A RECONSIDERATION OF THE CONCEPT OF ARCHITECTURAL SPACE IN THE VIRTUAL REALM

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

BY

GÖKHAN KINAYOĞLU

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

SEPTEMBER 2007

Approval of the thesis:

A RECONSIDERATION OF THE CONCEPT OF ARCHITECTURAL SPACE IN THE VIRTUAL REALM

submitted by **GÖKHAN KINAYOĞLU** in partial fulfillment of the requirements for the degree of **Master of Architecture in Department of Architecture, Middle East Technical University** by,

Prof. Dr. Canan Özgen
Dean, Graduate School of **Natural and Applied Sciences** _________________

Assoc. Prof. Dr. Güven Arif Sargın
Head of Department, **Architecture** _________________

Assoc. Prof. Dr. Zeynep Mennan
Supervisor, **Department of Architecture, METU** _________________

Examining Committee Members:

Assoc. Prof. Dr. Ayşen Savaş
Department of Architecture, METU _________________

Assoc. Prof. Dr. Zeynep Mennan
Department of Architecture, METU _________________

Asst. Prof. Dr. Mine Özkar
Department of Architecture, METU _________________

Instr. Dr. Namık Günay Erkal
Department of Architecture, METU _________________

Asst. Prof. Dr. Şebnem Yalınay Çinici
Department of Architecture, Yıldız Technical University _________________

Date: September 6, 2007

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Gökhan Kınayoğlu

ABSTRACT

A RECONSIDERATION OF THE CONCEPT OF ARCHITECTURAL SPACE IN THE VIRTUAL REALM

Kınayoğlu, Gökhan
M. Arch Department of Architecture
Supervisor: Assoc. Prof. Dr. Zeynep Mennan

September 2007, 92 Pages

The discovery of new geometries in the 19th century and the departure from an absolute to a relative understanding of space-time, together with the invention of higher dimensions have caused a shift towards the idealization of space. This new type of ideal space was called hyperspace. The counter-intuitive quality of hyperspace has opened up new formal possibilities and representation techniques in art and architecture. In a similar manner, with the introduction of computers, the virtual and immaterial quality of cyberspace has offered new design techniques and forms to architecture. Algorithmic design tools and the use of surface as the primary architectural element in cyberspace have caused a shift in the conception of space together with the way it is perceived.

Taking its departure point from physical space, this thesis investigates the upper and lower dimensions of space in order to understand and analyze the current conception of architectural space in the virtual realm. Three types of spatial qualities are investigated in detail: the ideal characteristic of hyperspace, the visual medium of cyberspace and the algorithmic formation of hypospace.

Keywords: New geometries, hyperspace, cyberspace, algorithmic design, surface.

ÖZ

MİMARİ MEKAN KAVRAMININ SANAL ALEMDE YENİDEN DEĞERLENDİRİLMESİ

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

Eylül 2007, 92 Sayfa

Mutlak bir yapıdan çıkarak göreceli bir anlayışa kavuşan zaman-mekan anlayışı ve 19.yy'da keşfedilen yeni geometriler ve üst boyutların bulunması ile üst uzay olarak adlandırılan ideal bir mekan anlayışı ortaya çıkmıştır. Üst uzayın sezgi karşıtı yapısı, sanatta ve mimarlıkta yeni biçimsel olasılıklar ve sunum teknikleri sağlamıştır. Benzer bir şekilde, bilgisayarların gelişi ile birlikte, siber uzayın sanal niteliği mimarlığa yeni tasarım teknikleri ve biçimler sunmuştur. Siber uzayda algoritmik tasarım araçları ile birlikte yüzeyin başlıca mimari yapı öğesi olarak kullanılmaya başlanması, mekanın kavranmasının yanı sıra algılanmasında da farklılaşmalara yol açmıştır.

Çıkış noktasını fiziksel mekan olarak alan bu tez, sanal alemdeki mimari mekanın mevcut yapısını anlamak ve analiz etmek için mekanın üst ve alt boyutlarını incelemektedir. Bu amaçla üç çeşit mekanın niteliği ayrıntılı bir şekilde incelenmektedir: üst uzayın ideal karakteri, siber uzayın görsel ortamı, ve son olarak, alt uzayın algoritmik yapısı.

Anahtar sözcükler: Yeni geometriler, üst uzay, siber uzay, algoritmik tasarım, yüzey.

ACKNOWLEDGEMENTS

The first and the most important of all, I would like to express my sincere gratitudes to my supervisor Assoc. Prof. Dr. Zeynep Mennan for her invaluable support and guidance, in addition to her endless patience to my constant postponings throughout the study.

I would like to thank my jury members Assoc. Prof. Dr. Ayşen Savaş, Asst. Prof. Dr. Mine Özkar, Inst. Dr. Namık Günay Erkal, and Asst. Prof. Dr. Şebnem Yalınay Çinici for their comments and suggestions.

I also would like to thank my family for their support, which for certain I will find whenever I need.

And last, but not least, I am grateful to Emine Kılıç, Elif Ensari and Refik Burak Atatür for standing behind in my rare moments of productivity.

