, Izrail Moiseevich. *The Coordinate Method.* New York: Gordon and Breach, 1969, p.xi.

[54] Ibid. p.ix.

[55] Walker, Raymond. *Cartesian and Projective Geometry.* E.Arnold, London, 1953.

[56] Cache, Bernard. "Plea for Euclid."

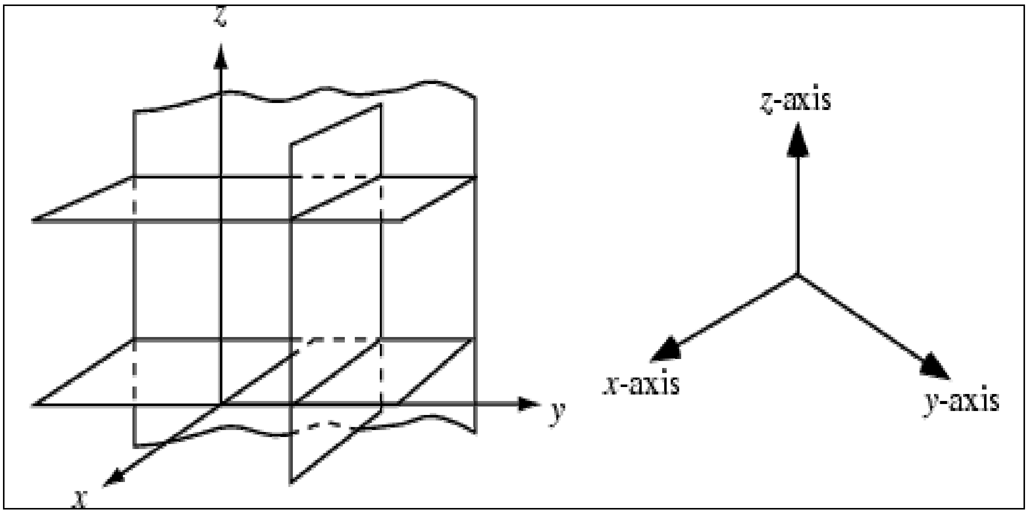

Figure 4: Cartesian Coordinate System defined by René Descartes.

MathWorld, http://mathworld.wolfram.com/CartesianCoordinates.html.
Last accessed in March 2005.

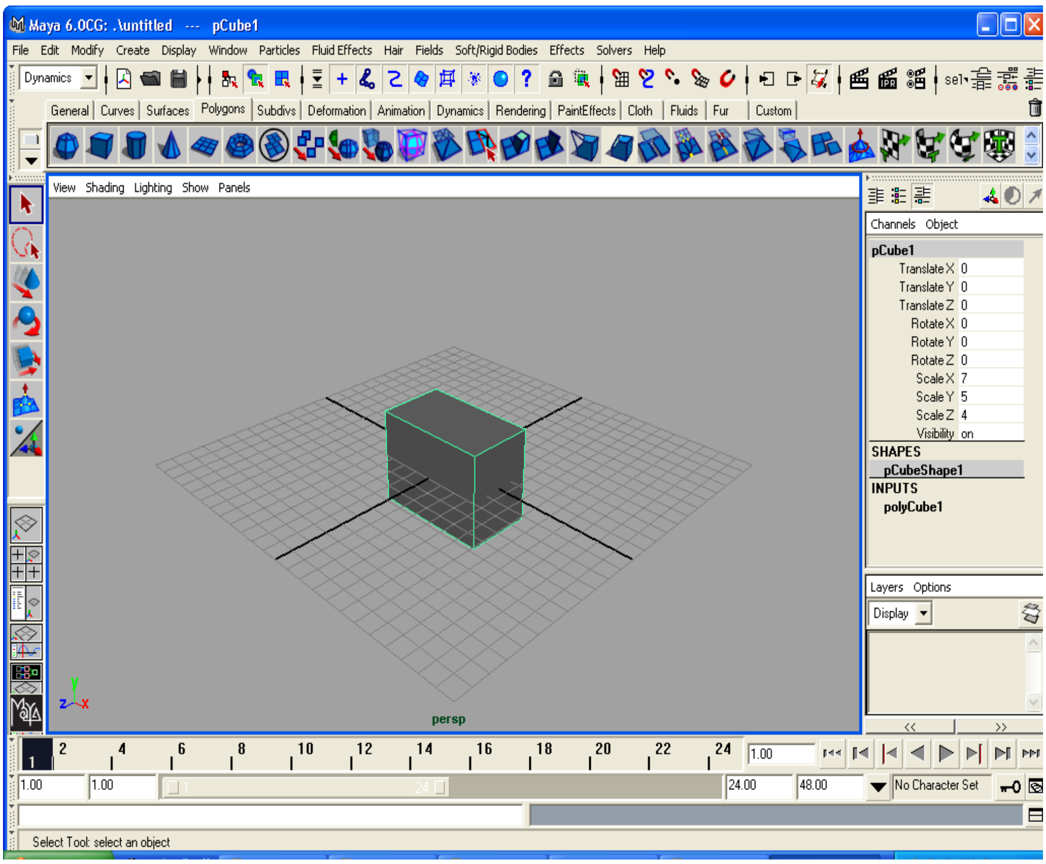

Figure 5: Cartesian Coordinate system in MAYA.

2.2.2 Topology and Architecture

Topology, a branch of mathematics concerned with the preservation of properties under continuous deformation, has had many influences both on mathematics and architecture, especially after the introduction of computational design tools. Although it was the French mathematician Jules Henri Poincaré who first introduced topological studies in his book *Analysis Situs* in 1895, the first official use of the term topology was by Johann Benedict Listing in *Vorstudien zur Topologie* in 1847.[57] Listing, defining topology as the study of unchanged properties under deformation, states that:

> By topology we mean the doctrine of the modal features of objects, or of the laws of connection, of relative position and of succession of points, lines, surfaces, bodies and their parts, or aggregates in space, always without regard to matters of measure or quantity.[58]

Therefore, topological studies concern the transformation of the quantitative properties of geometric forms without affecting their qualitative properties. Defined also as the "geometry of the rubber sheet", a topological transformation simulates the potential transformations of a figure on a rubber sheet.[59] The transformation of the rubber sheet thus includes stretching, curving, folding or twisting, where the relations between the parts of the figure are preserved. However, in order to admit the original form and the transformed one as

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[57] Flegg, H. Graham. *From Geometry to Topology*. New York: Crane, Russak & Co. Inc., 1974, p.170. Flegg analyses the topological studies through historical references from Leibniz, Euler Moebius, Riemann and Poincaré.

For further information on *Analysis Situs* of Jules Henri Poincaré, also see Veblen, Oswald. *Analysis Situs.* New York: American Mathematical Society*, 1931.*

[58] James, I.M.. *History of Topology.* Science B.V., Amsterdam, New York, 1999.

[59] Di Cristina, Guiseppa. "The Topological Tendency in Architecture*."* *Science and Architecture*. Ed. Guiseppa Di Cristina. Wiley Academy, 2001, pp.6-13

topologically equivalent, the continuous transformations should not include cuts and tears.[60]

Bernard Cache, defining topology as "focusing on what is left, order and continuity" states that *"topology enables one to focus on fundamental properties from which our Euclidean intuition is distracted by the metric appearances."* [61] What survives after the topological transformations are the relations between the parts that affect the consequent formal definition. Therefore, through topological transformations, a rectangle can be transformed into a square or even into a triangle after several operations.[62] Bearing in mind that the figures are being transformed from other figures, an ellipse, a triangle and a square, or even a cube, a cylinder and a cone are considered as being topologically equivalent.[63] Accordingly, the ability to work on relations marks the possibility of representing the same topological properties through various geometric definitions.

As studies on mathematics and geometry, topological studies also significantly influence the architectural design process and the conception of design ideas. These studies, especially with the introduction of computational design tools help to define a flexible system in architecture. Owing to the shifted attention from formal definitions to the relations embedded between figures, topological studies provide a conceptual resource for design ideas besides introducing a new technique to operate on the whole design process[64] and the dynamic variation of form.

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[60] Ibid

[61] Cache, Bernard. "Plea for Euclid."

[62] Ibid.

[63] Di Cristina, Guiseppa. "The Topological Tendency in Architecture."

[64] Ibid.

2.2.3 Reflections of Mathematical and Geometrical Paradigm Shifts on Architectural Design and Representation Processes

Since design and representation processes are seen to evolve with mathematics and geometry, the territories of these disciplines can be said to overlap and recast the role and mode of architectural representation. The departure from the *Cartesian grid* and conventional modes of design in the experimentation of form, space and process, announces a new definition of architectural theory and practice. With the advent of an informational age, this revolutionary practice consists of a search for ways of responding to the complex relations defined in and around the design process. The tools used in the computational design approach, such as parametric design, associative geometry, diagrammatic abstraction, parametric and numerical representation, all address a growing complexity and dynamism within the design process. Thus, the new design environment introduced with the new techniques allows the designer to capture and create new relations.

The shift in design strategies introduced by advanced computational design tools, together with transformations and progresses in mathematics, affected not only the computer sciences, but also the so-called conventional means of representing design ideas. These advances have revolutionized the static notions of conventional architectural representation, and replaced the use of paper and pencil with the dynamic use of parameters, equations, and algorithms. Although the consequences of these developments announce a change in the ways design ideas are now represented, geometry continues to orchestrate the evolution of design ideas as well as their representation. Through the advances in computer sciences, the designer is able to explore the potentials of geometry and represent them in two and three-dimensional studies.

In a similar way, the resulting shifts in architectural design, mathematics and geometry have led to new definitions of form-making processes, that rely less on shape than mathematical relations. Topological studies on a flexible model enabled with computational design tools, thus challenge the form-generation processes through continuous transformations. Architectural design process, featured by the topological studies, is defined by Branko Kolarevic as "indicating a radical departure" from the conventional approaches of architectural design since the digitally-generated forms are calculated and transformed by these topological attempts.[65] Based on many computational design concepts such as parametric design, associative geometry, genetic algorithms or animation, the dynamic transformations of topological studies is actively participating in the architectural design process and thus the expression of form.

Along with that, topological studies and computational design concepts represent a mutual relation all through the architectural design process. The designer can define complex forms in continuous transformation only through the topological studies fostered with the computational design tools. On the other hand, the computational design concepts mostly depend on the topological descriptions and transformations of forms. Since specifying the relations between parts is of great importance in computational design approaches, especially in the parametric design approach, topological studies are undertaking a critical role. In computational design approaches, where form is defined parametrically, topological transformations can be carried out through manipulations on the parameters. Therefore, one can easily define a design process based on topological transformations of forms with the aid of computational design tools, which can be seen to be an emergent tendency in architectural design. This tendency is defined by Kolarevic as being a consequence of the dominance over the relations, interconnections or inherent qualities which are internally and externally present within the context of an architectural project. [66]

Topological structures call for design ideas, since their dynamic transformation represents the continuous evolution of form and process dependent on the aspects

[65] Kolarevic, Branko. "Digital Praxis: From Digital to Material."

[66] Kolarevic, Branko. "Digital Morphogenesis." *Architecture in the Digital Age: Design and Manufacturing.* pg. 13.

generating it.[67] Advanced with the computational design tools, these topological structures thus concern the dynamism inherent in the design process and the forms generated. Apart from their fascinating geometries, topological structures, such as the *Möbius strip*[68] and the *Klein bottle*[69], inherit the potential to challenge architectural conception with their conceptual qualities.

Released from formal priorities, topological structures help to define a dynamic architectural design process, where topological relationships gain great importance. It is not form but the interactions which now fascinate the designer. Topological structures foster the development of design ideas depending on relations and interactions, which are facilitated by way of parametric approaches, associative geometries, algorithmic procedures, NURBS, isomorphic polysurfaces, datascapes, and performative architectures.

Parametric design, embedding the definitions of shapes in parameterized representations, has the potential of defining a new approach both in architectural design and in architectural representation. Rather than specifying form through fixed and non-relative definitions, parameters that are relative to each other are being used, so that form inherits not a unique definition but a set of equations open to modifications and redefinitions.[70] Through the parametric model defined,

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[67] Di Cristina, Guiseppa. "The Topological Tendency in Architecture."

[68] The Möbius Strip is named after the German mathematician, August Ferdinand Möbius, who first published the single-sided figure in 1865. It is a two-dimensional surface with only one side which can be simply constructed by connecting two ends of a twisted linear strip. Although, it is a two-dimensional surface with only one side, but it has been constructed in three dimensions. The definition of Möbius Strip is cited form; Coxeter, Harold Scott Macdonald. *Non-Euclidean Geometry.* Washington, D.C.: Mathematical Association of America, 1998.

[69] The Klein bottle is a one-sided closed surface named after Felix Klein. A Klein bottle cannot be constructed in Euclidean space. The Klein bottle is a closed non-orientable surface of Euler characteristic (equal to 0) that has no inside or outside. It is best pictured as a cylinder looped back through itself to join with its other end. However this is not a continuous surface in 3-space as the surface cannot go through itself without a discontinuity. It is possible to construct a Klein bottle in non-Euclidean space. The definition of Klein bottle is cited form; Coxeter, Harold Scott Macdonald. *Non-Euclidean Geometry.* Washington, D.C.: Mathematical Association of America, 1998.

[70] Ibid. p. 17.

the designer becomes equipped to describe complex forms under topological transformations.

Another approach introduced by the proceeding shift is associative geometry, representing a whole set of potential formal variation, consisting of a set of parameters that can be formed into dependence relations.[71] Associative geometry has a repertoire of composite equations and dynamic operations adapting to various relations.[72] Enabling the topological transformations of already defined relations through a parametric model, the associative approach defines a flexible and deformable model that responds to modifications.

Moreover, having the potential of defining algorithms to set up new relations and parameters adjustable to these relations also enables the designer to make topological transformations. The re-defined mode of architectural representation thus inherits the potential to go beyond mere formalistic approaches. Despite these complex computational design and representation tools introduced, Bernard Cache describes computational architectural studies as still depending on the Cartesian coordinate system and Euclidean geometry.[73] Defining the dilemma, Cache states that:

> As far as technical applications are concerned, such as architecture, the digital age is still deeply Euclidean and will probably remain so for all the good reasons we have rehearsed. For instance, as CAD software becomes parametric and variational, designers can start to implement topological deformation into Euclidean metrics, which means that you can now stretch a model, and still maintain control of its metric relations. What will probably happen is that, one day or another, CAD software

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

[72] Cache, Bernard. "Plea for Euclid."

[73] Ibid.

kernels will benefit from the extension of Euclidean space within projective geometry. [74]

Therefore, extra effort is still needed to take advantage of developments in mathematics and geometry via the computational tools introduced. Although dependent mainly on Euclidean geometry, the computational tools and software enable to define a dynamic design process focused on the relations between the parts. Through the model identified, the designer can modify the relations, update them, and define the transformations owing to the network of relations, thus practice a continuous process where the clear distinctions between different phases of design tend to disappear.

2.3 Blurring of the Boundaries Between Different Stages of Design

Dissolutions in the representation process brought about with the definition of new strategies need to be questioned in terms of their restructuring of the design process, besides their experimental value. The challenges offered with technological advances and digital media also bring about the changes in the representation systems used. Through the integration of information in representation, that can be recycled back to data and bits, it has become possible to attain the desired flow of information in the process. Computers and computational design are thus proved to offer new strategies and tools for the representation of information and design ideas.

With the advent of computational design studies, the process may be asserted to have gone beyond being assisted by digital design tools, towards being entirely stimulated by these tools. In a process governed by techniques such as parameterization, animation, morphing, transformation, prototyping, scanning etc., the designer defines the relations to calculate the numerous equations used in these techniques and to make the system react to the changes in equations. In order to generate these new relations, computers and digital design tools are

[74] Ibid.

involved in the design process, from the initial to the final stages, blurring the boundaries between stages. With the dissolution of the strict boundaries between different phases of design and construction, the representational phases tend to overlap, making it difficult to define definite phases of representation. [75]

The database provided makes it possible to maintain the continuity between different stages of design, from concept to realization, indicating the potential of enriching the architectural design process. Definition of ideas through mathematical equations and relations subsumes all numerical and visual information related to design decisions, and provides for a representational short-cut between different stages. Consequently, it seems that both the tools and the entire process of architectural representation need to be (re-)evaluated in the light of recent developments and discussions. On the one hand, there are the confined practices of conventional modes of architectural representation, where it is possible to define representation as a specific phase in the design process, and on the other, there is the newly defined mode of architectural representation that has eroded the entire practice.

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

CHAPTER 3

FROM THE VISUAL TO THE NON-VISUAL IDIOM

Architectural drawings, whether as a product of conventional or computer-aided design processes, provide the necessary abstraction of design ideas and images. As an a-priori, drawings supply the basic communication interface between the designer and the related environments. However, despite studies in science and technology defining new directions for architectural works, the modes of representation are seen to remain somehow constant. Until the influential studies in mathematics and geometry in the 19th century, architectural representation followed the early Renaissance rules and techniques, those that are based mainly on the orthographic set. However, with the new technologies introduced, especially computer technologies, there opened up new directions for architectural representation via digital models, animations, virtual and augmented realities, immersive environments, 3D prints, and so on.