TABLE OF CONTENTS

ABSTRACT iv

ÖZ vi

ACKNOWLEDGEMENTS viii

TABLE OF CONTENTS ix

LIST OF FIGURES xi

1. INTRODUCTION 1

2. HYPERSPACE / IDEALIZATION – REPRESENTATION 5

2.1 Euclidean Geometry and the 5th Postulate 5

2.2 Counter-intuitive Geometric Models of Space 8

2.2.1 Non-Euclidean Geometries 9

2.2.2 n-dimensional Geometries 13

2.3 Physical Space and Ideal Space (extra-perceptual realm) 16

2.4 Representation Crisis: Debates on the Concept of Hyperspace 19

2.4.1 Idealization of the 4th Dimension: Seeing with the Mental Eye 20

2.4.2 Reflections of the Debate in the Artistic and Architectural Realm 22

3. CYBERSPACE / VISUALIZATION – DEMATERIALIZATION 26

3.1 Re-Idealization of Space: Cyberspace 26

3.1.1 The Cartesian Coordinate System 33

3.1.2 The Concept of Scale in Cyberspace 35

3.2 Algorithmic Design Tools 41

3.2.1 Development of CAD/CAM Software and Non-Euclidean Geometries 44

3.2.1.1 Non-Uniform Rational B-Splines (NURBS) 45

3.2.2 Parametric Design.. 48

3.3 The nth Dimension in Cyberspace.. 53

3.3.1 Higher Dimensions Through Multiple Variables 54

3.3.2 Family of Forms: Form Finding vs. Form Making.............. 56

4. HYPOSPACE / PARAMETERIZATION – MATERIALIZATION..... 60

4.1 The Formal Shift From Space to Surface in Virtual Realm ... 61

4.1.1 Effects of Algorithmic Design on the Concept of Surface .. 70

4.2 The Fold as an Agent 74

4.3 Hypospace: The Deduced n^{th} Dimension................................ 78

4.3.1 The Increasing Perceptual Gap Between Virtual and Real Space 80

5. CONCLUSION... 82

REFERENCES 85

LIST OF FIGURES

Figure 1: Pseudosphere. 10

Figure 2: Mobility of a piece of cloth on an eggshell. 12

Figure 3: A central projection of hypercube. 15

Figure 4: Hinton’s multi colored cubes 21

Figure 5: “Portrait of Ambroise Vollard,” by Pablo Picasso. 1910. 23

Figure 6: “Development of a Bottle in Space,” by Umberto Boccioni, 1911. . 24

Figure 7: “The Knife Grinder,” by Kasimir Malevich, 1912. 25

Figure 8: A screen capture from MUD 29

Figure 9: A screenshot from Habitat. 31

Figure 10: A screenshot from a contemporary Massively Multiplayer Online Game. 32

Figure 11: The seahorse fractal. 36

Figure 12: NYSE 3DTF Virtual Reality Environment 38

Figure 13: NYSE 3DTF Virtual Reality Environment 38

Figure 14: A screenshot from Marcos Novak’s “Liquid Architectures.” 40

Figure 15: A screenshot from Marcos Novak’s “Liquid Architectures.” 41

Figure 16: A NURBS Curve. 46

Figure 17: Parametric Monorail Station. 51

Figure 18: Variation of the Parametric Monorail Station. 51

Figure 19: Partial script of Parametric Monorail Station. 52

Figure 20: “Hystera Protera,” a family of forms. 57

Figure 21: Interactive computer model of transPORTs2001 58

Figure 22: Computer rendering of the physical model. 59

Figure 23: Conceptual model of “Dynaform” by Bernhard Franken, an example of a monocoque structure. 63

Figure 24: A view from MUTEN Istanbul Project (2006). 65

Figure 25: CNC-milled formworks of Embryo House, by Greg Lynn. 68

Figure 26: Eberswalde Library by Jacques Herzog and Pierre de Meuron 69

Figure 27: “Tables Projectives” by Objectile 73
Figure 28: “Stranded Sears Tower,” by Greg Lynn, site model. 77
Figure 29: “Stranded Sears Tower,” by Greg Lynn, plans of various tubes..... 77

CHAPTER 1

INTRODUCTION

> "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."[1]

Computers have altered both the design process and representation techniques in architecture. Used as a drafting device during the early years of their introduction, computers have evolved from a mere drafting and representation device into an autonomous design medium, offering the possibility of exploiting new geometries and design techniques. These new geometries and techniques have altered architecture; both in the way it is designed and the way it is conceived. The thesis will study these differentiations brought forth by the virtual medium in its attempt to understand and trace the alterations in the concept of space in architecture.

Euclidean geometry, discovered by Euclid around 300 B.C., has been accepted as the perfect systematization of space for centuries.[2] The orthographic set of representation and linear perspective are representation techniques that benefit from Euclidean geometry, which was thought to be the one and only way of

---

[1] Branko Kolarevic, "Introduction," in Architecture in the Digital Age: Design and Manufacturing, ed. Branko Kolarevic, New York: Spon Press, 2003.p.15.

[2] Bernard Cache, "Plea for Euclid" in http://architettura.supereva.com/extended/19990501/ep07en_01.htm Last accessed on August 2007.

constituting a geometrical system. However as stated by Linda Dalrymple Henderson, the discovery of non-Euclidean geometries in the 19th century by Nikolai Ivanovich Lobachevsky, Janos Bolyai and Georg Friedrich Bernhard Riemann has shown the possibility of different geometric systems.[3] The non-Euclidean geometries have opened up counter-intuitive geometric forms and the possibility of conceiving and representing higher dimensions of space, namely hyperspace which exceeds the three dimensions of physical space.

Various attempts were made to prove the existence of a spatial fourth dimension in the 19th century, which was initially tried to be conceptualized as a spatial entity like the first three dimensions, and only accepted as a temporal extension after Albert Einstein's "Theory of Relativity".[4] The ideal quality of this space composed of four dimensions, called hyperspace, prevented it from being represented through standard representation techniques like linear perspective. For that reason, a search for new techniques in art has been in the agenda towards the end of the 19th century. The invention of higher dimensions have caused a rupture in art and architecture in the first quarter of the 20th century, which resulted with movements like Cubism, Dadaism, Constructivism and Futurism, searching for new conceptions of space and alternative ways of representation beyond linear perspective.[5] The interpretation of time as a spatial dimension has turned the concept of time and movement into an integral part of these artistic styles.

The possibility of implementing virtualities into the computer has introduced a new kind of ideal space, namely cyberspace. Unlike hyperspace, cyberspace has a vast scope of visualization capabilities. For that reason, cyberspace has become a perfect model for representing concepts like hyperspace, non-

---

[3] Linda Dalrymple Henderson, The Fourth Dimension and Non-Euclidean Geometry in Modern Art, Princeton: Princeton University Press, 1983.

[4] Ibid.

[5] Ibid.

Euclidean geometries, fractals and higher dimensions that were hard to visualize beforehand.[6] However, it is not through its extended visual capabilities that cyberspace mainly affects architecture.

The ideal quality of cyberspace and computers have made algorithmic and parametric design techniques an integral part of computer-aided design. Algorithmic and parametric design allow architects to focus on the forces, fields and associations among entities rather than the final shape of the design. The design process with this technique does not involve a form making procedure but instead, the formal alternatives offered by a parametric model allow architects to choose from a "family of forms."[7] Therefore the architect does not draw the final form of the building but s/he deals with the algorithmic and parametric relations running in the background of the project. In cyberspace, projects with discrete forms are replaced with an ideal formation of continuity through parametric design processes. By changing the parametric values, the designer achieves various topological formations of the same object, all of which can be visualized with the same amount of detail, regardless of their formal or mathematical complexity. As a result, the architect designs a formless object or in other words a topological form.

The use of parametric design also introduces the concept of multidimensional design. By constructing a network of parameters through geometric associations, architects arrive at a complex system of relations, with each parameter creating a new dimension of the project. All possible values of a parameter create a group of different configurations for the project. As a consequence, a parameter's "family of forms" creates a separate dimension. In

---

[6] Michael Benedikt, "Cyberspace: Some Proposals," in Cyberspace: First Steps, ed. Michael Benedikt, Cambridge, Massachusetts: The MIT Press, 1991. p.122.