Consequently, the use of computers are regarded as marking a historic step forward in drawing, representation and communication, where there is need for a more accurate definition of methods and procedures. Along with that, the architects had a critical role in tracing the contours of this new design environment. Referring to the altered role of architects relative to the changes brought about by the *information age*, Branko Kolarevic states that;

> Architects, as they have done for centuries, are trying to interpret these changes and find an appropriate expression for an architecture that captures the zeitgeist of the dawn of the

> Information Age, which befits the information revolution and its effects.[1]

Thus, the architectural representation process is acquiring great importance where the designer's objectives confront with the potentials offered by this *information age* to define a proper way of expression of design ideas. It is through the architectural design process altered with the acknowledgement of computational tools that, the designer can find new ways to express, represent, and further manipulate his ideas.

The altered architectural design process, also promotes formal studies, since the computational design tools ease the definition of complex forms with the conceptual and technical basis provided. The desire to depict more complex forms and relations through the medium used makes the design process, as well as the representation process more complicated. Hence, in some cases, the conventional tools and the orthographic set are not efficient enough to respond to this desire.

On the other hand, the use of computers enables to work with more complex relations through mathematical equations and parametric relations. It is through these relations and equations used in the computational design approach that the designer can cope with complex phenomena. Accordingly, the computational design tools functioning as generative and representational devices through a numeric set can be introduced to the process, where there is need for new reference systems to depict the complexity of design ideas and formal studies.

As a consequence of these changes in design processes and tools, the representation process witnesses a radical shift from the conventional orthographic set to the numeric set. The challenging new design environment, with its redefinition of the representation process, no more utilizes computers and computational tools for the transfer, manipulation or printing of already

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[1] Kolarevic, Branko. "Digital Morphogenesis." *Architecture in the Digital Age: Design and Manufacturing*. p. 27.

conceptualized ideas.[2] Instead, the new design environment enables the conception of design ideas, as well as their representation and manufacturing through the very same medium offered by the computational tools.

When the computational tools go beyond being mere instruments for representation to define the whole process, they become the process itself.[3] Governed and directed by computational tools and techniques used, different phases of design process are merged to define a continuous process. Owing to the parametric relations and mathematical equations enabling the continuity between phases, it is possible to define an ever-changing relation between the process and the product.

With the use of computational tools, the parametric and geometric relations of the structured model can be defined, where the emphasis shifts to process rather than the shape. As a consequence of this shift in the architectural design approach, concentration is on the definition of the model rather than its representation. With the acknowledgement of computational design tools structuring the whole process rather than simply assisting it, the designer becomes capable of working with the same numeric set of the model throughout the whole process. As a result, it becomes possible to create a model responsive to changes anytime and anywhere without an extra workload of redrawing or recalculating.

Along with that, in cases where it is possible to use the same medium to conceptualize, calculate and present, one can note that any integrated data is simultaneously assimilated in the relations and numeric representation.[4] Hence, new data can be introduced to the system, or already assimilated data can be modified without any difficulty since all are coded by the same numeric set. The

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[2] Terzidis, Kostas. *Expressive Form: A Conceptual Approach to Computational Design.* London and New York: Spon Press, 2003. p. ix.

[3] Toy, Maggie. "Editorial." *AD: Hypersurface Architecture II.* Academy Editions: London, Vol. 69, no. 9-10, 1999. p 4.

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

defined relations and mathematical equations can absorb the changes, modify the model simultaneously and adapt to the newly defined conditions. The use of a same numeric set throughout the whole process, responding to representation, prototyping and manufacturing phases, enables this process of adaptation.

Since different phases of design now depend on each other and can be dynamically updated subsequent to any modification in the system, the once clear distinctions between different phases of design begin to blur. The adaptable and responsive computational model announces the continuity between different phases of the design process by hosting the conception of design ideas and their assistance through equations and relations. Indeed, the designer defines the files used in manufacturing or representation processes while s/he conceptualizes his/her design ideas and structures the computational model. Moreover, if the files used in the manufacturing phase are modified, all the other files used in other phases will be automatically restructured, including even the concept generation or representation phases. This marks the continuum between different phases of design, enabled with the computational model defined.

On the other hand, characterized by the depiction of relations, data input and data modification, such a continuous process can propose numerous solutions in one model. Instead of multiple representations independent of each other, such a process makes a particular definition of a model, which is open to articulations and modifications through visual or non-visual numeric representations.[5] Therefore, numerous solutions through modifications and redefinitions on the same model can be defined throughout the design process.

In such a process, numeric studies take the attention rather than visual ones, since information is represented non-visually in the relations and their resultants. The relations defined by the numeric set can take action in all phases of design enabling simultaneous representation of any state in a numerical way without any visual concern. The designer responds to these changes in the architectural design

[5] Aish, Robert. “Computer-aided Design Software to Augment the Creation of Form.” p. 97.

process by dealing more with the process rather than its visualization, in other words working without intending visual representation. This leads to the replacement of visual representation in the conventional design approach with the non-visual numeric representation of quantitative thinking in the computational design approach.

Owing to the model defined, the end-product alters simultaneously with data integration and modification within this evolving design process. The computational design process is thus governed by process-based studies making use of relations and equations that aim to define a constant evolving process, where the end product is never finalized.

Although non-visual numeric representations can be visualized whenever needed, the designer intends to delay this urge as much as possible. The delaying of representation phases with the use of informative relations not only gives rise to new experiences but also to experimental studies. By taking the advantage of this delay, the designer acquires the opportunity to generate multiple relations and constantly re-evaluate this open-ended process that is responsive to modifications. Moreover, by delaying the representation process consciously, design ideas can be released from the visual and material constraints that may hinder the generative process.[6] With the importance placed on the delay of representation, the way for a process-based design approach is paved with its flexible, responsive and evolving character that has rendered itself independent from the visual and formal constraints of conventional representation process.

The conscious delay of representation marks a process which is never concluded. This state is defined by Ali Rahim as *"systemic delay"*, defined as; *"By systemic*

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[6] See the architectural design experiment performed in order to unload the mind of visual representations or memes, at Coderel (Computational Design Research Lab), METU, Department of Architecture, Spring term 2005, offered by Zeynep Mennan: Mennan, Zeynep. "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.

delay we mean the temporal interstice of conceptual development between initial idea and its material form." [7] Rahim, defines the interstice between concept and its material form as an opportunity for experimental architects aiming to move beyond the deterministic thought processes with the aid of computational design tools.[8]

3.1 Techniques and Strategies of Non-Visuality

In the new architectural design process defined with the introduction of computational design tools, process is seen to be in constant evolution with data integration and modification. Within the continuous redefinition of the design process it is hard to stabilize a specific phase for representation. Yet when captured, this is the numeric representation of the stabilized phase. This is due to the fact that the project is dealt with the numeric definitions of the relations and equations in order to respond to its constant evolution, marking the shift from visual to numeric representations in architectural design.

The altered mode of architectural representation from the visual to the numeric hosts the representation process in all phases of design. For that reason, the numeric representation of design ideas and formal studies are always concealed within the relations and equations throughout the design process. This leads to the participation of architectural representation in the design process from the beginning to the end. Since it is the same numeric set that defines the concept generation, representation or manufacturing phases, the representation phase participates in the whole process as an agent that provokes its generation. This numeric set used not only helps to decode but also recode design ideas and various relations. Consequently, the architectural representation process, more than being a mere visual and formalistic process, becomes a catalyst for the generation of design ideas, their constant evolution and transformation.

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[7] Rahim, Ali. "Systemic Delay: Breaking the Mold." *AD:Contemporary Processes in Architecture.* Academy Editions: London, Vol. 70, no. 3, 2000. p. 7.

[8] Ibid.

Through the employment of computational design tools and approaches, the designer can take a constructivist stance and challenge conventional design processes with the new strategies introduced. The architectural representation process, being numerically eroded in the continuous design process, can perform as a strategy. The advent of non-visual representation as a strategy in terms of the process itself, and its impacts on the transformation of the conception of design, are seen to derive from architectural discourse's recent and growing concern with non-determinism. The designer, acknowledging the non-visuality of representation as a strategy, structures the model so that it embeds the representation files within the numeric definitions. Hence, s/he departs from the formal and visual determinacy of the conventional design approach.

These redefinitions are triggered especially with the advent of new design approaches such as parametric design, associative geometry and algorithmic procedures. These computational procedures bring about new definitions for architectural representation by enabling their immediate modifications during design development and documentation.[9] This is possible due to the fact that, the whole process is generated via the same numeric definition of relations and equations used in these computational procedures, which can respond to changes by restructuring the model simultaneously. These procedures, whether set on parameters, relations or algorithms, all regard the architectural representation process as being numerically embedded in a design process where visualization has been consciously delayed.

The delay of representation, concentration on the process together with the use of computational design tools, enables further the definition of a non-linear design process where back and forth movements are welcomed. Previous design processes were seen to be mainly dependent on linearity between phases of conception, form generation and representation. Achieving linearity, as a fascination, counterparts the delay in design process where a clear route is aspired

[9] Rotheroe, Kevin. "A Vision for Parametric Design,"
Architecture Week, http://www.architectureweek.com/2002/0710/tools_1-1.html.
Last accessed in May 2005.

from the beginning to the end.[10] Yet the non-linear process that acknowledges all kinds of delay including visual delay, alters the intended linearity and gives way to an operational ground enabling to generate and experiment design ideas.

Along with that, these computational procedures also enable to move backward and forward during the design process, which also counts for the non-visuality of representation. Responding to formal manipulations, data inputs and changes in design decisions, the computational model offered makes possible to work actively on all stages that are relative to each other. This leads to the definition of a non-linear process where the designer can move between different phases of process. It becomes possible to make modifications at any phase of the design process, since all the sub-assemblies related to that phase and their numeric representation will simultaneously respond to these modifications. The use of non-visual numeric representations embedding design decisions and modifications marks a radical departure from the orthographic set of conventional architectural representation.

3.1.1 The Orthographic Set and the Numerical Set in Process Management

Architectural drawings, whether produced manually or by the aid of the computer, provide the required interface for the communication of design ideas.[11] Through the use of a drawing system, a set of graphical conventions are established such as perspective drawings and orthographic sets made up of plan, section and elevation drawings, to access and also to transfer the design ideas. However, marking a radical change, the use of digital tools and the applicability of computer graphics

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[10] Mennan, Zeynep, Kütükçüoğlu, Mehmet and Kerem Yazgan, "Title: Delayed.", *Anytime*. Ed. Cynthia, Davidson. Cambridge, Mass.: The MIT Press, 1999. pp. 70-73.

Achieving a linear route, from the beginning (A) to the end (B) of a work is defined in *Title: Delayed* as an obsession among architects where any point along this route is considered as a delay in relation to point B.

[11] Bermudez, Julio and Klinger, Kevin. "Digital Technology & Architecture,"
The Association for Computer Aided Design in Architecture, http://www.acadia.org/ACADIA_whitepaper.pdf.
Last accessed in October 2005.

to modeling, prototyping and even manufacturing processes, also affect what is drawn, how it is drawn and what it is drawn for.[12] Therefore, the representation set used and the architectural design process can be asserted to influence one another, especially with the introduction of computational design tools.

In the conventional architectural representation process, the drawing is so structured that each line is drawn individually and needs individual alteration in any modification. Moreover, if a single line needs modification, all independently represented parts of the orthographic set, such as the plan, the section or the elevation, may need serious revisions or even need to be redrawn.[13] On the other hand, in a CAD drawing, a set of "graphic primitives" such as lines, rectangles, polygons, and arches, arranged in a two-dimensional coordinate system, are used to abstract design ideas.[14] With the use of these graphic primitives, the geometric model is defined on the computer screen, which is a suitable medium allowing modification. The designer can define the geometric composition in two or three dimensions, on the basis of plan or elevation, where s/he can modify the composition simply by identifying commands such as 'erasing', 'stretching', 'mirroring' or 'rotating'. However, since the components forming the geometric composition are defined independent from each other, the operations alter only the individual component on which it is defined. In order to modify the whole composition, the designer should anticipate these operations and define the geometric composition so that all the components become dependent to each other.

There are also significant differences between a graphics-based CAD system and a more sophisticated mode of CAD system. The software development in computer-aided design, as compared to the sophisticated mode of computational design, seems to have simply mimicked the hardware tools such as pencils,

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[12] Ibid.

[13] Bridges, Alan H.. "Computer-Aided Design or Computers and Design." *Computers in Architecture.* Ed. Francois Penz. Hong Kong: Longman, 1992. pp. 41-52.

[14] Ibid. pp. 41-52.

brushes and sketch pads, whereas, the parametric software results in the automation of traditional tools.[15] Even the geometric models of the CAD approach are based on the primitives used in conventional architectural design such as points, lines, basic geometric shapes or basic surfaces. Hence, the practice may be accused of relying on analog operations, and tutoring with non-associative geometric models of conventional means of architectural design.

However, in a more sophisticated computational design system, relations or identified objects are used, components of which are predefined, rather than the graphic primitives displayed on the graphic screen. For instance, a perspective representation of an object in the CAD approach inherits the rigidity of the perspective drawings of Dürer and Brunelleschi, since it is the replication of the image on the computer screen; however, a CAD model is different from a conventional perspective drawing in the sense that it is not a concluded object, but has an existence of its own.[16] The CAD model, therefore, allows making significant changes in the structure which affects the final perspective representation. However, despite the opportunity of altering the positions of the observer and the observed object in the CAD approach, it may still be charged of not compelling the limits of software use in representation.

Through applying computational design operations, the designer may trigger the process and the image simultaneously and alter the scene only by conserving the basic relations guiding the procedure. The whole process of perspective representation may even be appraised in equations and numerical expressions without the assistance of a visual representation. The structured perspective model is not a 3D composition of primitives, but instead a numerical and relational definition of a condition through the database used.

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[15] Asanowicz, Aleksander. “Computer-Tool vs. Medium,”
Vienna University of Technology, http://info.tuwien.ac.at/ecaade/proc/asan/asanowic.htm.
Last accessed in December 2004.

[16] Bertol, Daniela. “Architecture of images: An Investigation of Architectural Representations and the Visual Perception of Three Dimensional Space,” p. 90.

In such a numerical representation, where each force and component can be expressed numerically, an alternative is introduced to visual and geometric representation. By coding the relations in numerical representation, the designer writes the script of the model, structuring both the design and also the representation process. The resultant model is defined by William Mitchell as being an algebraic definition of operations; "*Technically, the design world models an algebra- a set of things together with operations defined on those things and closed in the set.*"[17] In that case, the designer becomes able to map the different conditions via a catalog of actions defined by these algebraic operations.

On the other hand, translation from an orthographic set to a numerical set requires the assimilation of these algebraic definitions in all phases of the design process. It also implies a shift from visual to non-visual modes of conception. Thinking through new tools of representation such as control parameters and associative relations, allows deciphering how this non-representative process informs the design process. The condition where the computer as a tool becomes the medium for design process is defined by Aleksander Asanowicz as inheriting a potential for being a partner in enhancing the designers' creativity and their communication.[18] Asanowicz states that;

> A tool becomes a medium as it is used for things that were not its original intention. When a tool becomes a medium, it gains immeasurably in potency and in its ability to help for our thinking - and thus to take a role as a partner in enhancing our creativity.[19]

Until recently, the computers were used simply as drafting tools for representation that aid the architectural design process. However, with the advent of

[17] Mitchell , William J.. *The Logic of Architecture: Design, Computation, and Cognition.* Cambridge, Mass.; London : MIT Press, 1990. p. 128.

[18] Asanowicz, Aleksander. "Computer-Tool vs. Medium."

[19] Ibid.

computational design approaches, the computers are taking on the role of functioning as generative devices of the design process, a change which also alters the role of architectural representation. Architectural representation is no more generated a-posteriori, but instead is in constant definition within the design process.

This new ubiquity of representation encompasses orthographic representation towards a new definition of representation as the process itself, and alters its analog character to the digital. Therefore, it seems necessary to work with and define a new set of representation, since conventional analytic representation interfaces such as plan, section and elevation render ineffective in contributing to the complexity of software, or to the dynamics of the paradigm introduced.

The numeric representation of the geometric complexities of new forms transform the notion of architectural representation from the orthographic set to a numerical set, supporting the designer in the composition of subsequent stages, decomposition of premature stages and communication with reference disciplines such as mathematics. Such a new mode of representation entails new uses where the visual orthographic set is replaced with non-visual computational representation. As a result, the shifts in the design processes and the representation set used, lead to a redefinition of architectural representation and of architectural design processes.

The numeric representation of design ideas throughout the whole design process is conceptually and technically made possible with the introduction of computational design tools. One way of attaining this shift in the representation of design ideas is performing parametric design approach through associative geometry or algorithmic procedures, which enable to embed the representation of design ideas within the relations and equations used.

3.1.2 Parameters and Parametric Design Strategies

Computational design approach in architecture was guided by the conventional practice until the existing software was updated with programming, modeling and production techniques borrowed from other disciplines. Algorithmic procedures, associative geometry studies, scripting techniques and especially the parametric design approach, which are known to be commonly used in automotive and aerospace industries, fundamentally revised computational design processes, and introduced a new approach aiding the design process and going beyond mimicking the conventional drafting process. Branko Kolarevic defines the parametric design as a process where the designer deals with mathematical formulas and parametrical values, and breeds variations within a family of entities.[20] Equations are used to represent the mathematical and geometric relations between objects. Accordingly, parameters, as variables to which other variables of the formula can be related, gain an essential role within the computational design approach.[21]

By expressing the relational network within and between objects, the designer acquires the capacity to regenerate, redefine and reconfigure relations. Since, in parametric design approach, parameters are related to each other through equations and relations, when one entity is modified in the defined model, other entities will automatically update themselves. Such an interactive simulation of the variations is possible via the transformation and modification of parameters. A parametric model's ability to define and modify the geometry of the system is associated with its being a dynamically interconnected set of parameters.[22] Thus, parameters and parametric definitions of models acquire a major role within the computational design approach.

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[20] Kolarevic, Branko. *Architecture in the Digital Age: Design and Manufacturing.* p. 263.

[21] Szalapaj, Peter. "Parametric Propagation of Form."

[22] Senagala Mahesh. "Time-like Architectures: The Emergence of Post-spatial Parametric Worlds." Mahesh Senagala, http://www.mahesh.org/articles/ postspatialarchitecture.pdf.
Last accessed in September 2005.

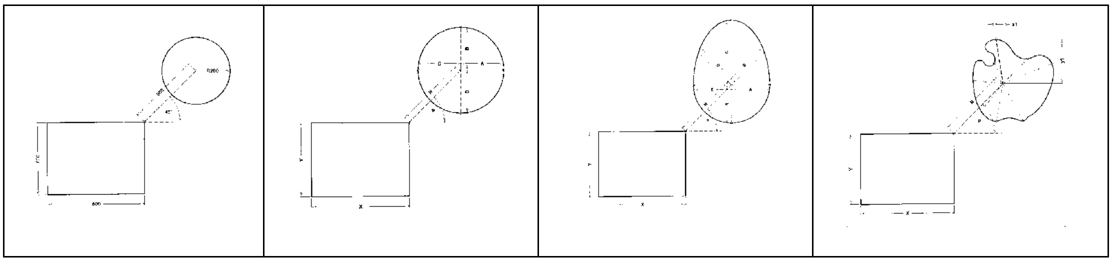

Figure 6: Mark Burry's study on relation based conditions.

Vienna University of Technology, http://info.tuwien.ac.at /ecaade/proc/burry/conclusi.htm. Last accessed in December 2004.

Along with that, the possibility of modifying parameters and equations, results in the description of not only one specific solution of defined relations, but instead, a whole repertoire of potential outcomes.[23] Hence, once the designer defines the parametric model, s/he also defines a pro-creative environment where s/he can work with unbounded series of possibilities. By changing one parametric value, or an already defined relation, the resulting product or equation is also changed simultaneously, thus enriching the repertoire of its potential outcomes.

However, as a strategic decision, one may or may not define a model made up of fragmented equations, which are relative to each other. If the relations in the model are all related to one another, any change in the parameters will automatically affect the result. However, if there is a fragmented model, changes in the parameters initially affect the fragment to which they belong, and then manipulate the whole. Such a fragmented model is used mostly in cases where there is data entry from different disciplines or authorities.[24] Nevertheless, a wide index of possibilities are defined whether the model is a fragmented one or not.

[23] Ibid.

[24] Oosterhuis Kas. "Parametric Design in New Canal Town,"
Architecture China, http://www.architecturechina.cn/en/issue3/article26.htm.
Last accessed in October 2005.

Oosterhuis, referring to the design experience in New Canal Town in Shangai, defines the parametric design processes as being open for input from other disciplines, and transparent to other experts as a consequence of the clearly identified relationships among all elements.

Moreover, in order to attain a repertoire of potential outcomes, the decisions and relations are recorded in the history of the program which makes it possible to move backwards and forwards during the design process. Mark Burry, drawing attention to the accumulation of different values of parameters and relationships defined between these parameters in the software database of the newly defined medium, states 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.[25]

By means of storing relations as parametrically defined mathematical equations, one can work on a model capable of recalculating the equations in case of a modification. In addition, since the decisions are all embedded in the resultant relations, the designer can re-examine the decisions at any time and remodel them. Thereby, with the ability of manipulating parameters, and updating them at any stage of design process, a freedom of experimentation is acquired on diverse circumstances. Mark Burry defines such a freedom, where the design decisions are inherited in the representation of relations allowing their manipulation at any time of the design process, as being "a large database of adventure".[26] Such an adventure defines a new design environment, a non-linear process, in which parameters can be changed and relationships remodeled.[27] Therefore, the main advantage endowed with such a flexible system is the tolerance with respect to instantaneous changes in design ideas at any stage of the design process.

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[25] Burry, Mark. "Paramorph: Anti-accident methodologies." p. 79.

[26] Burry, Mark. "Between Intuition and Process: Parametric Design and Rapid Prototyping." *Architecture in the Digital Age: Design and Manufacturing.* Ed. Branko Kolarevic. London and New York: Spon Press, 2003. p. 149.

[27] Ibid.

Given the freedom of changing the values of parameters and updating the generated situations in a parametric model, the designer can experiment between different stages of the design process in a non-linear manner, that is, making abrupt jumps even from the manufacturing phase towards concept generation or vice versa. However, in a conventional design approach or a non-parameterized computer-aided design approach, earlier decisions and circumstances had to be saved for reconsideration and modification. Still in that case, it would have necessitated significant changes in the model and a series of manipulations in the drawings. It is only after several stages of erasing and redrawing actions that the actual situation in the conventional design approach can be altered. Even in computer-aided architectural design models which are not based on parametric software, each part has to be modified by a series of deleting and drawing operations, since parts have not been defined relative to each other.[28] Yet, the parametric model, associated with parametric expressions, allows the designer to select particular parameters and change them simply, while deriving alternative solutions in a quick and accurate way, for what once took days to generate manually.[29]

Along with the modification of parameters and equations, parametric design approach also enables data integration at any stage of the design process, modifying and remodeling variables each time new data is integrated. The model can absorb continuous data flow and adapt itself simultaneously with a minimum of work-load. This model, acting as a potential real-time tool that is open to data integration is portrayed as establishing a continuous feedback loop between different stages of design.[30] By the agency of this feedback loop, besides introducing new data to the model, the output of one stage can be used as an input

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[28] Szalapaj, Peter. "Parametric Propagation of Form."

[29] “Swiss Re.” *Digital Fabricators.* pg. 16.
The Association for Computer Aided Design in Architecture, University of Toronto, Faculty of Architecture Landscape and Design, http://www.fabrication.ald.utoronto.ca/exhibitions/digital_fabricators/ digital_fabricators_catalogue.pdf.
Last accessed in October 2005.

[30] “Postagriculture.” *Digital Fabricators.* p. 58.

for the other. Accordingly, through the use of parameters, it is possible to modify and describe the variables acting both as input and output for the equations defined.

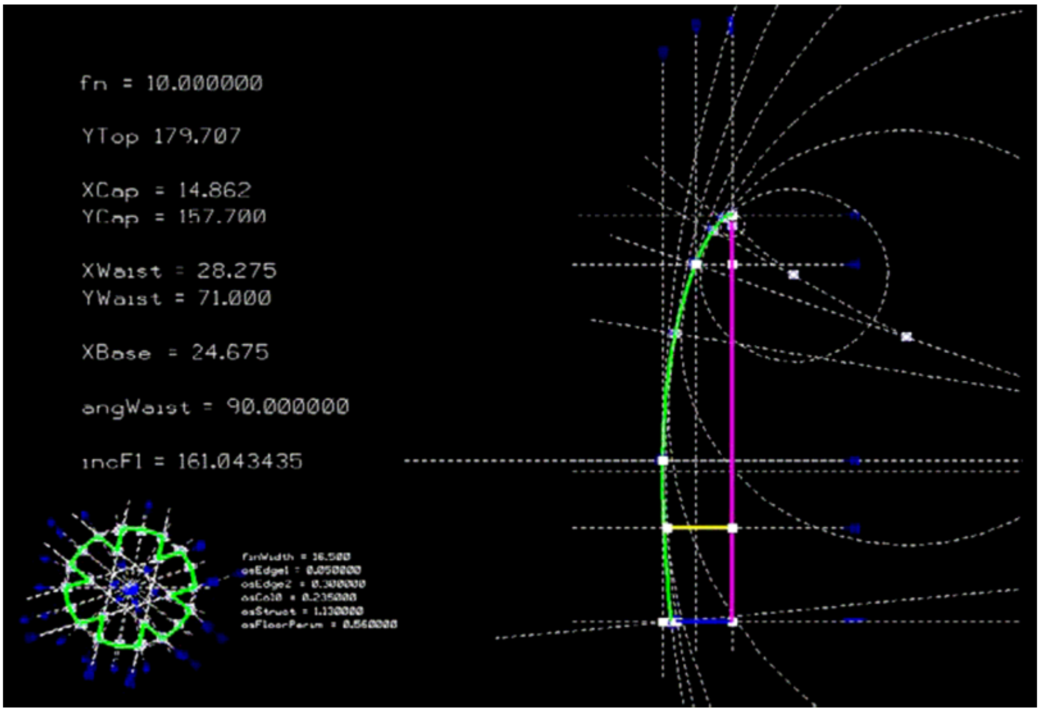

Figure 7: Parametric modeling of Swiss Re Tower by Foster and Partners.

"Swiss Re." *Digital Fabricators.* p. 16.
The Association for Computer Aided Design in Architecture, University of Toronto, Faculty of Architecture Landscape and Design, http://www.fabrication.ald.utoronto.ca/exhibitions/ digital_fabricators/ digital_fabricators_catalogue.pdf.
Last accessed in October 2005.

Such an open structure, able to take in data and renovate itself in accordance with the reference systems used, is defined by Kas Oosterhuis as an "open design game" that has the potential to differentiate, absorb, transform and adopt.[31] This "open design game" process, drawing on the advantage of being parameter-based, is thus tolerant of data integration from different disciplines at different times.[32]

[31] Oosterhuis Kas. "Parametric Design in New Canal Town."

[32] Ibid.

Being an "open game" such structures are open to user/designer interventions and make possible to work with a group of people specialized in various fields, and diversifies data entries. Since the model is capable of updating itself after each data entry or data annihilation, the feedback loop expands and subsumes different stages of the design process. Consequently, the boundaries between these different stages are blurred by the offered model that modifies itself simultaneously, subsequent to data entry from structural engineers, city planners or other authorities, owing to its parameterized network of counter-relations.

Regardless of parametric changes and extra-disciplinary data integration, the model can respond to modifications structurally, but also formally. Since form is responsive to relations, it can be modified and redefined according to changes in relations. It may be concluded that, parametric design software allows working with more complex shapes, operating on their geometric definitions, and informing the overall process. Branko Kolarevic, highlighting the mission of parameters and parametric approach in defining an operative ground for experimentation, states that;

> Parametrics can provide for a powerful conception of architectural form by describing a range of possibilities, replacing in the process stable with variable, singularity with multiplicity, using parametrics, designers could create an infinite number of similar objects, geometric manifestations of a previously articulated schema of variable dimensional, relational or operative dependencies. When those variables are assigned specific values, particular instances are created from a potentially infinite range of possibilities.[33]

The parametric model, assigned with different parameter values may provide a potential set of form studies instead of one fixed solution, and lead to variation subsequently. Altering the variables, reshaping the attributes, or redefining the equations, infinite formal possibilities can be elaborated in a dynamic and

[33] Kolarevic, Branko. "Digital Morphogenesis." Architecture in the Digital Age: Design and Manufacturing. p. 17.

responsive model, a fact due to the parametric definition of form rather than shape.[34] By means of drawing attention to the importance of operating with parameters in the derivation of form and the generative character of computational tools, Kolarevic designates the departure from the traditional approach to a form generation process:[35]

> In a radical departure from centuries old traditions and norms of architectural design, digitally-generated forms are not designed or drawn as the conventional understanding of these terms would have it, but they are calculated by the chosen generative computational method. Instead of modeling an external form, designers articulate an internal generative logic, which then produces, in an automatic fashion, a range of possibilities from which the designer could choose an appropriate formal proposition for further development. [36]

Form can be modified and redefined since it is responsive to changes in relations on account of their parametric descriptions. The ability to test an infinite number of possibilities and write various form-generation procedures extend the formal repertoire. Thus, a family of different forms can be defined and controlled in real time. Even the automatic adjustment of parameters to the changes allows the designer to observe the propagation of changes on dependent relations, and hence upon the dependent geometry.[37] Guiding an unbounded form generation process and its simultaneous observation, the parametric approach subsequently assists the widening of a formal repertoire.

Moreover, since equations and parameters enable to define complex relations and forms, a parametric description of forms is seen to extend the geometric capacity

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[34] Burry, Mark. "Paramorph: Anti-accident methodologies." pp. 78-83.

[35] Kolarevic, Branko. "Digital Morphogenesis." *Architecture in the Digital Age: Design and Manufacturing.* p. 17.

[36] Ibid

[37] Szalapaj, Peter. "Parametric Propagation of Form."

to model complex forms. The high level of complexity calculated and represented effectively through parametric description prop up the study on complex geometric forms. Given the convenience of defining and controlling complex curves and surfaces through the relations and equations, the designer is no more restrained with the geometric definitions of straight lines, arcs, planes, cylinders, spheres.[38] New software tools are replacing these primitives in order to depict the desired flexibility of the model, having the potential to deform according to the accumulated or integrated information.

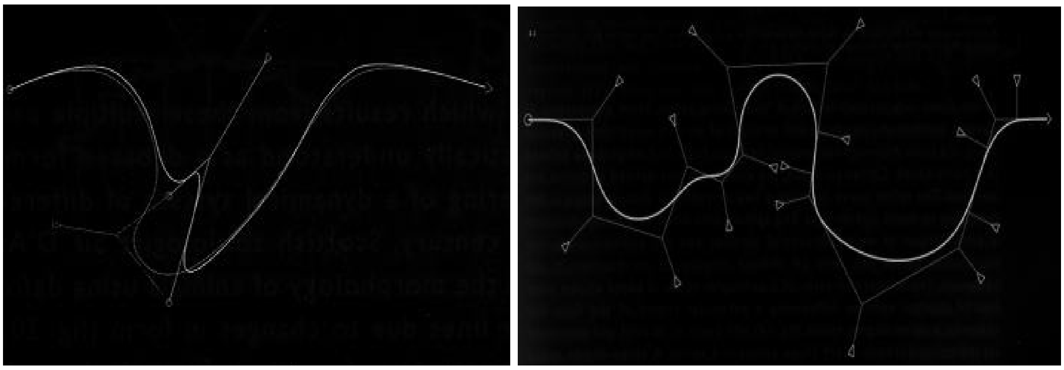

Figure 8: *NURBS* adjustable to designer's interventions.

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

One of these new software tools most commonly used is the *Non-Uniform Rational B-Splines* known as *NURBS. NURBS,* used in parametric modeling, are able to restore the information input and react to manipulations both in two and three dimensions. Using such mathematical modeling techniques to represent complex shapes and free forms through mathematical relations, allows the process to evaluate many alterations in both strategy and form, and at any stage. For that reason, the parametric approach offers more than the representation of form: Form, defined in parametric software, subsumes all the information and updates its parametric definition with reference to the modifications in the system. Kolarevic defines the parameter-based form as inheriting the potential of being a

[38] Mitchell, William J.. "Foreword." *Expressive Form: A Conceptual Approach to Computational Design.* London and New York: Spon Press, 2003. p. vii.

"mutable entity" that evolves dynamically with its "high plasticity" instead of being a stationary model.[39]

The desire to attain formal richness, besides altering the design process, also marks a radical shift in the standard sequencing of the architectural design process.[40] The sequences of parametric equations guide all phases of the design process and eliminate differentiations between phases. Form generation, representation, manufacturing or construction phases are controlled through the same parametric definition, allowing testing different experiences, different space qualities or different material properties. Most of the experimentations on the parametric design approach and computer-aided manufacturing techniques try to explore such new potentials.

One example of such studies is the *"Lattice Archipelogics"* project, an installation by *Servo* in collaboration with *Smart Studio*, exhibited at the *"Latent Utopias"* exhibition, where movement patterns are regarded as generative forces for the system.[41] Intended to generate a new material through real-time interaction between the object and the user, *Servo* used special software and parametric modeling to convert movement patterns into lighting patterns.[42] The data obtained from the users is stored in the parameters, affecting the relationships and thus the behavior of the model. The user/visitor actively participates in the design process since his/her movements are captured simultaneously by the sensors, which are scanned into numeric data and transmitted to the relations.

The relations can accommodate new data entries, and the model, being entirely parametric, responds to the transformations in the parameters. The defined model

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[39] Kolarevic, Branko. "Digital Morphogenesis." *Architecture in the Digital Age: Design and Manufacturing*. p. 19.

[40] Ibid. p. 18.

[41] "Latent Utopias" exhibition, 26 Oct. 2002- 2 Mar. 2003, Graz, Austria. Curators: Zaha Hadid and Patrik Schumacher.