[7] Branko Kolarevic, "Digital Morphogenesis," in Architecture in the Digital Age: Design and Manufacturing, ed. Branko Kolarevic, New York: Spon Press, 2003. p.26.

other words, the higher the number of parameters the project consists of, the higher dimensions it governs.

The virtual realm has added an immaterial quality to architectural practice with no connections with the physical world. In this ideal world of the cyberspace, the constituents of architecture have also changed from physical materials to geometric elements, leading to the recent priority of the surface. With the departure from the material constraints of the physical world, surface has introduced distinct geometrical possibilities into architecture, becoming the only constituent of architecture in cyberspace.

To understand the alterations and shifts in the architectural space of the virtual realm, this thesis will mainly focus on the differentiations on the conception of space within cyberspace under the influence of new design techniques and geometries together with the upper and lower conceptions of space; the hyperspace and the hypospace.

CHAPTER 2

HYPERSPACE
IDEALIZATION – REPRESENTATION

2.1 Euclidean Geometry and the 5th Postulate

Considered as one of the oldest scientific research in geometry, Euclid's *Elements* (ca. 300 B.C.) formulated a system of deductive geometry.[8] It is known that previous studies were made on geometry in Ancient Greek or Egypt, but these were separate and isolated researches without a common logical order:[9] Cache notes that what Euclid achieved was to gather these theoretical notions and systematize them in a common logical ground. *Elements* was mainly composed of Definitions, Common Notions and Postulates. To construct a logical formation of geometric axioms and rules, Euclid started with definitions of geometric properties, like the point, the line and the plane. Each definition was dependent on others, and gained its validity through previous definitions.[10] To define a plane Euclid needed to use lines, where a line was formerly defined via points.[11] Definitions were followed by Common Notions, which included logical propositions such as "The whole is greater than part" or "Things which are equal to the same thing are also equal to one another."

---

[8] Bernard Cache, "Plea for Euclid" in http://architettura.supereva.com/extended/19990501/ep07en_01.htm Last accessed on August 2007.

[9] Ibid.

[10] Robin Hartshorne, Companion to Euclid: A Course of Geometry, Based on Euclid's *Elements* and Its Modern Descendants, Berkeley: American Mathematical Society, 1997. pp. 25-27.

[11] Ibid.

Finally, Euclid proposed his basic five Postulates through which he developed the so-called Euclidean Geometry.

The postulates are:

i) A straight line may be drawn from any point to any other point.

ii) A finite straight line may be produced to any length in a straight line.

iii) A circle may be described with any center at any distance from that center.

iv) All right angles are equal.

v) If a straight line meet two other straight lines, 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 less than two right angles.[12]

The postulates define a planar kind of geometry. The shortest distance between two points is always a straight line and the sum of interior angles of a triangle is always equal to two right angles. The geometry defined by Euclid is the simplest way of interpreting geometric relations, which can be grasped without further knowledge and it can be easily intuited, for it is the fittest way of representing three-dimensional space.[13]

Architectural representation has made extensive use of Euclidean Geometry. As both perspective and orthographic representation use linear and planar projections, they strictly follow the rules of Euclidean Geometry. Filippo Brunelleschi (1377-1446) used Euclid's study on optics while developing perspective drawing and followed the geometrical axioms of the *Elements* in his

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

[13] Bernard Cache, "Plea for Euclid" in http://architettura.supereva.com/extended/19990501/ep07en_03.htm Last accessed on August 2007.

study.[14] He proposed a central view, where the subject is located, and positioned the objects according to the subject through a "cone of vision" in three-dimensional space. Imaginary straight lines were projected from the subject to the points on the objects represented and they were plotted on the drawing accordingly. Although linear perspective is not a one to one representation of objects, the whole process depends on Euclidean Geometry.[15] Another major application of Euclidean Geometry in architecture is the orthographic projection. Instead of converging to a point, the projected lines remain parallel in orthographic projections.[16] The central view of perspective is replaced by planar projection. The objects are represented as if they are looked at through imaginary planes at infinity. Both linear perspective and orthographic projection remain in the field of Euclidean Geometry, although both kinds of projection are altered versions of representing the reality.[17]

The introduction of computer software to the field of architecture did not change much the way architects draft and design for a long time. Primary Computer Aided Drafting and Design software depended strictly on Euclidean Geometry.[18] Such software used Platonic solids as primary constructive elements, where variations were formed via the deformation of those solids. Although methods of drafting and modeling have changed with the introduction of new software, current software still adopts three-dimensional space with Euclidean geometric rules.

The general characteristics of Euclidean Geometry also define a specific kind of space, which is called Euclidean Space: It is considered to be an infinite and

---

[14] Erwin Panofsky, Perspective as Symbolic Form, New York: Zone Books, 1997. p.2.

[15] Ibid.

[16] Robin Evans, "Architectural Projection," in Architectural Projection; Architecture and Its Image, eds. Robin Evans, Eve Blau and E. Kaufman, Montreal: The MIT Press, 1989. p.3.

[17] Erwin Panofsky, p.2.

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

immeasurable blank field with homogeneous and isotropic quality.[19] A figure or a shape can be formulized without any differentiation or deformation in its shape depending on its position or direction in Euclidean Space. It is a perfect systematization of space, in which one can describe any shape, whether it is one, two or three dimensional, with complete accuracy.[20] For this reason, it was considered to be the only way of representing geometry and space for more than two thousand years.

Although Euclidean Geometry is a perfect systematization, the Fifth Postulate, also called the Parallel Postulate, is considered more like a theorem instead of an axiom. It has been thought as the weakest point in Euclidean Geometry. Various attempts were made throughout the centuries to prove the validity of the Fifth Postulate.[21] Until the beginning of the 19th century, other types of geometries were thought to be impossible, but the fallibility of the Parallel Postulate gave rise to new geometries.

2.2 Counter-intuitive Geometric Models of Space

Euclidean geometry is a planar, flat geometry that is intuitive, in other words, it can be perceived through common sense. Thought as the only possible geometric systematization until the 19th century, it heavily depended on the validity of parallel lines, which were defined by the Fifth Postulate of the *Elements*. By the first half of the 19th century, scientists from Germany, France, Russia and Hungary have proven the possibility of new geometries in consecutive studies. With the discovery of such new geometries, the definition

---

[19] Howard Percy Robertson, "Geometry as a Branch of Physics," in The Concepts of Space and Time, ed. Milic Capek, Dordrecht: D. Reidel Publishing Company, 1976. p.410.

[20] Francis Macdonald Cornford, "Invention of Space," in The Concepts of Space and Time, ed. Milic Capek, Dordrecht: D. Reidel Publishing Company, 1976. p.5.

[21] For more detailed information on attempts to prove the Parallel Postulate, see the first chapter of Roberto Bonola's Non-Euclidean Geometry: A Critical and Historical Study of Its Developments, U.S.A.: Dover Publications, 1955.

of “absolute geometry” has shifted from Euclidean geometry to a kind of geometry, which is defined by four postulates.[22] All of the new geometric systems benefited from these postulates and specialized through different interpretations of the “parallel postulate,” like Janos Bolyai and Nikolai Ivanovich Lobachevsky’s hyperbolic geometry and elliptical geometry of Georg Friedrich Bernhard Riemann, which both constitute the foundations of non-Euclidean geometries.[23]

Another development in the first half of the 19th century is that of n-dimensional geometries. As in the case of non-Euclidean geometry, a single discoverer cannot be named for n-dimensional geometries. By proving the validity of n-dimensions, the concept of a “hyperspace,” in which space has four or more dimensions, has been introduced. The possibility of higher dimensions challenged the perceptions of laymen, as neither non-Euclidean geometries nor the possibility of n-dimensions could be experienced through visualization, for both are counter-intuitive concepts.[24]

2.2.1 Non-Euclidean Geometries

Accepting the impossibility of proving the Fifth Postulate and attempting to find other possible solutions for parallelism, new geometries have been developed in the 19th century. The first alternatives for Euclidean geometry were developed by Nikolai Ivanovich Lobachevsky (1793 - 1856) in 1829 and by Janos Bolyai (1802 – 1860) in 1832. They both followed the same procedure while questioning the Parallel Postulate, that is; “*through a given point not on a given line, more than one line can be drawn not intersecting the given line*.”[25] In this

---

[22] Bernard Cache, “Plea for Euclid.”

[23] Harold Scott MacDonald Coxeter. Non-Euclidean Geometry, Washington D.C.: Mathematical Association of America, 1998.

[24] Linda Dalrymple Henderson, The Fourth Dimension and Non-Euclidean Geometry in Modern Art, Princeton: Princeton University Press, 1983. p.7.

[25] Ibid., p.4.

type of geometry, any number of parallel lines can be drawn to a given line instead of one, as it is the case in Euclidean geometry.

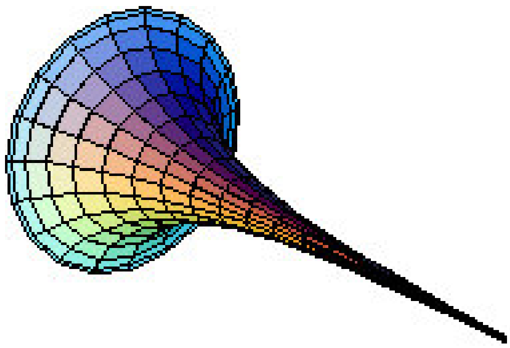

Figure 1: Pseudosphere.
Eric Weisstein, "Pseudosphere," in MathWorld--A Wolfram Web Resource, created by Eric Weisstein, http://mathworld.wolfram.com/Pseudosphere.html Last accessed on August 2007.

Bolyai-Lobachevskian geometry is also called "hyperbolic geometry."[26] In hyperbolic geometry, the definitions of planar geometry are followed but the geometric shapes of the elements change according to the position of the element and basic assumptions of the geometry. Lines are not straight in hyperbolic geometry or a triangle would have a sum of interior angles less than two right angles, but it still conforms to the rules of Euclidean geometry.[27] Surfaces have constant curvature, which is always negative. The most basic shape in three-dimensional space with a constant negative curvature is a

[26] Ibid.

[27] Ibid.

"pseudosphere."[28] (Fig. 1) It is a symmetrical surface with a ridge at the center and it approaches to infinity in both positive and negative directions. On a pseudosphere, it can be seen that from a given point more than one parallel can be drawn to a line.[29]

Georg Friedrich Bernhard Riemann (1826 – 1866) founded another type of non-Euclidean geometry in 1867, which is called "elliptical geometry" or Riemannian geometry.[30] Taking its simplest shape as a sphere, Riemannian geometry proposed surfaces with positive curvature, where the sum of a triangle's interior angles will be more than that of two right angles.[31] For the shortest distance between two points on a sphere will always be a great circle, lines are redefined in Riemannian geometry: Any pair of lines will meet at two points producing a pair of points, making it impossible to draw parallel lines in any combination in Riemannian geometry.[32]

Riemannian geometry introduced the possibility of varying curvature of surfaces or spaces.[33] In surfaces and shapes with constant curvature, any shape can be moved without any deformation in its original shape, as it is the case on the surface of a sphere. Whereas in Riemannian geometry, shapes with varying curvatures do not allow translations without deformation.[34] To give an example,

---

[28] Thomas F. Banchoff, Beyond the Third Dimension: Geometyr, Computer Graphics and Higher Dimensions, New York: Scientific American Library, 1990. p.187

[29] For more detailed information and visualization on "pseudosphere," http://www1.kcn.ne.jp/~iittoo/us20_pseu.htm Last accessed on August 2007.

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

[31] Capi Corrales Rodriganez, "From Space as Container to Space as Web," trans. Emmanuela Moreale, in Mathematics and Culture I, ed. Michele Emmer, Berlin: Springer, 2004. p.128

[32] Roberto Bonola, Non-Euclidean Geometry: A Critical and Historical Study of Its Developments, U.S.A.: Dover Publications, U.S.A., 1955. p.63.

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

[34] Ibid.

on an eggshell, one cannot move a piece of cloth that is covering a part of the egg. To move the cloth to top of the egg, the cloth would wrinkle as the curvature of the surface decreases, and in order to move the cloth to the bottom of the egg, one should tear the cloth for moving. If the eggshell was perfectly spherical, the cloth would have perfect mobility, for the curvature of sphere would be constant all around.[35] The discovery of Riemann about the deformation of figures in movement has also contributed to the Special Theory of Relativity of Albert Einstein.[36]

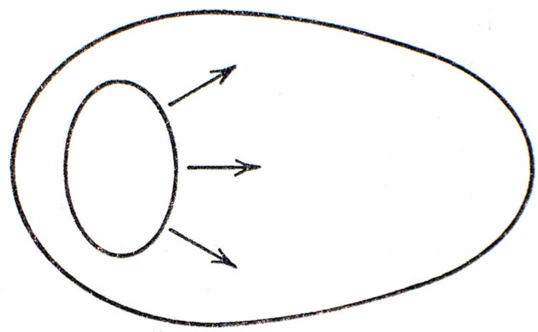

Figure 2: Mobility of a piece of cloth on an eggshell.
Graham Nerlich, The Shape of Space, Cambridge: Cambridge University Press, 1976. p.63.