[42] "Lattice Archipelogics." *Digital Fabricators*. p.76.

governs not only the generation, prototyping or manufacturing processes but also representation and organization processes. Described as a ready model for immediate output, all sorts of two-dimensional representations, simulations and prototypes can be extracted directly from the model.[43] High complexity in program and geometry has become possible through the use of parametric design approach, itself enabled by computational design tools. The parametric model also enables high precision rapid-prototyping despite complex geometries.[44]

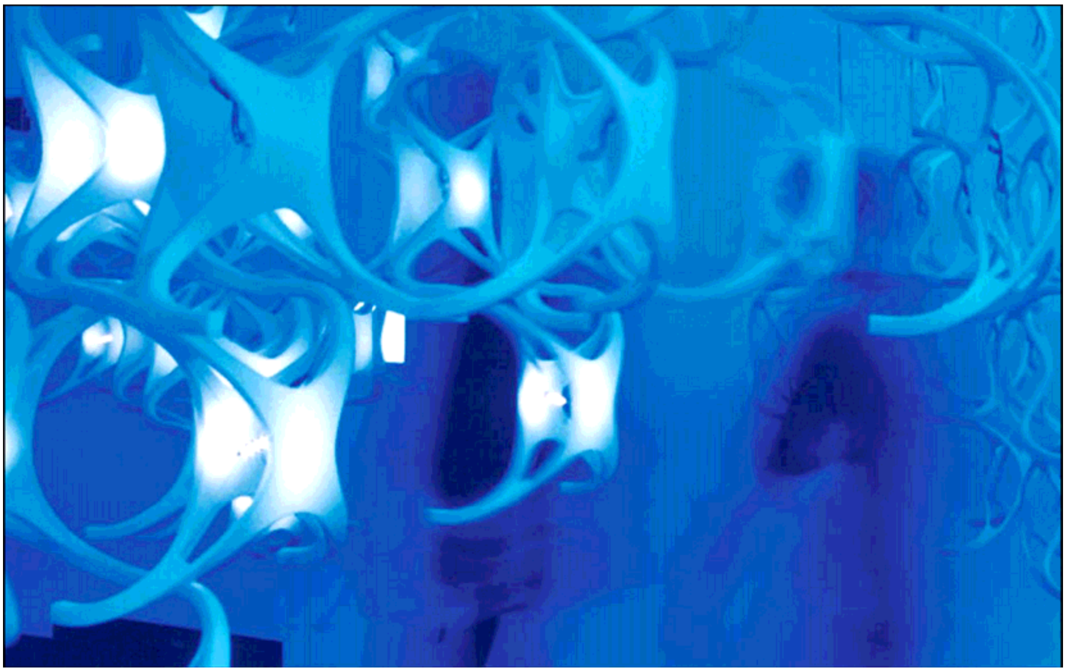

Figure 9: The nests transforming movement patterns to lighting designed by Servo in collaboration with Smart Studio for the "Latent Utopias" exhibition.

"Lattice Archipelogics." *Digital Fabricators.* p.76.
The Association for Computer Aided Design in Architecture, University of Toronto, Faculty of Architecture Landscape and Design, http://www.fabrication.ald.utoronto.ca/exhibitions/ digital_fabricators/ digital_fabricators_catalogue.pdf.
Last accessed in October 2005.

By taking the advantage of the prospective uses of the parametric approach, *Servo* and *Smart Studio* displayed a prosperous experience and established the search for new material properties through the interface provided by the parametric

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[43] Ibid.

[44] Ibid.

approach. The challenge presented by the potential of the parametric approach can be said to unfold through information about the parameterized models, and an open-minded approach to the unpredictability and the flexibility of the system: Kolarevic notes that one can then go beyond comprehending computational design as a mere production of “blobby” forms and initiate its definition as a generative approach.[45] Hence, parametric design is one of the most commonly used approaches that respond to all stages of design intentions and expressions. The parametric design approach can as well be supported by auxiliary generative processes such as algorithmic processes, scripting techniques and studies of associative geometry.

3.1.2.1 Parametric Design Through Associative Geometry

One approach that assists parametric design in defining a flexible, modifiable, deformable and responsive model is the use of associative geometry, which depends on the modification of already established relations within a geometric model. Associativity of architectural design is defined by Mark Burry as being dependent on a geometric definition of a model, all of which elements are “mutually linked.”[46] Having the ability to record the derivation of its formative parameters, the associative model responds to the modifications geometrically through the relations between the geometric components.[47] In consequence, the associative geometric model, being a collection of mutually connected elements, has the ability to update itself according to modifications in neighboring elements.

In parametric design through associative geometry, the designer deals with a repertoire of composite equations and dynamic operations adapting to various relations. Referring to the designer’s experience with a collection of possible geometric configurations, Robert Aish defines an associative model as

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[45] Kolarevic, Branko. “Digital Morphogenesis.” *Architecture in the Digital Age: Design and Manufacturing*. p. 27.

[46] Burry, Mark. “Paramorph: Anti-accident methodologies.” pp. 78.

[47] Ibid. pp. 79.

"representing not only one design solution, but a whole set of potential variation."[48] Aish, claims that, unlike an associative model, a non-associative one can represent only one design solution and any change in that solution requires considerable editing skills.[49]

In such an approach, attention shifts rather to the geometric configuration than the parametric inputs. Although the model and the relations can be updated according to the changes in parameters or intentionally, the focus is on the geometry of the model. The rich formal repertoire of the model is attained through the modification of the geometry by means of parametric interventions rather than a redefinition or erasure of the model.[50] The model allows any changes to be transmitted throughout automatically by way of a dynamic set of geometric dependencies. Even a unique change in the specific definition of the geometry, makes the system evolve itself and adapt its elements to the newly defined condition. Drawing attention to the designation of the geometric associations between the entities, Chris Yessios correlates the functional definition of geometry and the evolving character of the models: Yessios claims that;

> Geometry here does not only function as a static measure of invariant and unitary characteristics, but also as a plane of consistency, upon which differential transformations and deformations can occur, which are manifested at singular moments of an ever-changing spatial body.[51]

As a consequence, the designer gains the desired ability to test different design scenarios by way of an associative interface, the relations and parameters of which are defined by the user. While working on an associative model, one can

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[48] Aish, Robert. "Computer-Aided Design Software To Augment the Creation of Form." pp. 97-104.

[49] Ibid.

[50] Burry, Mark. "Between Intuition and Process: Parametric Design and Rapid Prototyping.". p. 149.

[51] Yessios, Chris. "Is There More to Come?." *Architecture in the Digital Age: Design and Manufacturing.* Ed. Branko Kolarevic. London and New York: Spon Press, 2003. p. 266.

select anyone of the elements associated with all the other elements, move it, redefine it, or change the parameters implanted in its associative definition at any stage of the design process.

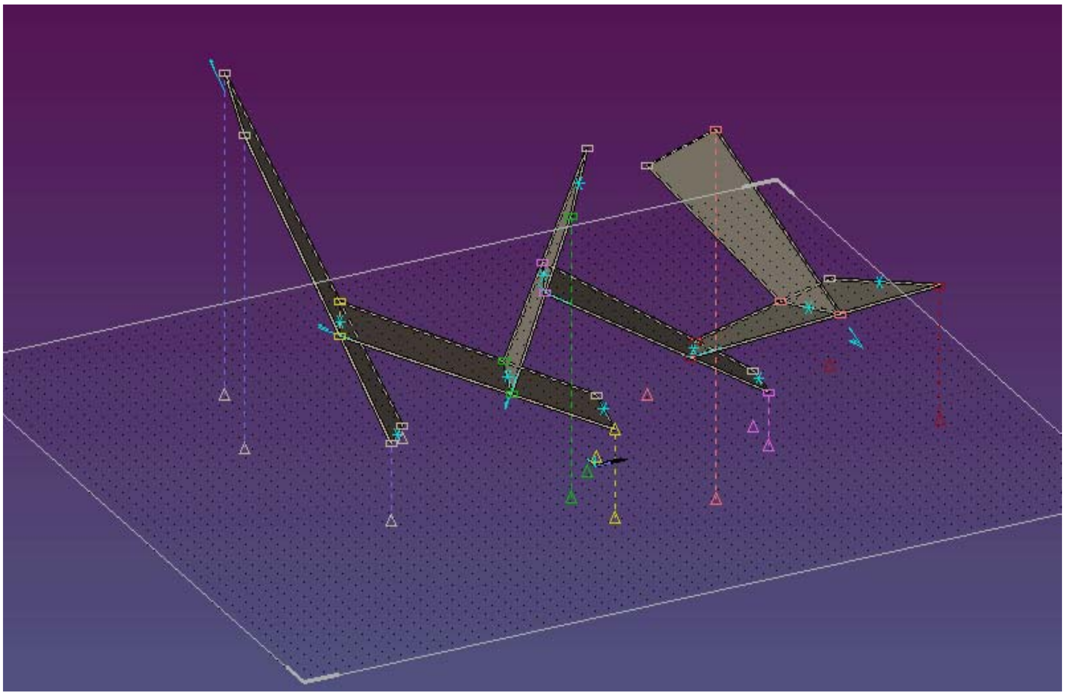

Figure 10: Associative geometric model defined for the Philibert De L'pavilion designed by Objectile.

Objectile, http://www.objectile.net.
Last accessed in November 2005.

Bernard Cache, referring to the experiments of his studio *Objectile* on associative architecture in *Philibert De L'Orme pavilion* installation, defines the flexibility of the model via the geometric relations between elements as the first level of associativity.[52] Aiming to define a fully associative design process, Cache proposes a second layer of associativity, the one in between the files which already have complex geometrical relationships.[53] The associativity between files

[52] Cache Bernard. "Towards A Fully Associative Architecture." *Architecture in the Digital Age: Design and Manufacturing.* Ed. Branko Kolarevic. London and New York: Spon Press, 2003. p. 142.

[53] Ibid.

is provided mainly through the representation of the scenario that is embedded within the relationships and geometric definition of the model. Since all the files and geometric models are associative and can respond to changes automatically by updating themselves, the manufacturing process also becomes associative. This means that, the modification of some elements in the form generation process automatically affects the files used in the manufacturing procedure.

Through the "fully associated" model, the designer is equipped to inform the subsequent stages of the form generation process. Therefore, the "fully associative" model allows again a non-linear design methodology, a freedom made possible by the blurring of the boundaries between different stages of design.

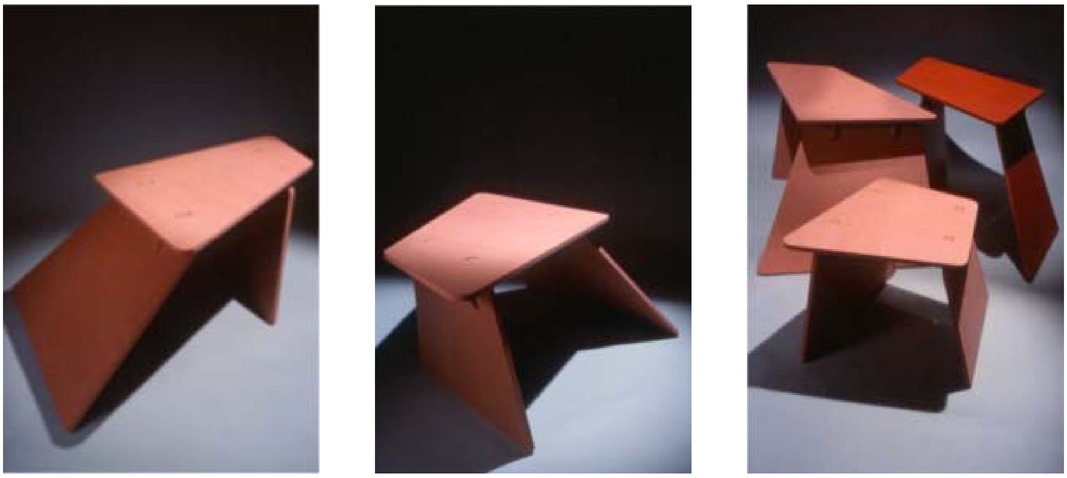

Figure 11: "Living Factory" prototypes designed by Objectile.

Objectile, http://www.objectile.net.
Last accessed in October 2005.

In the *Living Factory* (2003) project, where *Objectile* made use of parametric design software through associative geometry, a flexible model is defined enabling easy modification and visualization of variations.[54] The user can actively

[54] "Architectures Non Standard."
Centre Pompidou, http://www.cnac-gp.fr/Pompidou/Communication.nsf/ docs/ ID1F84C0C0C0E499D4C1256DF3005B4132/$File/dp%20.pdf.
Last accessed in January 2006.

participate in the design of the tables. The modifications are decided according to the needs and desires of the user that are controlled through the parametric software. Preserving the relations between the parts, the base model is transformed, where the gravity centers of the tables are simultaneously recalculated and adjusted to the current situation. Owing to the parametric model defined through the numerical chain, the conception, design and manufacturing phases are overlapping. The tables of *Objectile* are machined in 5 minutes and are assembled in 15 minutes, where this accelerated process gives the user the opportunity of participating in the whole design and manufacturing process.[55]

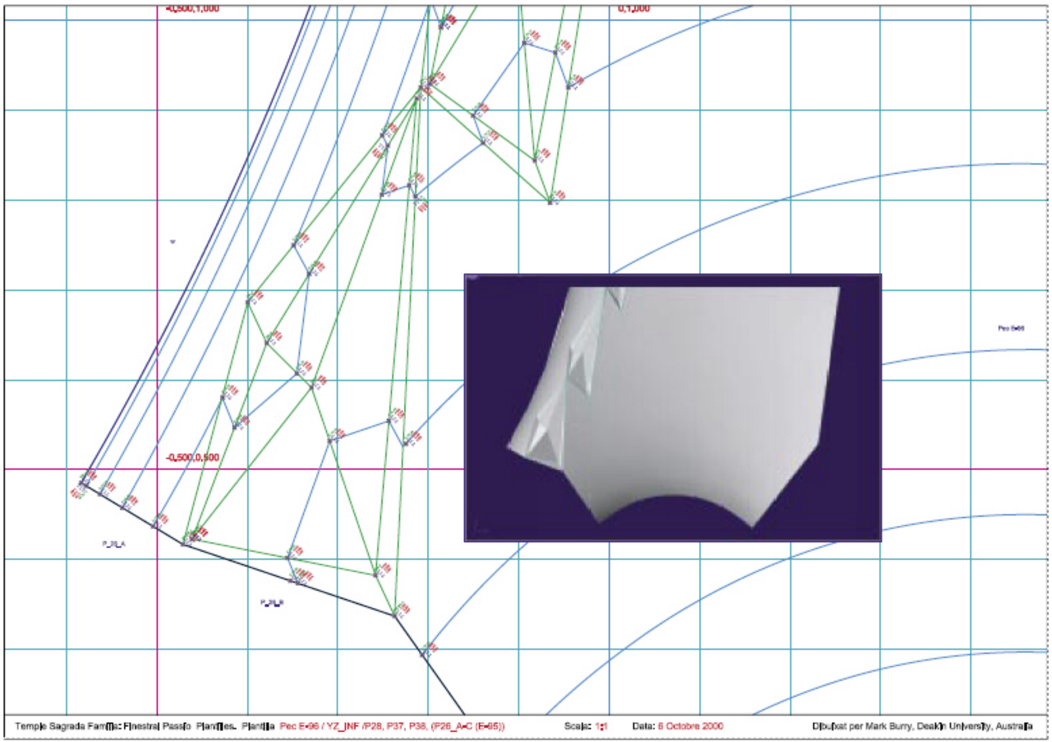

Figure 12: Associative definition of the geometry of the west transept rose window at Antoni Gaudì's unfinished Sagrada Familia.

"The Sagrada Familia." *Digital Fabricators.* pg.15.
The Association for Computer Aided Design in Architecture, University of Toronto, Faculty of Architecture Landscape and Design, http://www.fabrication.ald.utoronto.ca/exhibitions/ digital_fabricators/ digital_fabricators_catalogue.pdf.
Last accessed in October 2005.

[55] Ibid.

Such a "full association" is defined by Mark Burry as the ability to define, determine and reconfigure geometrical relationships, which he states to be of great importance in associative geometric studies.[56] In his momentous work of design and construction of the west transept rose window at Antoni Gaudì's unfinished *Sagrada Familia*, Mark Burry makes use of associative geometry and parametric design. The Spanish and Australian teams working on the project made use of associative geometry in order to generate a hierarchy of thousands of relations. Hence, they acquired a model which updates all the relations and so the geometry of all the related parts of the window.[57]

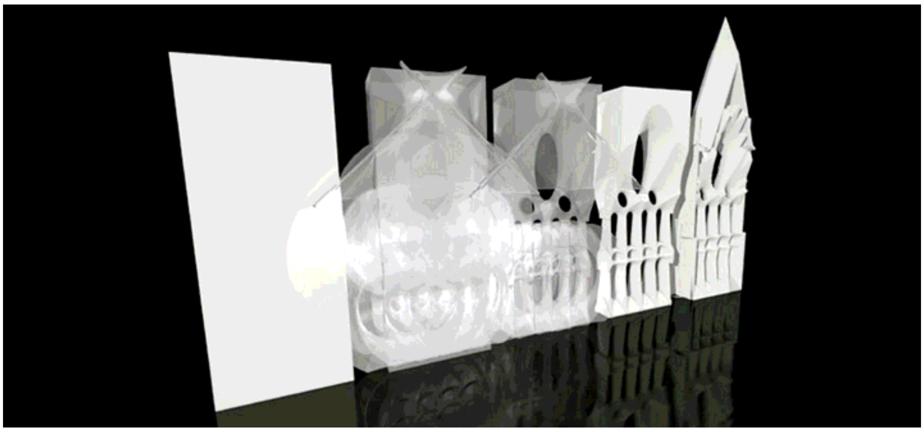

Figure 13: Studies for the west transept rose window at Antoni Gaudì's unfinished Sagrada Familia.