Euclidean geometry is accepted as a specific case of non-Euclidean geometry, one with no curvature, and which lies in between the Bolyai-Lobachevskian geometry and Riemannian geometry.[37] A surface or a space will always have a "space constant" used for denoting the amount of curvature. A surface with a negative space constant, the resultant curvature will form a pseudosphere in Bolyai-Lobachevskian geometry, whereas if the space constant was zero, it

[35] Cornelis J. M. Van de Ven, Concerning The Idea of Space: The Rise of a New Fundamental in German Architectural Theory and in the Modern Movements Until 1930, Ph.D. dissertation, University of Pennsylvania, 1974. p.63.

[36] Linda Dalrymple Henderson, The Fourth Dimension and Non-Euclidean Geometry in Modern Art, p.6.

would be a plane in Euclidean geometry and a sphere in Riemannian geometry if it had positive space constant.[38]

2.2.2 n-dimensional Geometries

The search for higher dimensions has always been a challenge for mathematicians. Starting with attempts in analytical geometry, any shape can be visualized in a Cartesian coordinate system up to the third dimension. Further dimensions are achieved through addition of new variables to the first three dimensions; x, y and z.[39] Although any number of dimensions can be added, these dimensions remain in the hypothetical realm and cannot be visualized via the Cartesian coordinate system. For this reason, mathematicians have tried to find alternative ways to visualize the upper dimensions.

Arthur Cayley and Giuseppe Veronese, in 1870 and 1881 consecutively, were the first to form a system for n-dimensional geometries.[40] Imagining a shape in the fourth dimension that is perpendicular to all three dimensions seemed illogical at first. As the third dimension is achieved through rotating a plane around a line, the fourth dimension should be achieved by rotating a cube or a box around a plane, and the resulting figure should be perpendicular to the other three dimensions.[41] Linda Dalrymple Henderson states that in order to

---

[37] Capi Corrales Rodriganez, "From Space as Container to Space as Web," p.128

[38] Ibid.

[39] Linda Dalrymple Henderson, The Fourth Dimension and Non-Euclidean Geometry in Modern Art, p.6.

[40] Ibid. p.7.

[41] Charles Henry Smith, "How the Fourth Dimension May Be Studied," in The Fourth Dimension Simply Explained, by ed. Henry P. Manning, New York: Munn&Company, 1910. p.88.

understand n-dimensional geometries, one should redefine his/her common notions of geometric principles starting from the very basic assumptions.[42]

Studies on n-dimensional geometries have resulted in hyper geometries, which are geometric shapes in four or more dimensions. The widely known figure is the hypercube, which is produced by extruding each face perpendicular to it through all three dimensions.[43] The hypercube is a perfect four-dimensional figure, to which all of the Euclidean geometry's axioms and postulates can be applied without exception. In 1880's, Stringham and Schlegel have modeled four-dimensional hypersolids by projecting them into the third dimension and have had a wide impact on society, which also led to the popularization of n-dimensional geometry.[44]

In order to understand the spatial quality of the fourth dimension, generally a dimensional analogy is made by giving the example of the passage from two to three dimensions.[45] As a two-dimensional being cannot grasp the quality of the third dimension, but instead can only see projections, or intersections of the three-dimensional world, human beings can only see the projections of the fourth dimension on the three-dimensional world.[46]

Another approach to represent the fourth dimension is to consider it as time.[47] Instead of considering the fourth dimension as a spatial entity, it is then accepted as a temporal dimension. A shape in fourth dimension may be

---

[42] Linda Dalrymple Henderson, The Fourth Dimension and Non-Euclidean Geometry in Modern Art, p.7.

[43] Ibid. p.8.

[44] Ibid.

[45] Lawrence M. Krauss, Hiding in the Mirror; The Mysterious Allure of Extra Dimensions, From Plato to String Theory and Beyond, New York: Penguin Books, 2005. p.76.

[46] Edwin Abbott, Flatland : A Romance of Many Dimensions, (1884), Oxford : Oxford University Press, 2006.

visualized through slices of it in the third dimension. With this kind of approach, the whole object is represented by several figures and the combination of them represents the four-dimensional object. Various studies have been made to represent time as a new dimension at the beginning of 20th century. Movements in art like Cubism and Futurism, or Max Bill's sculptures in visualizing hyper geometries, Eric Mendelsohn, Le Corbusier, Eero Saarinen and Gaudi's projects can be considered as examples of these studies. With this kind of approach concepts like duration, mobility and instance came into consideration.

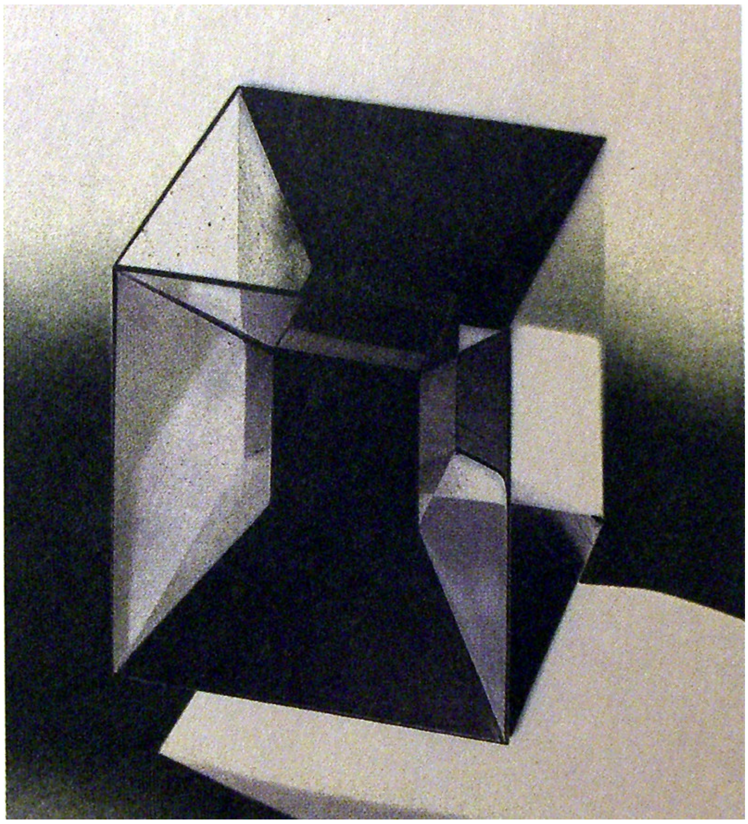

Figure 3: A central projection of hypercube. Stainless steel sculpture, by Attilio Pierelli.

Thomas F. Banchoff, Beyond the Third Dimension: Geometry, Computer Graphics and Higher Dimensions, New York: Scientific American Library, 1990. p.115.