The Association for Computer Aided Design in Architecture, University of Toronto, Faculty of Architecture Landscape and Design, http://www.fabrication.ald.utoronto.ca/exhibitions/ digital_fabricators/ digital_fabricators_catalogue.pdf.
Last accessed in October 2005.

The use of associative geometry here not only allowed for defining and working on complex and curved geometry, but also it's manufacturing in a rapid and easy way. The process from the design phase till the manufacture depended on the same geometric model and parametric definition constructed at the outset as a flexible

[56] Burry, Mark. "Between Intuition and Process: Parametric Design and Rapid Prototyping."

[57] "The Sagrada Familia." *Digital Fabricators.* p. 11.

model of the whole assembly. Through the model's ability to absorb information and respond with minimum work-load, it was possible to move within different phases of design.[58] They first dealt with the exterior of the rose window and resolve all its constituents, and then the interior part of the window since they should integrate data to the model after some part of the construction has been finalized.[59] Such flexibility in the design process, where the manufacturing can be followed by data integration to the model and its simultaneous modification, could have only been possible through a parametric design approach based on associative geometry.

3.1.2.2 Parametric Design Through Algorithmic Procedures and Scripting

Another means of assisting parametric design is through algorithmic procedures with their deployment of open-ended computational processes and generative design techniques. Despite the extensive use of algorithms and algorithmic procedures in computer programming, their employment in architectural design appears principally after the introduction of computational design methods to architectural design processes, marking a radical shift in the practice.

An algorithm, defined as a computational procedure to work off complex situations and problems, identifies a problem in a finite number of steps according to a generic key plan.[60] Initially the problem and the procedure that will be applied via codes, charts or mathematical operations are defined. Through the interface enabled with the use of these tools, the program of the process, that is the algorithm, is written. Working with algorithms, thus substitutes the established tradition of procedure description with calculated and coded sequences of command programming.[61] In view of these, the algorithmic approach offers the

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[58] Ibid.

[59] Ibid.

[60] Terzidis, Kostas. *Expressive Form: A Conceptual Approach to Computational Design.* p. 65.

[61] Kolarevic, Branko. "Digital Morphogenesis."

potential to go beyond mere design techniques and introduce a creative, deformable and unpredictable process. Hence, the inherent potential of the algorithmic procedure opens the grounds for a responsive model that can react to the modifications throughout the design process.

The algorithmic description of the geometry and the procedure is enabled through a network of mathematical models and generative procedures where a set of parametric variables and regulations are defined. In order to define that set, the designer besides using the software programming inherited within the computer interface, may prefer to go beyond the rules already identified within these programs. Through coding the relations and regulations, s/he can then define his/her own procedure and write the script of the design process. Scripting, defined as writing simple computer programs, makes possible to control and automate operations through a series of codes and instructions.[62] The instruction set defined by the codes and syntaxes consists of smaller instruction files that can be executed by the computer-aided design program used. In this manner, through programming the process, one can redefine existing computational design tools as generative devices extending simple drafting tools. [63]

Algorithmic procedures through scripting are considered as broadening the horizons of the human intellect, and offer what is uncommon, unpredictable and unimaginable.[64] Kostas Terzidis, referring to the new formal paradigm altered with the use of computational tools, defines the algorithms as engines for the introduction of a new design environment for formal, material and topologic explorations.[65] One of the most striking characteristics of algorithmic procedures is the productivity of the design process, since algorithms open up the possibility

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[62] The Spatial Information Architecture Laboratory, RMIT University, http://www.sial.rmit.edu.au /Projects/Strange_Procedures.php.
Last accessed in October 2005.

[63] Terzidis, Kostas. *Expressive Form: A Conceptual Approach to Computational Design.* p. 65.

[64] Ibid. p. 5.

[65] Ibid.

of exploring new forms. The ambition to seek and explore new outcomes is welcomed within the flexibility of the system.

Moreover, through the unpredictability of the system, the design ideas can be liberated from the visual constraints and formal images of our perceptual field.[66] Concentrated on the definition of program rather than form, the designer leads an open-ended design process, through which new insights can be inscribed into the scripted algorithm. Within that open-ended process, the designer gains the opportunity to come up with unpredicted results, since s/he defines the regulations of which results are not envisaged.

Another virtue of working algorithmically is its provision of an adaptable model that can be easily altered by changing the parameters of the script. Through modifying the internal structure, that is, the script, the whole process can be manipulated and a new set of possibilities defined. As a consequence, every new execution of the algorithm may give rise to the evolution of design solutions tracked by new outcomes. On the other hand, the scripted algorithm does not only define numerous outcomes subsequent to the changes, but also assists their selection or elimination according to the constraints integrated into the script. This makes possible to define a set of potential solutions through controlling the script rather than making a selection according to formal criteria.

[66] Such a process of non-visualization for the extension of the perceptual field is discussed in Mennan, Zeynep. "Non Standardization Through Non-Visualization: Scriting 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, and also in a different context in Mennan, Zeynep. "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. Referring to a statistics workshop undertaken by Teğet Architecture on translating urban knowledge into a formal language, Mennan discusses the perceptual disorientation that results from quantitative representation and the conscious delay of the visual/spatial interface. The perceptual disorientation through the shift from the visual/ textual to the numerical/computational is introduced as a way of enhancing productivity by suspending acquired visual/formal layers.

By shifting the focus from formal to numeric descriptions, the designer can enrich the architectural design process and augment the perceptual field.[67] Algorithmic procedures are seen to surpass conventional design and form generation processes in their definition of new and complex forms through a modifiable, open-ended and responsive process. Therefore, algorithms, regarded as procedures for parametric computational design processes, initiate the employment of new formal definitions within a generative procedure.

Consequently, algorithmic procedures and scripting techniques define a new design environment which alters both the conventional architectural design process and the role of the designer. The designer, in this newly defined medium, needs to comprehend the algorithmic procedure not as a representational tool for visualization and form generation, but instead as a generative tool responding to every phase from form-generation to manufacturing.[68] In an algorithmic procedure, the script serves as representational tool that by-passes visualization, while allowing it at any instance of the design process. Moreover, the script can be transferred directly to modeling and manufacturing tools without any modification. Scripting then blurs the boundaries between different phases of the design process and dissolves the representation process within the whole design process. However, such a redefinition of the design process stresses the importance of the designer's self-adaptation to the shift from visual to non-visual modes of conception.

In order to have control over the process but not on the outcomes, and to facilitate such complex computational programming, the designer needs to adapt to the new grounds of design and architectural representation. Understanding, evaluating and

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[67] Such an augmentation of the perceptual field, and of Gestalt theory is suggested by Zeynep Mennan in: Mennan, Zeynep. "Des Formes Non Standard: Un 'Gestalt Switch'." ("Of Non Standard Forms: A 'Gestalt Switch"), *Architectures Non Standard*. Eds. Fréderic, Migayrou, and Zeynep Mennan. Paris: Editions du Centre Pompidou, 2003. pp.34-41.

[68] Kolarevic, Branko. "Digital Morphogenesis and Computational Architectures," Cumulative Index of Computer Aided Architectural Design, http://cumincades.scix.net/data/works /att/fbc9.content.pdf.
Last accessed in November 2005.

interpreting the inherent behavior of these newly offered elements is indicated as being of great importance in order to develop such parametrically complete representations.[69] Therefore, translation from an orthographic set to the numerical set of algorithms and scripts, requires the assimilation of coding by the designer in all phases of the design process. Although one can use the scripting languages offered within the packages of computer-aided design programs (i.e. Maya Embedded Language (MEL), 3dMaxScript, Generative Components and Form Z), one may also personally define and code a program.

The designer's defining his own program through scripting may delineate a more advantageous and generous process. Referring to the importance of the designer's ability to code and decode the program, William Mitchell states that; *"The more we invest in coding such procedures, the less restrictive the shape economy becomes, and the more extensive and interesting the design domains that architects can explore."* [70]

Designed by Toyo Ito in collaboration with Cecil Balmond in 2002, the *Serpentine Pavilion* is a contemporary example of parameterized design approach through the use of algorithmic procedures. Aiming to define an innovative design experience to generate new geometries, the architects relied here on algorithmic procedures. The schema of the pavilion is a simple box systematically assembled by a pattern of intersecting lines.[71]

The pattern is derived from an algorithmic procedure depending on the extension of a cube as it rotates.[72] The algorithmic procedure defining the conceptual and geometric modeling of the program leads to an unpredictable design process. The

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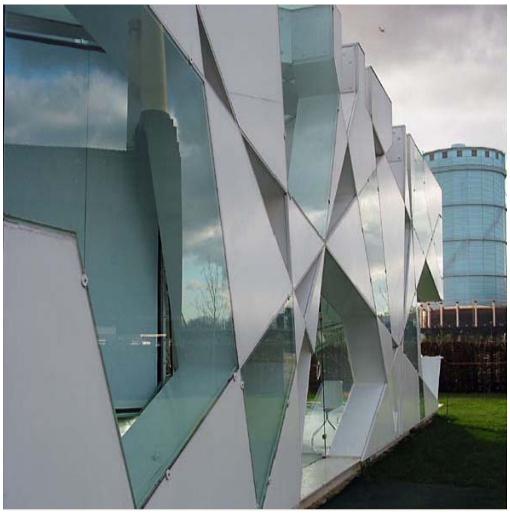
[69] Yessios, Chris. "Is There More to Come?." p. 263.

[70] Mitchell , William J.. "Foreword." p. viii.

[71] Arup, Arup Projects, http://www.arup.com/europe/feature.cfm?pageid=331.
Last accessed in November 2005.

[72] Slessor, Catherina. **"**Geometrical games combined with an inventive approach to structure and materials inspire this eccentric temporary tea house in Hyde Park." *The Architecrural Review*. Sept.2002.

lattices of triangles and trapezoids originating from the complex model are non-predicted. Depending on the spiraling algorithm, the subdivisions of the box connect the adjacent sides in a variable ratio specified via the algorithm.[73] Thus, a controlled randomness is attained in the design process as a consequence of the algorithmic procedure in computational design approach.



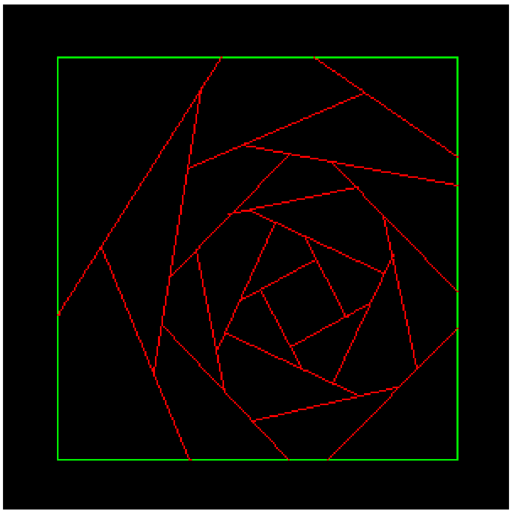


Figure 14: Algorithmic studies for the Serpentine Pavilion.

Olll, Architecture Gallery. http://www.0lll.com/lud/pages/architecture/ archgallery /itoserpentine /battersea/pages/battersea_03.html.
Last accessed in November 2005.

3.2 From a Deterministic to an Indeterministic Design Process

Following the radical changes computational design tools have brought in the architectural design process, architects started to work on models providing for an open-ended and non-linear design process. Liberated from the conventional modes of form generation processes and representation of design ideas, architects can now operate with the generative potentials offered by the computational design techniques. The internal generative logic guides the intentional search for a transformable, responsive and adaptable model. The emphasis placed on

[73] Arup, Arup Projects, http://www.arup.com/europe/feature.cfm?pageid=331.
Last accessed in November 2005.

topological studies and computation-based generative techniques gave rise to the definition of interdependencies between relations, programs and information. Branko Kolarevic describes these interdependencies as organizational principals that structure the process and generate form.[74] He concludes that the rejection of the determinisms of conventional design process results in the abandonment of predictable relationships between process and form, leading to the indeterminacy of computational design processes.[75]

In this new design environment, computational design techniques are used to define the procedure, the relations and the constraints of the working model. Prior to the structural definitions, the model constructs itself with data integration and defines the generative processes of computational design. Since the model is open to interventions and modifications with its dynamic and adaptable character, it is possible to end up with infinitely variable cases which have not been previously predicted.[76] The suspicious state about the end product, despite the precise definition of relations and constraints, is the consequence of indeterminacy in the design process. This indeterminacy, enabling constant transformation, is intentionally sought out, since it substitutes the fixed determinism of the conventional design approach.

With the proposed indeterminacy, the designer becomes capable of finding new formal, material and topological properties through the use of generative computational techniques, such as parametric modeling, associative geometry, algorithmic procedures and scripting.[77] The potentials offered by means of these techniques initiate a shift from the deterministic techniques of conventional design, and signal a sophisticated yet indeterminate design process. The designer,

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[74] Kolarevic, Branko. "Towards Non-Linearity and Indeterminacy in Design."

[75] Kolarevic, Branko. "Digital Praxis: From Digital to Material."

[76] Ibid.

[77] Goulthorpe, Mark."Precise Indeterminacy,"
Bentleyuser, http://www.bentleyuser. org/features/Features.asp?offset=10&ID=48.
Last accessed in November 2005.

equipped with a transformable model, can now perform in a non-linear process, where s/he can visit early decisions, redefine them and simultaneously work on the resultant state. Such back and forth movements mark the abandonment of the linear models in conventional design approach, as well as a liberation from their constraints. This free movement within the design phases is rendered possible through the agency of computationally based generative techniques used to configure the model.

The relations and constraints defined in the model, do not function as limitations or obstacles, but on the contrary, facilitate the definition of an unpredictable, uncertain and indeterminate model that affiliates in accordance with the operations.[78] However, the definition of the relations and the general structure of the model are of great importance in order to make possible the generative role of the indeterminate model. Thus, the dependencies between elements and relations should be defined attentively to enable different approaches to the problem. Along with that, acting through an indeterminate model, a set of outcomes can be defined instead of a particular one, with simultaneous interpretation and manipulation of the generatively constructed model.[79] Taking the advantage of working with sets of different outcomes, the design process can go beyond determinism and demonstrate an open-ended creative process that relies on indeterminate ways of thinking.

Within such indeterminacy, the designer may tend to legitimate the accidental definition of the possible outcomes, since the unpredictability and emergence of accidental forms are embraced intentionally.[80] Indeed, the generative procedures

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[78] Kolarevic, Branko. "Digital Morphogenesis and Computational Architectures."

[79] Ibid.

[80] Mark Burry. "Between Intuition and Process: Parametric Design and Rapid Prototyping."

Mark Burry suspects the considerable visual status and appreciation attained by accidental effects, and the approval of architecture produced through accident. Burry indicates that "emerging critical theory has no embarrassment in accepting, or benignly accommodating or even celebrating the accident or the error." He introduces "paramorph" in response to the accidental non-intended outcomes where he implies intention as a substantial difference.

of computational design accept accidental and emergent definition of forms as launching *"fields of indetermination"* leading to a diversity of unpredicted outcomes.[81] Through such a generative process depending on dynamic and relational definition of models, the designer may celebrate the intentional accidental outcomes instead of avoiding them.

However, the interdependencies between different stages of design should be defined, in order to attain the *"fields of indetermination"* that affiliate with accidental theories. The new design environment rejects the independence between different stages of design and embraces indeterminacy. The abandonment of clear distinctions between the conceptual definition of design ideas, the changes in form-finding process, representation and manufacturing, lead to indeterminacy and pave the way for a non-linear design process. Through the complex definition of interdependencies between the constituent parts of the model, enabling continual definition of new and unexpected outcomes, the designer is intentionally seeking out non-linearity, indeterminacy and emergence.[82]

Enabling simultaneous interventions, unfolding early decisions and the diversity of possible outcomes, the non-linear model designates a potential shift from a deterministic design approach to an indeterministic one. Reading the design process in a linear mode is identified by Ali Rahim as undermining the potential

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Also see Perez Gomez, Alberto and Pelletier, Louise. *Architectural Representation and Perspective Hinge,* Cambridge, Mass.: MIT Press, 1997. Perez Gomez and Pelletier, scrutinizing the transformations in architectural representation over the centuries, acknowledge the accidental as a legitimate design outcome.

[81] Kolarevic, Branko. "Digital Morphogenesis and Computational Architectures."

Kolarevic associates the concepts of emergence and "fields of indetermination", in his delineation of the definition of actions and reactions as creating "fields of indetermination" from which unexpected and genuinely new forms might emerge. He defines attitudes in contemporary critical discourse as intentionally seeking indeterminacy in design processes, through the ways ("methods") and means ("devices") of digital form generation, where the accidental plays a major role in creating the "fields of indetermination"

[82] Kolarevic, Branko. "Towards Non-Linearity and Indeterminacy in Design."

complexity of the contemporary design process.[83] Consequently, attention should be paid to construct the desired model to make use of the potentials offered within a non-linear model defined through computational design tools. The competence of the model in defining the desired level of indeterminacy is also related with the designer's prevision of the possible interdependencies between parts. The defined model should be capable of altering or unfolding the design decisions and should be able to work in coordination with all stages in order to relieve the determinism of a linear mode.