[47] Linda Dalrymple Henderson, The Fourth Dimension and Non-Euclidean Geometry in Modern Art, p.9.

2.3 Physical Space and Ideal Space (extra-perceptual realm)

Euclidean geometry has set forth the main characteristics of geometry for more than 2000 years. In 1637, by using the axioms and postulates of Euclid, René Descartes (1596-1650) has formalized the concept of space by a mathematical systematization.[48] Different from Euclidean geometry, Descartes had a metric approach to space. He has constituted a coordinate system with an origin point and three dimensions all perpendicular to each other. An underlying grid is defined by these coordinating dimensions; he could then formulate any given shape, especially planar curves.[49] The space defined by Descartes can be considered as an infinite system, where smaller and finite spaces can also be defined. Cartesian space is an isotropic (that is a space in which all three directions have the same qualities), homogeneous (that is, any point in space has the same properties with another point), and infinite concept.[50] Besides still being widely used for representing physical space, the Cartesian coordinate system is also used in 2-dimensional and 3-dimensional computer-aided drafting and modeling software.

The three-dimensional space Descartes proposed was a perfect system for space representation, but Isaac Newton (1642-1727) has proposed still an additional dimension to Cartesian space. He attached time as the fourth dimension to the three spatial dimensions, and stated that the first three dimensions are planes or "slices" in the fourth dimension regarded as time.[51] Like Descartes, Newton has also thought of space as an absolute and immutable entity: He defined absolute

---

[48] Thomas Dahl, "The Transformation of Space and the Construction of Engineering Knowledge and Practice – From Renaissance Perspective Thinking to Gaspard Monge's Descriptive Geometry" published in Transforming Spaces, The Topological Turn in Technology Studies. eds. Mikael Hard, Andreas Lösch, Dirk Verdicchio, 2003.

[49] Margherita Barile, "Cartesian," in MathWorld-A Wolfram Web Resource, created by Eric W. Weisstein, http://mathworld.wolfram.com/Cartesian.html. Last accessed on August 2007.

[50] Ibid.

[51] Edward Slowik, Cartesian Space-time; Descartes' Physics and the Relational Theory of Space and Motion, Dordrecht: Kluwer Academic Publishers, 2002. p.20.

space as something immovable and remaining always the same, without having any external relations.[52]

This concept of absolute space seemed infallible until the discoveries in physics and mathematics in the 19th century.[53] With the analysis of electromagnetic force fields and the motion of light rays, it was seen that under certain conditions, physical space was becoming curved and was losing its absolute and homogeneous quality.[54] In the Special Theory of Relativity, Einstein claims that space is not an empty thing but instead is a field, which can only be represented by four parameters, three spatial and one temporal, and is relative to moving systems in every instance.[55] The relative quality of Einstein's conception of space as a field is only valid in extreme situations, like rapid movements or gigantic distances.[56] Einstein also proved that objects in motion could not maintain their shapes and would deform according to their speeds. A spherical body would then become ellipsoid in motion and at the speed of light any shape will turn into a planar figure.[57]

In addition to physical findings, the discovery of new geometric systems has also proved the possibility of spaces with variable curvatures, as previously mentioned. Unlike physical discoveries that altered the absolute properties of

---

[52] Isaac Newton, "On Absolute Space and Absolute Motion," in The Concepts of Space and Time, ed. Milic Capek, Dordrecht: D. Reidel Publishing Company, 1976. p.97.

[53] Cornelis J. M. Van de Ven, Concerning The Idea of Space: The Rise of a New Fundamental in German Architectural Theory and in the Modern Movements Until 1930, Ph.D. dissertation, University of Pennsylvania, 1974. p.63.

[54] Ibid., p.67.

[55] Hendrik A. Lorentz, "The Einstein Theory of Relativity", 1920 in http://www.gutenberg.org/files/11335/11335.txt, Last accessed on August 2007.

[56] Cornelis J. M. Van de Ven, Concerning The Idea of Space: The Rise of a New Fundamental in German Architectural Theory and in the Modern Movements Until 1930, Ph.D. dissertation, University of Pennsylvania, 1974. p.67.

[57] Stephen Kern, The Nature of Time and Space 1880-1918, Cambridge, Massachusetts: Harvard University Press, 2003. p.184.

space, new geometric systems have brought alternative ways of representing space and changing the perception of space. Staying in the realm of physical space, non-Euclidean geometries did not propose counter-intuitive spaces but instead proposed counter-intuitive geometries, like hypercube or pseudosphere, which are both alterations of previously known Platonic solids: the cube and the sphere.

With the newly introduced scientific facts and mathematical theorems, it was shown that an absolute and a priori space could not exist, for different kinds of space conceptions and alternative systematizations of geometric space were possible. However, while Euclidean geometry suffices the needs of architects or engineers, a physician studying space can only manage to gather data through non-Euclidean geometry.[58] However, although the existence of ideal spaces and other geometric systems were proven, the space human beings perceive and experience, and the one that architecture deals with, is still perfectly physical and Euclidean.[59] As Bernard Cache states in his *Plea for Euclid*;

> As regards multidimensional phenomena, insofar as we want to give an easy intuition of them, the best geometric vehicle remains 3D Euclidean space. Not that we want to repeat Kant's error saying that Euclidean space would be the unique form of spatial intuition, but we cannot avoid the fact that there is a highly positive feed back between our Euclidean intuition and the experimental behavior of physical space. In his dialogue with Bertrand Russell, Henry Poincaré who, certainly, cannot

---

[58] Linda Dalrymple Henderson, The Fourth Dimension and Non-Euclidean Geometry in Modern Art, p.16.

[59] Cornelis J. M. Van de Ven, Concerning The Idea of Space: The Rise of a New Fundamental in German Architectural Theory and in the Modern Movements Until 1930, p.67

> be suspected of empiricism, would conclude that "Euclidean geometry is not true but is the fittest"[60]

The important point to note here is that, with scientific advances, previous space conceptions are not invalidated, but the fallibility of absolute truths is shown. As Henderson states, the proving of non-Euclidean geometries became synonymous with the rejection of tradition and coined with the term revolution for some artists.[61]

2.4 Representation Crisis: Debates on the Concept of Hyperspace

By the end of the nineteenth century, the collapse of absolute truths and scientific facts that have been valid for more than two thousand years had a wide impact on society. With the introduction of the concept of hyperspace and new geometries, various attempts were made to represent these counter-intuitive concepts. In various areas like painting, sculpture, literature and architecture; some artists, writers and architects have tried to understand and visualize new geometries, the fourth dimension and the concept of hyperspace.[62] The counter-intuitive quality of new geometries and hyperspace has forced the artists to find new representations. By departing from the linear perspective system, and adopting new conceptions of space, artists, in the beginning of the 20th century, have found new movements in art and architecture, like Cubism, Dadaism, Surrealism, Constructivism and Futurism.[63] Attempts for representing the higher dimensions in literature have led to various science- fiction stories and novels by Gustave Fechner, Herbert George Wells, Lewis Carroll and Edwin Abbott. In order to understand the nature of the fourth dimension and new geometries,

---

[60] Bernard Cache, "Plea for Euclid." Poincaré's quotation is from; Henri Poincaré, *La Science et l'hypothese*, Paris, 1902.