On the other hand, structuring the relations and constraints of the model is of great importance, since the desire for a non-linear, indeterminate and unpredictable model may yield towards an unintentional 'over-constraint problem'.[84] The primary goal of defining the relations of the model that assist the generative procedures and computational operations may fail when the model encounters the problem of over-constraint. Referring to the importance of the degree of dependency in the explicit or implicitly declared relationships Mark Burry states that;

> If the model suffers from over-constraint in relationships declared early in the design process, subsequent design decisions might be invalidated simply through the inability of the regeneration process to comply with conditions set by the designer earlier on.[85]

However, the risk of resulting in an over-constraint definition can be avoided in a generative design process independent of the linear models' limitations. Since the non-linear model enables to revisit the design decisions, the designer can check his decisions, the relations set between elements and the level of dependency between them, thus detect the risky conditions. Although the process is guided by

[83] Rahim, Ali. "Systemic Delay: Breaking the Mold."

[84] Burry, Mark. "Between Intuition and Process: Parametric Design and Rapid Prototyping." p. 150.

[85] Ibid.

computational design procedures, if the model is a linear one, it necessitates numerous actions to be redefined, so as to detect and eliminate the decisions leading to an over-constraint model.

The designer has a critical role in defining the desired indeterminate model, embracing a generative procedure that leads to a set of unexpected outcomes. Initially, the shift from a deterministic to an indeterministic process demands the giving up of an acquired mental set for adaptation into another.[86] In order to make use of the potentials offered within the new design environment of computational design, the designer should abandon the gathered deterministic and linear practices of his/her mental set. Besides, s/he should be open-minded to allow for a certain level of unpredictability, uncertainty and indeterminacy to end up with a favored experience. The capability of the offered model, and to what degree it fulfills the desired ambitions, is claimed to be related with the designer's perceptual and cognitive abilities.[87]

In order to define the indeterminate, flexible, modifiable and responsive model which does not suffer from an over-constraint problem, the designer should have the required knowledge about the inherent potentials of the techniques used for self-adapting to the non-linear computational design process. It is through being open to the alternative design method that one can take full account of the potentials enabled by geometric modeling and constraint definition.[88] To tackle with the problems emerging throughout the promotion of design ideas and their abstraction and representation with the new tools, the designer should release his/her ideas from his conventional practices and handle the situation from a different point of view. In order to facilitate the effective use of computational design tools and provide a generative medium, s/he should be aware of the

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[86] Mennan, Zeynep. "Des Formes Non Standard: Un 'Gestalt Switch'.

[87] Burry, Mark. "Architectural Design Based on Parametric Variation and Associative Geometry," Vienna University of Technology, http://info.tuwien.ac.at /ecaade/proc/burry/conclusi.htm. Last accessed in December 2004.

[88] Kolarevic, Branko. "Digital Morphogenesis and Computational Architectures."

advantages offered by the design environment and train himself/herself according to its requirements.

As a consequence, the new design environment necessitates the liberation from the deterministic modes of conventional architectural design such as conception, abstraction, representation and even training, to ensure the indeterminacy claimed in computational design approaches.

3.3 Temporary Visualization of Design Ideas and Conscious Delay of the Representation Process

Being a consequence of the current changes in the architectural design process that is influenced by the introduction of computational design strategies and tools as well as the geometric and mathematical advances, the architectural representation process can be asserted to revolutionize itself. Under the influence of these changes, a generative design process detached form the visual/formal constraints of conventional design approach seems to be deliberately sought. In order to delineate the desired generativity and flexibilty, mathematical models based on the parametric definition of relations and equations are being used, which evolve constantly with data integration and modification.

The definition of ideas through parameters and mathematical equations makes it possible to maintain the continuity between different stages of design, from concept to realization. Since the representation of design ideas is also guided with the same numerical set, the designer can assist the continuous stages through these parameters and relations. The offered process subsumes all numerical and visual information related to design decisions and provides for a representational short-cut between different stages.

The possibility of working on the same database throughout the whole design process, from concept generation to manufacturing, owing to the numeric set defined, enables to visualize the current state of formal transformations at any interval of the design process. With computational approaches, the designer does not necessarily finalize the design process to make a visual representation of frozen states, but instead temporarily visualizes design ideas by taking snapshots from the evolving process. Thus, the design process gains the possibility of ending up with a set of representations from different stages displaying different formal studies instead of a fixed single representation.

By means of capturing snapshots or numeric representations, the design ideas and the current state of the process can be visualized without any significant work-load. The numeric definition of the design process enables the tracing of a certain state of the process to visualize it temporarily. Since the same numeric definition assists the visualization and representation processes as well, two-dimensional or even three-dimensional representations can be displayed easily. By temporarily freezing the constant evolution of the model, the dynamic evolution of the design ideas can be visualized and their transformation with visual, numeric or three-dimensional representations can be captured.[89] The effects of the changes in parameters on the model can be visualized simultaneously if needed, since visualization follows the same parametric definitions that aid the representation. Taking the advantage of temporary visualization, it is possible to explore the yet unrevealed aspects of design during the transformation of the model from one state to another.[90] Therefore, post-representation of design ideas in the conventional architectural representation process is altered with the temporary visualization of design ideas owing to the mathematical model defined.

As a consequence of the attention placed on process rather than form, architectural representation is consciously delayed, which enables the constant evolution of design ideas. Through the *systemic delay,* the desired indeterminacy and unpredictability can be defined, where the potentials offered with the

[89] Belibani, Rosalba and Gadola, Anna. “On Digital Architecture,”
Vienna University of Technology, http://info.tuwien.ac.at/ecaade/proc/belibani/ belibani.htm.
Last accessed in September 2005.

[90] Ibid.

computational design processes can be exploited and maximized.[91] In computational design strategies, attention on process is appreciated and visualization delayed consciously to facilitate the definition of the desired generative design process.

[91] Rahim, Ali. "Systemic Delay: Breaking the Mold." p. 7.

CHAPTER 4

DIAGRAMS AS MODERATORS FOR CREATIVIY AND NON-VISUAL REPRESENTATION

Diagrams, indicating relationships between parts, function as mediators that suppose the interactive formation and transformation of these relations.[1] Through the use of charts, sketches, drawings or even phrases, diagrams inherit a potential for the visual or non-visual demonstration of exact situations as well as of possible configurations.

4.1 From Analytical to Generative Diagrams

Peter Eisenman defines the use of diagrams in architectural practice as "analytical devices or as generative devices."[2] When used as analytical devices, diagrams represent the already established relations and do not initiate interpretation. On the other hand, the diagrams used as generative devices are the abstract representations of the relations and forces; therefore they aid to define a generative process by shifting the focus from form to relations.

However, the history of diagrammatic practices witnesses their most common use as analytical devices, with the attention placed on type. In such analytical use of the diagram, the aim is to cover the most appropriate formal definition for the specific function identified. William Braham highlighting the correlation of form and function states that:

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[1] Van Berkel, Ben and Bos, Caroline. "Diagrams, Interactive Instruments in Operation." *Any Magazine.* No. 23, 1998, p. 23.

[2] Eisenman, Peter. "Diagram: An Original Scene of Writing." *Any Magazine.* No. 23, 1998, p. 27.

> Since the late eighteenth century, building typology has provided the dominant model of an architectural working method, even though architects have rarely been able to maintain any kind of useful distinction between typologies of function (the museum, church or house) and typologies of form (the pyramid, atrium, or basilica).[3]

In their analytical use, diagrams are considered as a 'working method', which concludes formal solutions in a rational way, dependent on the formal conventions of the designer's perceptual field, as well as the cultures and appropriate forms of practice.[4] In such analytical reasoning, one formal solution is dictated for the specified function, instead of generating multiple instances of the analyzed situation. The desire to depict the most appropriate form for the specified function thus brings together a fixation in typology.

Recent diagrammatic practices in architecture witness a drastic shift from the analytical to the generative. Associated mostly with Deleuzian discourse, more bold and radical attempts are made to make use of diagrams both conceptually and instrumentally.[5] The analytical practice of the diagram, which used to end up with the definition of the most appropriate form, is now being replaced with a Deleuzian approach, in which the diagram does not end up in a fixed solution. The transformed use of diagrams in the recent years has multiplied diagrammatic architectural practices regarding the diagram as an inspirational and generative tool.

Describing the diagram as a generative device, Eisenman defines it as "*a mediation between a palpable object and a real building*".[6] Considered as a

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[3] Braham, William. "After Typology: The Suffering of Diagrams." *AD: Contemporary Processes in Architecture.* Academy Editions: London, Vol. 70, No. 3, 2000. p. 9.

[4] Ibid. p.10.

[5] Ibid.

[6] Eisenman, Peter. "Diagram: An Original Scene of Writing." p. 27.

generative device that liberates design ideas from formal determinism, the use of diagrams under the influence of Deleuzian notions, marks the departure from typological practice. This focus on the generative character of diagrams then opens up the grounds for topological practices, consciously avoiding typological fixation: Interest now shifts to the fluctuation between the generative process for defining relations, and the formal outcome. The formal indeterminacy resulting from an attention placed on relations, thus offers a generative design process where the typological practice gives way to a topological one.

Within this new paradigm, where the analytical use of diagrams is substituted with their generative use, the representational form of diagrams is also altered. Eisenman defines diagrams as a form of representation, and referring to their analytical use, states that; *"Although it is often argued that the diagram is a post representational form, in instances of explanation and analysis the diagram is a form of representation."* [7] Generative diagrams differ from traditional forms or representation because they represent the oscillation between the actual and the virtual; what is visually represented via the generative diagram does not coincide with what is actually denoted. Peter Eisenman defines diagrams as graphical abbreviations for the communication and representation of design ideas and states that:

> Generically, a diagram is a graphic shorthand. Though it is an ideogram, it is not necessarily an abstraction. It is a representation of something in that it is not the thing itself. In this sense, it cannot help but be embodied. It can never be value- or meaning-free, even when attempts to express relationships of formation and their processes. At the same time, a diagram is neither a structure nor an abstraction of structure. While it explains relationships in an architectural object, it is not isomorphic with it. [8]

[7] Ibid.

[8] Ibid.

Generative diagrams aid in liberating design from the formal determinism of typological practices, precisely because the visual representation of the diagram is not isomorphic with the design object. Hence freed from typological constraints, diagrams enable the generation of new instances, since they do not dictate the formal outcome of identified relations through their representation, but rather clarify them.

In this new diagrammatic approach, the definition of relations takes over the definition of form, thus welcoming continuous data input. The continuous data input onto the diagram can be considered as having a significant role in defining the departure from the type-oriented diagrammatic studies, where the diagram is now composed of multiple layers of condensed information. Inheriting multiple layers of information that are overlapped on each other, diagrams also enable manipulation and modification of any layer, while continuous data input allows for the delay of formal expression. A constantly evolving diagrammatic process liberated from formal concerns initiates infinite representations for the formal solutions.

Current diagrammatic practices can be said to stimulate the designer’s creativity and lead to a more dynamic design process compared to analytical diagrammatic practices, representing the already mentioned relations and conditions. Direct translation of the diagram into a formal expression in the conventional use of diagrams is now substituted with a delay of formal expression, liberating from formal determinism. Since the diagram proposes the mediation between relations and their concrete reflection on form, the delay of formal expression leads to a more generative design process, where attention is placed on the relations and forces breeding the diagram.

The departure from a typological to a topological practice, concentrated on relations redefined with continuous data integration, also brings forth the abandonment of the linear practice between conceptualization, form-generation and visual representation. The replacement of representative analytical diagrams with non-representative generative ones enables the definition of a non-linear process. The convergence of Deleuzian notions about the diagram, and the introduction of computational design tools initiating non-linear design processes, support the accommodation of 'non-linearity' in generative diagrammatic practices, defined by William Braham within the context of transformations in computational design practice;

> 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. [9]

Non-linearity in diagrammatic practices is assisted with computational design tools to enable the simultaneous capturing of changes, as well as the easy modification of identified relations. It is the dynamism of the process defined through non-linear practice that enables a free circulation between different stages, open to reciprocal interactions between them.

The non-linearity and dynamism of current diagrammatic practices, constructing and projecting design decisions, is also influenced by shifts in partnered disciplines such as art, architecture, mathematics and science. Therefore, it may be asserted that developments in technology, and shifts in both architectural design processes and representation techniques, also result in the diagram's shifting use and content.

4.1.1 Diagrams as Generative Devices

Defining the diagram as a proliferating machine, Ben van Berkel and Caroline Bos mark its current disjunction from conventional uses and state the significance of the diagram for the architectural design process as follows:

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[9] Braham, William. "After Typology: The Suffering of Diagrams." p. 11.

> For architecture, the diagram conveys an unspoken essence, disconnected from an ideal or an ideology that is random, intuitive, subjective, not bound to a linear logic that can be physical, structural, spatial, or technical. [10]

The diagram, defining the apparent or possible relations besides embedding condensed information, is a device that triggers a generative design process and proliferates design ideas.[11] Through diagrams, the designer does not only code the relations and forces or decodes them into material form, but also proposes a generative process detached from "pre-existing typologies": Van Berkel and Bos, making extensive use of diagrams in their architectural practice, define them as mediators of the design process and state that;

> We see it (diagram) as an external element, in between the object and the subject that we use to introduce other themes and organizations into a project with the aim of escaping from pre-existing typologies. [12]

Therefore, the condensed information inherited in the diagram defines a process that is suggestive and released from conventions. The traces of the diagram's potency in altering typological studies and proposing a generative process are also recognizable in the representation process. The diagrams have significant potential as means of representation, besides being generative and abstract tools in the design process. Defining a strategy, the diagram actively participates in and directs the process rather than passively representing established formal decisions. However, representation through diagrams differs from the conventional representation techniques in the sense that the diagram is considered as an agency between the real and the virtual, constructing formal indeterminacy:

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[10] Van Berkel, Ben and Bos, Caroline. "Diagrams, Interactive Instruments in Operation." p. 20.

[11] Ibid. p. 21.

[12] "Deep Planning,"
Editoriale Domus, Domus, http://www.edidomus.it/ Domus/magazine/edicola_articolo.cfm?codice =15787&lingua=_eng.
Last accessed in December 2005.

> An instrumentalizing technique such as the diagram delays typological fixation. An experimental or instrumental technique does not proceed as literally from signs. If aspects such as routing, time, and organization are incorporated into the structure using an instrumentalizing technique, concepts external to architecture are introduced into it rather than superimposed. Instances of specific interpretation, utilization, perception, construction and so on unfold and proliferate applications on various levels of abstraction, liberating the design from a tendency toward fixed typologies. [13]

Although the diagram is considered as a form of representation that compresses information in a logical and legible way, it triggers the designer's creativity and opens up new grounds for their interpretation. Since the abstracted representation of condensed information does not signify what it actually represents, such representation can stimulate new perceptions and insights. Van Berkel and Bos, leading significant architectural projects making use of diagrams and diagrammatic approaches, do not appraise diagrams as tools for representation and communication, but as a design method. They operate with the diagrams to activate the formation of design ideas and their interactive transformation. Van Berkel and Bos refer to the use of diagrams as an instrumental technique that goes beyond a mere representational design technique. They state that:

> A representational technique implies that we converge on reality from a conceptual position and in that way fix the relationship between idea and form, between content and structure. When form and content are superimposed in this way, a type emerges. This is the problem with an architecture that is based on a representational concept; it can not escape existing typologies. [14]

[13] Van Berkel, Ben and Bos, Caroline. "Diagrams, Interactive Instruments in Operation." p. 21.

[14] Ibid.

Van Berkel and Bos conclude that the use of diagrams as instrumental technique, opposed to their use as representational technique, obstructs typological fixation.[15] Consequently, the attention paid on the diagram's manifesting the relations and topological forces enables intense fusion of information into the diagram, at the expense of formal expressions.

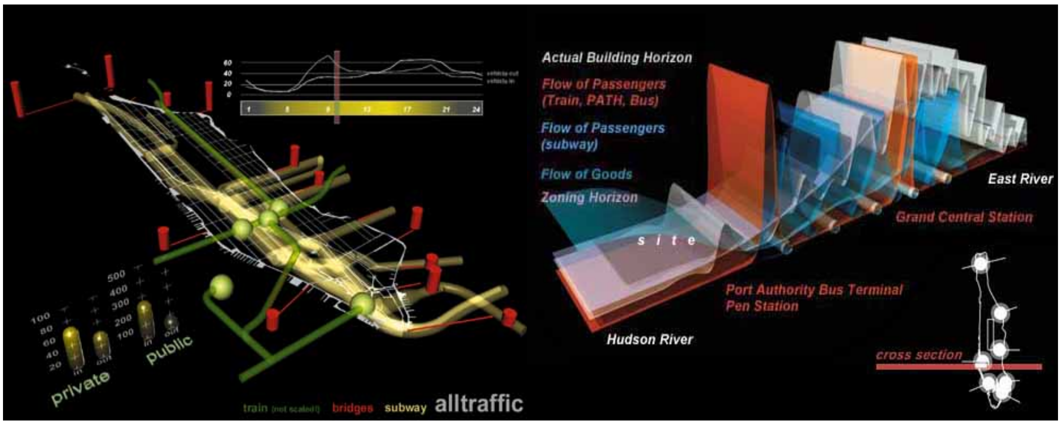

Figure 15: Representations of the diagram studies for IFCCA New York project by UN Studio. Van Berkel, Ben. And Bos, Caroline. *UN Studio UN Fold*. Rotterdam: Nai Publishers.