[61] Linda Dalrymple Henderson, The Fourth Dimension and Non-Euclidean Geometry in Modern Art. p.17

[62] Ibid. p.xx.

[63] Ibid. pp.xx-xxiii.

some philosophers and scientists have also tried pseudoscientific and mystical approaches.[64] The belief in the possibility of representing the fourth dimension spatially ended by the popularization of Einstein's general Theory of Relativity, which accepts the fourth dimension as a temporal entity.[65]

2.4.1 Idealization of the 4th Dimension: Seeing with the Mental Eye

As Henderson calls it, hyperspace philosophy was formed towards the end of the 19th century, to visualize the counter-intuitive notion of the fourth dimension.[66] It did not look for scientific facts for its validation but instead, hyperspace philosophers strictly believed in the existence of a fourth dimension. Charles Howard Hinton has formed the foundations of hyperspace philosophy by his two major studies *A New Era of Thought* and *The Fourth Dimension*.[67] Hinton's works were the first non-mathematical explanations of higher dimensions. Throughout his study, he believed that it was possible to devise a way of looking for seeing and intuiting four-dimensional objects.[68] In order to explain the fourth dimension, Hinton has also developed a learning system using multi-colored cubes.[69]

---

[64] Ibid. p.23.

[65] Ibid., p.xx.

[66] Ibid., p.28.

[67] Charles Howard Hinton, A New Era of Thought, London: S. Sonnenschein & Co., 1888, and Charles Howard Hinton, The Fourth Dimension. Montana: Kessinger Publishing, 1997, originally published in 1904

[68] Lawrence M. Krauss, Hiding in the Mirror; The Mysterious Allure of Extra Dimensions, From Plato to String Theory and Beyond, p.83.

[69] Linda Dalrymple Henderson, The Fourth Dimension and Non-Euclidean Geometry in Modern Art, p.28.

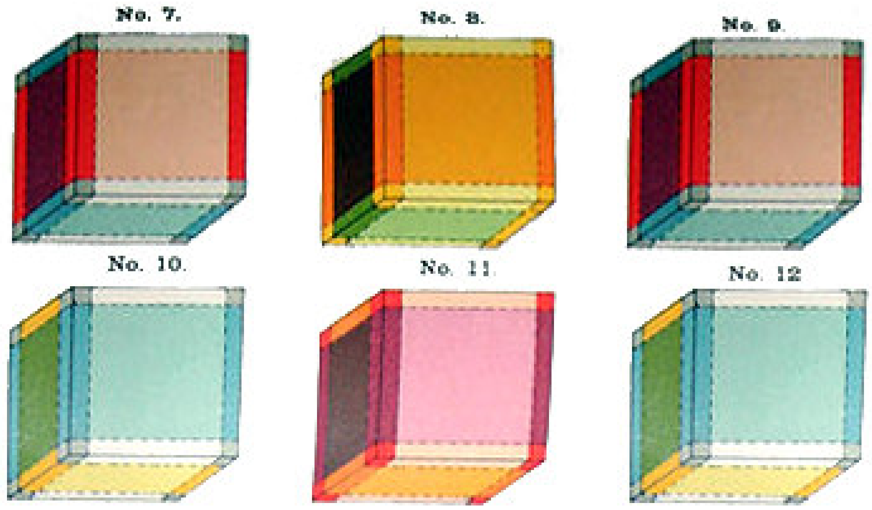

Figure 4: Hinton's multi colored cubes. By connecting the same colored faces, a hypercube was formed.

http://www.flickr.com/photos/banubula/17427758/

Last accessed on August 2007.

The most criticized point in hyperspace philosophy was its anti-positivist stance.[70] Henry Slade, known as a psychic in United States, has performed various tricks like untying a knot without touching it, joining solid wooden rings or transporting objects from sealed containers.[71] He claimed that he was performing these tricks by passing to extra dimensions and tried to prove the existence of extra dimensions through them.[72] Slade's tricks had widespread impact on society and also some scientists. The mathematical existence of higher dimensions had led to a misconception that a mathematical extra perceptual realm could also exist physically as well as spiritually.[73]

---

[70] Ibid.p.23.

[71] Ibid.

[72] Ibid.

[73] Lawrence M. Krauss, Hiding in the Mirror; The Mysterious Allure of Extra Dimensions, From Plato to String Theory and Beyond, p.78.

Similar to hyperspace philosophy, another anti-positivist stance was that of the theosophists in the late 19th century. The forerunner of theosophy was Madame Blavatsky.[74] Instead of a four-dimensional sight, Theosophists had the idea of an "astral vision."[75] Blavatsky referred to the "fourth dimension of matter in space" rather than "the fourth dimension of space" in her writings and believed in the perception of higher dimensions through the natural development of human beings in a theosophical fashion.[76] Among many followers of Theosophy like Wassily Kandinsky, Frantisek Kupka and Piet Mondrian, some hyperspace philosophers were also found like Claude Bragdon and Peter Demianovich Ouspensky.[77]

2.4.2 Reflections of the Debate in the Artistic and Architectural Realm

Discovery of the concept of hyperspace had a wide effect on art and architecture in the first quarter of 20th century. Art movements like Cubism, Futurism and Suprematism were all affected from non-Euclidean geometries and upper dimensions. As Henderson states, "the fourth dimension and non-Euclidean geometry emerge as among the most important themes unifying much of modern art and theory."[78] This section will deal with the approaches taken by artists and architects to represent non-Euclidean geometries and fourth dimension, leaving aside the theoretical background of art movements and styles, which are beyond the scope of this thesis.

Among many different approaches in art, the most influential one was Cubism. Departing from the single point view of linear perspective, Cubism has found its

---

[74] Ibid.

[75] Linda Dalrymple Henderson, The Fourth Dimension and Non-Euclidean Geometry in Modern Art, p. 32.

[76] Ibid. p.31.

[77] Ibid., p.32.