4.1.2 From Functional Diagrams to Abstract Machines

The use of diagrams in the architectural design process witnesses a radical shift when functional diagrams fall out of use, mostly with the introduction of the Deleuzian concept of the "abstract machine". In architectural practice, diagrams have mostly been used as to relate process, function and form. Rudolf Wittkower's introduction of the "nine-square grid" to describe Palladian villas in the late 1940s, Christopher Alexander's *Pattern Language* are instances of diagram-based studies and use of the so-called 'bubble' diagrams which aim to

[15] Ibid.

rationalize the formal solutions for the conditions described through the analytical use of diagrams.[16]

The functional use of diagrams, aiming to match requirements and functions with the most appropriate formal definition, used to find its most powerful architectural expression in Christopher Alexander's interpretation. Alexander defines diagram as "*a pattern which, by being abstracted from a real situation, conveys the physical influence of certain demands or forces*."[17] Alexander also introduces the term "pattern language" and the use of "patterns" in design, where he states that: "*A pattern is a careful description of a perennial solution to a recurring problem within a building context, describing one of the configurations which bring life to a building*." [18] Alexander's method is structured so as to notice and identify problems in order to describe the most effective solution and therefore formalize the process. [19]

The so-called 'bubble' diagrams, composed of bubbles, arrows, and labels, are used to represent sizes, adjacencies, and approximations etc. for various activities.[20] By means of drawing graphic assemblages, certain relationships are

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[16] Eisenman, Peter. "Diagram: An Original Scene of Writing." p. 27.

For further information about the analysis of Palladian villas see: Rudolf. Wittkower, "Principle of Palladio's Architecture, Palladio's Geometry: The Villas." *Architectural Principles in the Age of Humanism.* New York: Random House, 1965, pp. 70 – 76.

See :Alexander, Christopher. *A Pattern Language: Towns, Buildings, Construction*. New York: Oxford University Press, 1977. to get detailed informaiton about the Christopher Alexander's definition of"*pattern language*" and the use of "*patterns*" in design.

Also see Alexander, Christopher. *The Timeless Way of Building*. New York: Oxford University Press, 1979. where Alexander defines "*pattern language*" and how it applies to the design.

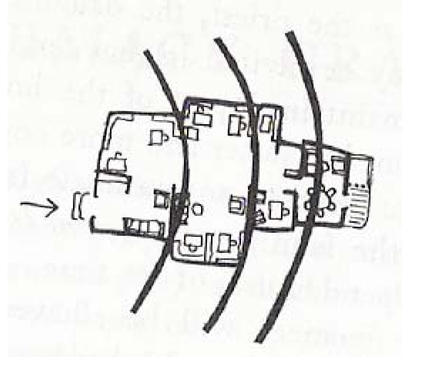
[17] Alexander, Christopher. *The Timeless Way of Building*. New York: Oxford University Press, 1979.

[18] Alexander, Christopher. *A Pattern Language: Towns, Buildings, Construction*. New York: Oxford University Press, 1977.

[19] Ibid.

[20] Do, Ellen Yi-Luen and Gross, Mark D.. "Thinking With Diagrams in Architectural Design," Univerdity of Washington, http://depts.washington.edu/ redline1/AIRE264.pdf.
Last accessed in December 2005.

highlighted, whereas size and shape are often left undetermined.[21] However, in cases, where it is aimed to define the most appropriate functional organization, the ‘bubble’ diagrams are directly converted into formal outcomes.



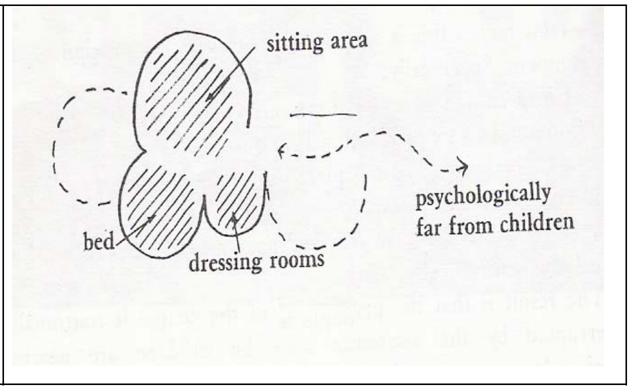


Figure 16 (left): The intimacy gradient for an office defined by Christopher Alexander.

Alexander, Christopher. A Pattern Language: Towns, Buildings, Construction. New York: Oxford University Press, 1977, p.612.

Figure 17 (right): ‘Bubble’ diagram for the organization of a room.

Alexander, Christopher. A Pattern Language: Towns, Buildings, Construction. New York: Oxford University Press, 1977, p. 650.

On the other hand, the Deleuzian notion of the “abstract machine” introduces a diagrammatic practice detached from material reality and representing not yet declared possible relations[22]:

> An abstract machine in itself is not physical or corporeal, any more than it is semiotic; it is diagrammatic…It operates by matter, not by substance; by function, not by form…The diagrammatic or abstract machine does not function to represent, even something real, but rather constructs a real that is yet to come, a new type of reality.[23]

[21] Ibid.

[22] Van Berkel, Ben and Bos, Caroline. “Diagrams, Interactive Instruments in Operation.” p. 21.

[23] Deleuze, Gilles. A Thousand Plateaus: Capitalism and Schizophrenia. Minneapolis: University of Minnesota Press, 1987, pp. 141-142.

In light of Deleuze's consideration of abstract machines, contemporary diagrammatic practices may be asserted to implement a more experimental and open-ended process. Since they are abstractions away from materiality, they function as conceptual devices that proliferate design ideas and trigger studies on topology. Being a description of potential relationships, distinct from material reality, abstract machines fall apart from the functional diagrams in that they do not suggest direct formal or relational implications. Emphasizing the departure of diagrammatic practice from the functional to the abstract, Stan Allen claims that:

> Unlike classical theories based on imitation, diagrams do not map or represent already existing objects or systems but anticipate new organizations and specify yet to be realized relationships. The diagram is not simply a reduction from an existing order. Its abstraction is instrumental, not an end in itself. Content is not embedded or embodied but outlined and multiplied. Simplified and highly graphic, diagrams support multiple interpretations. Diagrams are not schemas, types, formal paradigms, or other regulating devices, but simply place-holders, instructions for action, or contingent descriptions of possible formal configurations. They work as abstract machines and *do not resemble what they produce*.[24]

Therefore, the diagrams have no direct implication with their formal expressions, but rather generate multiple possible formal interpretations. Manuel De Landa, in his reading of Deleuze and diagrams, refers to such absence of inherent visual connection between diagrams and their representations, underlining as well that the visual aspect of diagrams is emphasized when used specifically for analytical or descriptive purposes.[25] De Landa refers to Deleuze's interpretation of matter-matter and matter-form relations in his philosophy of form-generation to explain further on the relationship between diagram and form:

[24] Allen, Stan. "Diagrams Matter." *Any Magazine.* No. 23, 1998, p. 16.

[25] De Landa, Manuel. "*Deleuze, Diagrams and the Genesis of Form." Any Magazine.* No. 23, 1998, p. 30.

> The question of the objective existence of problems (and their defining diagrams) is a crucial issue in Deleuze's philosophy of matter and form, a philosophy which attempts to replace essentialist views of the genesis of form (which imply a conception of matter as an inert receptacle for forms that come from the outside) with one in which matter is already pregnant with morphogenetic capabilities, therefore capable of generating form on its own. [26]

Therefore, the definition of relations takes over the definition of form in diagrammatic studies. Since formal definition emerges from the definition of relations between parts, different circumstances or changes in the relations may give rise to different formal definitions, hence also marking the shift from typology to topology.

4.2 Diagram Practices in Computational Design Approach

Computational design tools introduced provide a generative basis for creating and maintaining the sophisticated models of diagram studies. Visual programming languages and software used in computational design programs provide an ideal design environment to work through diagrams: These tools facilitate the definition of multiple layers besides their modification and interaction with each other.

Altered with the introduction of computational design tools such as parametric design, associative geometry, algorithmic procedures or scripting, the use of the diagram in the architectural design process delineates the dynamism in the process. With the aid of these computational design tools in transferring data and relations into the digital medium, focus is now placed on performance rather than on form.[27] In processes relying on diagrammatic abstraction, information inherited in a condensed and non-visualized form can be channeled through the computational design tools introduced.

[26] Ibid.

[27] Kolarevic, Branko. "Towards Non-Linearity and Indeterminacy in Design."

It has been mentioned in the previous chapter that a model is defined with the aid of computational design tools such as parameters, associative geometry, algorithms or scripts, enabling intervention on embedded information and interpretation for suggesting possible outcomes: Such computational design tools are seen to welcome and enable data input into the process.[28] Their association with the conceptual appreciation of generative diagrams seems to defeat the limitations of conventional design processes in handling complex situations. In the computational design approach where information is transferred and interpreted via codes, the diagram provides further in dealing with complexity and informing the design process. The ability to map complex situations and render inter-relations between entities extends into the interpretation of various possibilities in design and formal expressions. Moreover, the associated use of diagrams and the computational approach enables the definition of new relations, highlights new reference systems and allows multiple interpretations of the information driven in.

4.2.1 Abstracting Multiple Layers of Information through Diagrams

Through the application of diagrams as abstract machines, the designer can scan diverse situations and define existing or possible relations. Since the information flow is continuous, abstract machines come in multiple layers of condensed information. Therefore, the diagrams implicate multiple layers of information and relations overlapped on each other.

Composed of a set of layers, the diagram associates substances with relations so that it abstractly renders their multiple sequences into one.[29] Moreover, by rendering multiple functions and actions over time, the diagram also embeds multiple layers of thought and phases of work undergone. Layers overlapping

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[28] Glynn,Ruairi. "Interactive Architecture: Building Space Between the Physical and Virtual," Ruairi Glynn-Medialab Arts, http://www.ruairiglynn.co.uk/medialabarts/dissertation/rglynninteractivearch.pdf.
Last accessed in December 2005.

[29] Eisenman, Peter. "Diagram: An Original Scene of Writing." p. 29.

with others and defining cross-structures, also allow for modifications, enabling revisions and progressions between the multiple layers of information: The diagram hence assists the anticipation of new relations and defines a generative process.

Figure 18: Multiple Layered diagram study for IFCCA_New York project by UN Studio.

Van Berkel, Ben. And Bos, Caroline. *UN Studio UN Fold*. Rotterdam: Nai Publishers.

Owing to the multiple layers of the diagram, it is possible to add or take out information from the diagram. Since any layer in the diagram's definition can be reached individually, altering the information inherited in any specific layer does not necessitate extra work-load. Moreover, it also suggests the potential of switching the individual layers on and off, which may lead to the gradual or abrupt transformation of a multi-layered diagram into a simple one or vice versa. The designer can also change the opacities of the layers either technically or conceptually, through which s/he can interpret the relations established, or define new organizations. Working through the layers of information, where the designer can add new layers, delete some or change the opacities of the layers, brings together the advantage of experimentation with different perspectives and insights.

4.2.2 Continuous Data Integration into the Diagrams

Diagrams in computational design processes are structured to respond to the constant evolution of relations and forces with data integration and modification. The diagram, assisted with computational design tools which can respond to continuous data flow, adapts itself to the currently defined conditions with a minimum work-load. This versatility of the diagrammatic structure makes possible to work actively on all levels, that are either dependent or independent of each other. The designer can decide which layers will be modified and which layers will actively respond to this modification. With this freedom offered in the depiction of relations, data input and data modification, the use of diagrams suggest different perspectives and numerous solutions in one model.

Moreover, the diagram acting as an infra-structural element can be rendered as supplying continuous feedback to the relations altered in different phases of design. Since the diagrammatic model defined is open to interventions, modifications, data entries or take outs, such feedback supply makes it possible to end up with infinitely variable relations and organizations which are not declared yet. Hence, numerous solutions can be defined through modifications and redefinitions on the same model throughout the design process.

In order to attain the desired generativity and ease of data integration to the process and the diagram, data is indicated and transferred through codes. Relations and forces are condensed in the codes during the computational design process, which makes possible their use throughout the whole process. Owing to the codes used, both the diagram and the other phases of the design process can easily assimilate data. Changes in the codes, affecting the relationships and thus the behavior of the whole model, can be absorbed because of simultaneous adaptability of computational design tools to the newly defined conditions.

4.2.3 Non-visualization and Delay of Formal Expression in Diagrammatic Practices

Being abstracted structures of relations and forces associated with a definite circumstance, diagrams generate possible interpretations of these relations, which in reality do not have a visual connection with what they produce. [30] Since the use of diagrams defines the mediation between the conceptual analysis of relations and their material outcomes, the conscious delay of formal expression gives the opportunity to experiment on the circumstances through the modification of relations or data. These modifications provide feedbacks to the diagram, as well as the other phases of the process, leading to the constant evolution of the diagram and consequently the whole process. Therefore, the formal expressions of these ever-changing relations are delayed consciously to facilitate the definition of a generative design process. This shift marks the departure from the functional use of diagrams, which intend a translation of the diagram into its formal expression.

Parallel to the shifts in computational design processes, which intend to highlight process rather than form, contemporary diagrammatic practices also intend to delay formal expression as much as possible. The conscious delay of formal expression releases design ideas from visual and formal constraints, giving way to a constantly evolving process in which the diagram provides continuous feedback of new relations and organizations.

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[30] De Landa, Manuel. "*Deleuze, Diagrams and the Genesis of Form.*" p. 30.

Diagrammatic practices, suspending visual representation for the sake of indicating relations and possible organizations, are seen to acquire importance and significance in computational design processes, in which interventions, modifications and data integrations can be eased with the help of tools. In order to achieve the desired generativity in computational design processes and to overcome the pragmatic determinism of formal expressions, the relations and forces affecting different layers of the diagram are altered or redefined constantly, thus delineating the maximization of possible outcomes.

In computational design processes, the relations and the data integrated to the diagram are coded, responding to all phases of the process, such as conception, manufacturing or representation. This non-visual representation in the code, instead of drawings, sketches or visual images, underlines the importance placed on process and information feedback, leading to the delay of formal expression.

Hence, following the altered mode of the architectural representation process, the guidance of diagrammatic studies in a computational design process blurs formal representation, and underlines the significance of process and information entry into the system. Through the coding of data, which can be handled easily via these tools, an instrumental representation is attained that enables conceptual, material and formal interpretations. In fact the ability to represent the development of process and form at any stage not only results from numerical and parametric representation, but also from the diagram's definition as a conceptual device. The diagrammatic practice poses a non-visual character in parallel with the computational strategies previously discussed. Being a network of relations, the diagram actively takes part in the construction of a non-visual language through its information-based representation gradually replacing conventional means of abstraction such as sketches and models.

The computational design tools, thus aid the diagrammatic process in the sense that, they enable the operative use of diagrams in a dynamic design process where formal expression has been suspended. Since computational design processes also consciously intend to delay formal expression, the use of diagrams as abstract machines help to attain the desired indeterminacy and liberation from visual constraints. Working through computational tools also eliminates the need for a representational interface, since the model enables to visualize the possible outcomes of an actual situation without any extra work-load. Thus, the use of visual programs in design processes based on diagrammatic software and continuous data flow, promotes the designer's work with diagrams.

4.3 Diagram-based Architectural Practices: Un Studio

One of the architectural offices that experiments with diagrams and computer-aided manufacturing techniques in order to explore their inherent potentials and define a generative design process is *UN Studio*. The design process of the master plan for a station area in *Arnhem* (1996-2007) is dependent on diagram-based studies that integrate time and user-based approaches into the process.[31] Consisting of six different transport systems met on the station area, the *Arnhem Central Project* defines an infrastructural organization guided by the search for overlapping areas of shared parameters and common values.[32] Emphasizing that the project is conceptualized on the basis of movement studies, the architects Ben van Berkel and Caroline Bos state that:

> Movement studies are the cornerstone of the proposal: the analysis of the types of movement on location includes the directions of various trajectories, their prominence in relation to other forms of transportation on the site, duration, links to different programs and interconnections. [33]

With the help of these motion studies on the physical movement flows of residents, city users, metropolitan business people or travelers in the Transfer

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[31] Van Berkel, Ben. And Bos, Caroline. *UN Studio UN Fold.* Rotterdam: Nai Publishers.

[32] Van Berkel, Ben and Bos, Caroline. “Diagrams, Interactive Instruments in Operation.” p. 22.

[33] Van Berkel, Ben. And Bos, Caroline. *UN Studio UN Fold.*

Zone Arnhem, *UN Studio* is scanning the site, and thus revealing the potentials of the station. Claiming that the flows of these physical movements of people make possible to define the relations between duration and territorial use, van Berkel and Bos state that:

> From these motion studies the station area gradually begins to emerge as a landscape of interrelated movements. The holes in this landscape create a system of shortcuts between programs, a hybrid of a centralized system and an exhaustive pattern of all possible connections. [34]

Subsequent to these studies, *UN Studio* introduces the diagram to abstract the information and relations scanned, which also helps to define the spatial, structural and technical organization required.[35] Accordingly, the "Klein bottle" diagram is introduced, which provides the necessary references for the transformations. [36]

Van Berkel and Bos make both a pragmatic and diagrammatic use of the "Klein bottle" diagram as an infrastructural element, as it helps to connect the different parts of the program and define a whole structure.[37] The architects highlight the advantage of using the "Klein bottle" diagram and state that *"The Klein bottle is as deeply ambiguous as it is comprehensive; it stays continuous throughout the spatial transformation that it makes to go from being a surface to a hole and back again."* [38]

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[34] Van Berkel, Ben and Bos, Caroline. "Diagrams, Interactive Instruments in Operation." p. 22.

[35] Editoriale Domus, Domus, http://www.edidomus.it/Domus/magazine/edicola _articolocfm?codice=15787&lingua=_eng.
Last accessed in December 2005.

[36] Van Berkel, Ben and Bos, Caroline. "Diagrams, Interactive Instruments in Operation." p. 22.

[37] Ibid.

[38] Ibid.

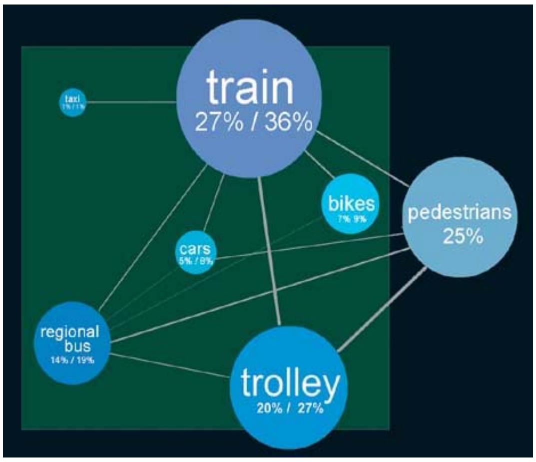

Figure 19 (left): Motion studies for the station area of Arnhem by UN Studio.

Editoriale Domus, Domus, http://www.edidomus.it/Domus/magazine/edicola _articolocfm?codice=15787&lingua=_eng.
Last accessed in December 2005.

Figure 20 (right): The Klein bottle diagram used as an infrastructural element for the station area of Arnhem by UN Studio.

Editoriale Domus, Domus, http://www.edidomus.it/Domus/magazine/edicola _articolocfm?codice=15787&lingua=_eng.
Last accessed in December 2005.

Starting with the idea that a "landscape with holes could also be perceived as a knot of planes", *UN Studio* defined the mathematical knots, which successively guided the spatial transformation of the surface into a whole through the conceptual implementation of the "Klein bottle" diagram.[39] Therefore, the "Klein bottle" diagram actively participated in the process where it guided the spatial, structural and technical interpretation. The diagram is seen to proliferate design ideas and evoke new insights into the process in the master plan studies for the *station area of Arnhem*.[40]

[39] Ibid.

[40] Ibid. p. 20.

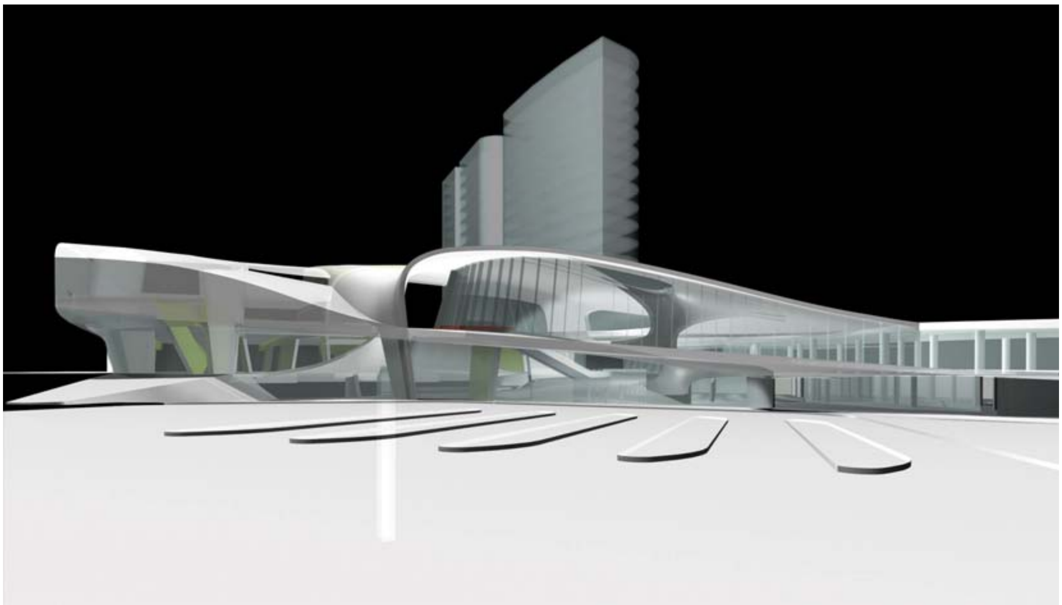

Figure 21: The side view of the station area of Arnhem by UN Studio.

Van Berkel, Ben. And Bos, Caroline. *UN Studio UN Fold*. Rotterdam: Nai Publishers.

Another project by *UN Studio*, in which the diagram is interpreted as a proliferator of design ideas and an abstract machine, is the *Möbius House* in Amsterdam (1993-1997). The house is designed for two users; husband and wife, who require both intimacy and separation during their 24-hour cycle.[41] Associating the project with their thoughts on contemporary life styles and their interpretation of movement studies as the infrastructural elements of design, van Berkel and Bos used the Möbius strip as the conceptual reference of the project.[42] The Möbius strip of two continuous lines that intersect and form a double spiral symbolizes the intersection of the two spaces, living and working, that form the basis of the house.[43] The Möbius strip is used as a conceptual reference since it enables the

[41] "Between Ideogram and Image-Diagram,"
Aarhus School of Architecture, http://www.a-aarhus.dk/~v/tekster/ideogram.rtf,
Last accessed in December 2005.

[42] Ibid.

[43] Ibid.

use of time in relation to the distribution of the program.[44] Therefore, different activities are condensed into one single structure where work, social life, family life and individual time are all displayed and participate in the definition of the loop structure.[45]

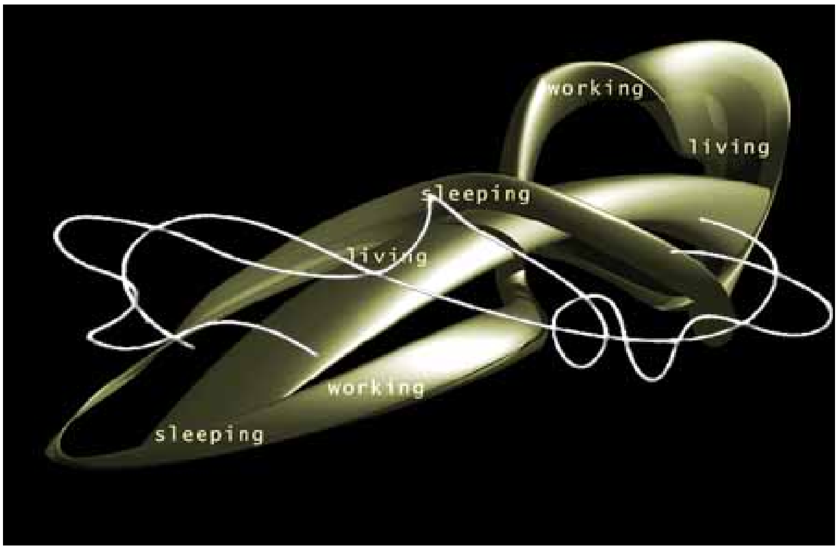

Figure 22: The Möbius strip used as a conceptual reference to associate the program and the movement aspects for the Möbius House project by UN Studio.

UN Studio, http://www.unstudio.com.
Last accessed in December 2005.

Structured with the information gathered from the daily life activities of the inhabitants, the movement through the double-locked torus signifies the organization of the activities around a continuous loop.[46] However, the use of the Möbius strip as an abstract machine throughout the design process remains conceptual and thematic since the literal reflection of the mathematical model of

[44] UN Studio, http://www.unstudio.com.
Last accessed in December 2005.

[45] Ibid.

[46] Floornature, http://www.floornature.com/worldaround/articolo.php/ art70/3/en.
Last accessed in December 2005.

the Möbius on the building is consciously avoided.[47] Stressing the significance of diagrams in architectural design process with reference to the *Möbius House* design experience, Van Berkel states that:

> While the Möbius diagram introduces aspects of duration and trajectory, the diagram is worked into the building in a mutated way. The instrumentalization of this simple, borrowed drawing is the key. The two interlocking lines are suggestive of the formal organization of the building, but that is only the beginning; diagrammatic architecture is a process of unfolding and ultimately of liberation. The diagram liberates architecture from language, interpretation and signification. [48]

Figure 23: The Möbius House project by UN Studio.

Archinect, http://www.archinect.com/gallery//displayimage.php?pos=-1429.
Last accessed in December 2005.

[47] UN Studio, http://www.unstudio.com.
Last accessed in December 2005.

[48] Ibid.

CHAPTER 5

CONCLUSION

As a consequence of developments in technology and computer-aided communication means, as well as studies in mathematics, geometry and science, the conception of space, its perception and visual expression have undergone significant changes in the 20th century. This radical shift was subsequent to the introduction of computational design tools, which altered the conventional architectural design approach, and opened up new grounds for the generation and experimentation of design ideas. Parallel to the changes in the design process, ways of representing design ideas have undergone significant changes. This study argued that the architectural representation process, acting as a critical design and communication tool for centuries, experienced a conceptual shift under the influence of computational design strategies and practices.

Studies on non-Euclidean geometry and n-dimensional geometries, which have stimulated the conception of time as a leading notion in design, have had significant consequences not only in science but also in art and architecture. The developments in mathematics and geometry, altering the perception of space, as well as the introduction of computational design tools, have triggered the redefinition of the architectural representation process. These developments, guided with the introduction of computational design tools, can be asserted to have given rise to new representational techniques and outputs, such as parametric models, animations, algorithms or 3D prints.

Emergent developments have also led to the alteration of the orthographic set, used for centuries for the conception and representation of design ideas, with the numeric set, introduced by computational design tools. Since the orthographic set used in representing design ideas could not match the complexity and flexibility of the parametric models defined through the computational design tools, numeric sets, operative in any phase of design, have been used in the recently defined design approaches.

Taking the advantage of using a numeric set in a design process defined and aided by computational design tools, the designer is unburdened from the usual conventions of form-generation processes. Within this newly defined realm, the attention is placed on the process rather than the definition of form, since form is generated by interactions among influences, relations, constrains or rules. In view of the fact that, these models are open to continuous data input with their responsive and flexible structure, infinite variables can be defined, instead of fixed design solutions. [1]

As a consequence, embracing computational design tools, architectural representation marks a historic step so as to reform into the indeterminacy of open-ended and responsive models offered. These changes mark the necessity of redefining the process of architectural representation in order to assist computational procedures and attain the desired generativity. Leading to the emergence of new formal definitions and unpredicted solutions, the generative design process has shifted the issue of form-making to that of form-finding:

> The predictable relationships between design and representations are abandoned in favor of computationally-generated complexities. Models of design capable of consistent, continual and dynamic transformation are replacing the static norms of conventional processes–fixed solutions are rejected and replaced with an open-ended exploration of infinitely variable potentialities. The emphasis shifts from the "making of form" to the "finding of form," which various digitally-based generative techniques seem to bring about intentionally. [2]

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[1] Kolarevic, Branko. "Digital Praxis: From Digital to Material."

[2] Ibid.

Computational tools are less used in visualization than in the derivation and transformation of form.[3] Within the computational realm, the idea of an a-posteriori representation after the finalization of a design output is replaced with temporary visualizations during the process. Attention shifts from visualization to process in order to attain the desired indeterminacy and unpredictability of possible outcomes in computational design processes, which are seen to search for the definition of a non-linear, parametric model that continually evolves with data integration. As a result, visual representation is consciously delayed to permit the constant evolution of design ideas and allow liberation from the visual/formal constraints of the conventional design approach.

Discussing the significance of the departure from conventions about visual images and patterns as well as their formal expressions in this study, the indeterminacy of computational design processes has been claimed to account for the abandonment of predictable relationships between process and form. Intentionally aiming for indeterminacy and flexibility, the new design strategies have been considered as providing a generative medium for the creation of new design ideas and dynamic operations, and the potentials presented by indeterminate models have been discussed.

The 'over-constraint' problem encountered by the designer has been referred to[4], in order to point at the importance of the degree of dependency between the relations and different parts of a model, in defining the desired indeterminacy and non-linearity. In order to avoid unintentional 'over constraint problems', the relations and equations need to be defined by taking into consideration possible interventions, so that the model can be flexible enough in adapting to various circumstances. However, considering all circumstances and their possible outcomes while defining the parametric model may result in a problematic

[3] Kolarevic, Branko. "Towards Non-Linearity and Indeterminacy in Design."

[4] Burry, Mark. "Between Intuition and Process: Parametric Design and Rapid Prototyping." p. 150.

situation, defined by Kolarevic as ‘a potential thinking overload’ for the conventionally trained designer.[5]

In order to achieve the desired flexible and experimental state, computational design processes have been seen to aim at overcoming the pragmatic determinism of conventional design approaches through conscious delay.[6] Based upon an evolving structure, the process can take the advantage of such ‘*systemic delay’* and maximize the potential of creativity with the aid of computational design tools.[7] The opportunity offered with the delay of representation capitalizes the process, resulting in significant alterations in the definition of the interface between process and representation. The thesis has underlined the significance of this shift in architectural representation processes, its possible consequences on the perceptual and cognitive fields of the designer, as well as his/her personal adaptation to this shift. The possible outcomes of delaying visual representation have been outlined as producing a ‘perceptual deception’ and ‘disorientation’ conflicting with the designer’s conventional training.[8]

This thesis has argued that the delay of representation consequent to the use of informative relations, gives rise to new experiences, hence to new experimental studies for the designer. By taking the advantage of this delay, the designer acquires the opportunity to generate multiple relations and re-evaluate an open-ended process constantly responsive to changes. In a generative process extending the visual determinism of conventional design, the formal repertoire evolves within a constant evolution of design ideas.

In this context, the study has referred to the use of diagrams as generative devices proliferating design ideas, as undertaking a critical role in computational design

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[5] Kolarevic, Branko. “Digital Morphogenesis.”

[6] Rahim, Ali. “Systemic Delay: Breaking the Mold.” p. 7.

[7] Ibid.

[8] Mennan, Zeynep. “From Number to Meaning: Prospects for a Quantitative Hermeneutics at Istiklal.”

processes, emphasizing their promotion of visualization delays and of studies focused on process rather than form. Diagrammatic practices have been analyzed in accordance with the shifts in architectural design and representation processes, referring to Deleuzian notions that redefine the discursive field. Diagrams, containing multiple layers of condensed information, are regarded as suspending the formal expression of design ideas, and stimulating the definition of a generative design process detached from formal/visual constraints. The computational design tools have been seen to support diagrammatic practices, as they ease data flow to the system defined, besides the manipulation of data under different circumstances. Therefore, architectural representation processes in diagrammatic practices are asserted to witness significant changes relative to the developments in computational design tools.

This new mode of representation requires also the self-adaptation of the conventionally trained designer to the new design environment. The designer should have the required knowledge about different disciplines and control over the digital design tools in order to acquire necessary information and inspiration as well as advantage of this new design environment. Manuel De Landa highlighting this paradigm shift states that:

> Architects wishing to use this new tool must not only become hackers (so that they can create the code needed to bring extensive and intensive aspects together) but also be able "to hack" biology, thermodynamics, mathematics, and other areas of science to tap into the necessary resources.[9]

Moreover, since operations on parametric software also signify design assessments, the designer needs to actively participate in the process of computing. Replacement of control over form with relational control, initiates an environment open to creativity and the exploration of new forms. The shift from a deterministic to a non-deterministic process demands "a new intellectual

[9] De Landa, Manuel. "Deleuze and the Use of the Genetic Algorithm in Architecture."

disposition", the giving up of an acquired mental set for adaptation into another.[10] The designer, trained within the orthographic and 3D model representation media, has to adapt to newly defined grounds for design and architectural representation.

The role of the designer has also changed significantly, since s/he simultaneously works on design and manufacturing phases as a consequence of the direct numerical link established between different phases of the design process.[11] By using the same computational model, information about manufacturing procedures are directly derived from the parametric model defined in earlier stages, overflowing the representation process based on orthographic drawings and introducing the use of non-visual, numeric definitions.

Changes in architectural design processes have followed paradigm changes in mathematics and geometry, and the increasing use of the computer as a generative device, altogether altering representation processes in architecture. The assistance of computational tools has blurred the boundaries between different phases of the process of design, all converted into the same numerical language, in which the designer now operates, questioning his/her conventional role and mental, technical equipments. The thesis has argued for overcoming the determinisms of conventional design processes, in favor of a generative process where the representation process is consciously delayed.

[10] Mennan, Zeynep. "Des Formes Non Standard: Un 'Gestalt Switch'."

[11] Kolarevic, Branko. "Digital Praxis: From Digital to Material."

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