[78] Ibid. p.xxiii.

way through altering the modes of perception.[79] Trying to represent the notion of a new space conception, cubism had introduced new ways of representing objects, environment and events. Through a multitude of views, distinct vistas are overlapped on a single frame using planar geometric elements like triangles or squares. The Cubist view of objects and environments is distanced from the daily visual perception.[80]

Figure 5: “Portrait of Ambroise Vollard,” by Pablo Picasso. 1910.
http://www.acsu.buffalo.edu/~jconte/Images/Picasso_Vollard.jpg
Last accessed on August 2007.

[79] Giedion, Sigfried. Space, Time and Architecture: The Growth of a New Tradition, 5th ed., Massachusetts: Harvard University Press, 1971. p.435.

[80] Ibid.

In a similar manner to cubism, Futurism tries to understand the different space-time conceptions by utilizing time and movement as its main constituent.[81] By taking successive intersections of spatial planes with the object varying in temporal dimension, different occurrences of the object collapse into a single instance creating a representation of the movement of the form through time.[82] As non-Euclidean geometries have shown the impossibility of movement in space without deformation, futurists have also claimed that the "inanimate forces" distort the shape of the object through displacement.[83] Futurism had searched for the essence of movement not only in painting and sculpture but also in architecture, music, literature, theatre and cinema.[84]

Figure 6: "Development of a Bottle in Space," by Umberto Boccioni, 1911.
http://www.moma.org/images/collection/FullSizes/00063018.jpg
Last accessed on August 2007.

---

[81] Caroline Tisdall and Angelo Bozzolla, Futurism, London: Thames and Hudson, 1977.

[82] Sigfried Giedion, Space, Time and Architecture: The Growth of a New Tradition, p.445.

[83] Caroline Tisdall and Angelo Bozzolla, Futurism,.p.79.

Figure 7: "The Knife Grinder," by Kasimir Malevich, 1912.
www.rollins.edu/Foreign_Lang/Russian/malev2sm.jpg
Last accessed on August 2007.

84 Ibid.

CHAPTER 3

CYBERSPACE
VISUALIZATION – DEMATERIALIZATION

Like hyperspace, cyberspace is another example of idealization of space. The first and most important difference between hyperspace and cyberspace is the capability of cyberspace in visualizing concepts beyond our perception. Unlike hyperspace, which offers a counter-intuitive and hard to visualize conception of space, the ideal quality of cyberspace can be visualized by the help of computer technologies. Cyberspace offers a virtual world with no connections to the material world. In addition to the capability of representing non-Euclidean geometries and higher dimensions with precision, the autonomous and ideal structure of cyberspace has also introduced new design tools and techniques to architecture, causing shifts and alterations in the design process.

3.1 Re-Idealization of Space: Cyberspace

> *"And after all, why have cyberspace if we cannot (apparently) bend nature's rules there?"*[85]

In 1984, William Gibson's world famous science-fiction novel Neuromancer was published.[86] The novel depicts a dystopian vision of near future where

[85] Michael Benedikt, "Cyberspace: Some Proposals", in Cyberspace: First Steps, ed. Michael Benedikt, Cambridge, Massachusetts: The MIT Press, 1991. p.198.

[86] William Gibson, Neuromancer, New York: Ace Books. 1984.

people jack in to computers through electric cables and experience and live in a parallel world that is generated via computers. The imaginary realm, namely 'the matrix,' copies the properties of the physical world, where people are only three-dimensional models in order to visualize their existing beings, where gravity or other forces are nothing but mathematical functions among objects in interaction, and all senses are generated by electrical impulses transmitted to sensory fields in the user's brain. In Neuromancer, human beings live in two lives, the first one taking place in the physical world and the alternate one in 'the matrix.'[87]

Gibson has introduced the term "cyberspace" for denoting the spatial characteristics of the matrix in Neuromancer. Being created by computers and not having any physical existence, the matrix has also been named as cyberspace throughout the novel. Gibson describes cyberspace as,

> A consensual hallucination experienced daily by millions of legitimate operators, in every nation, by children being taught mathematical concepts… A graphic representation of data abstracted from the banks of every computer on the human system. Unthinkable complexity. Lines of light ranged in the nonspace of the mind, clusters and constellations of data. [88]

The significance of Gibson's novel is the use of the term 'cyberspace' for the first time.[89] The cyberspace of Neuromancer is a virtual world for a community of people, whereas the concept of cyberspace may adopt many different functions and forms. Among many, the World Wide Web may be accepted as the most popular and widespread example of cyberspace containing millions of

---

[87] Michael Heim, "The Erotic Ontology of Cyberspace," in Cyberspace: First Steps, ed. Michael Benedikt, Cambridge, Massachusetts: The MIT Press, 1991. p.62.

[88] William Gibson, Neuromancer, p.51.

[89] Michael Benedikt, "Cyberspace: Some Proposals", in Cyberspace: First Steps, ed. Michael Benedikt, Cambridge, Massachusetts: The MIT Press, 1991.

web pages connected to each other, while it can also be an imaginary realm composed of texts without a single graphic element, or the graphic interface of computer-aided design software can yet be considered as another type of cyberspace.[90] Cyberspace is an idealized formation of space that is created, controlled and accessed via computers or other electronic devices that can be perceived, experienced and transformed through visual, auditory or verbal means.

Starting from the 1930's, several different attempts were made to create imaginary spatial fields. Mainly in the movie industry, the primary aim was to immerse the users into a surrounding image, so that they could feel like they were experiencing reality. The attempts involved the use of multiple projectors and screens to surround users with a continuous peripheral vision or with the help of head-mounted displays, stereoscopic images were used to create a three-dimensional effect of the scene.[91] For all those devices could only show stored information, like still images or recorded movies, they did not allow any interactivity. In 1970, Ivan Sutherland has produced the first interactive head-mounted display. [92] Unlike its predecessors, which were using pre-recorded images or videos, Sutherland adopted computer-generated images, composed from lines and simple geometric shapes.[93] The computer could change the output according to the responses from the user, allowing for interactivity. By using computer generated images, Sutherland's initial purpose was to visualize concepts that are beyond the possibilities of the physical world, while he had also foreseen the potentials of virtual reality in design, construction and other fields. [94]

---

[90] Rob Kitchin, Cyberspace, New York: John Wiley & Sons. 1998. p.2.

[91] Yehuda Kalay, Architecture's New Media: Principles, Theories, and Methods of Computer-Aided Design, Massachusetts: The MIT Press, 2004. p.184.

[92] Rob Kitchin, Cyberspace. p.46.

[93] Ibid.

[94] Ivan Sutherland, "The Ultimate Display," in Multimedia: From Wagner to Virtual Reality, eds. Randall Packer and Ken Jordan, New York: Norton & Company. 2002. p.253.

Another early implementation of cyberspace was the Aspen Movie Map Project. In the late 1970's, Architecture Machine Group in MIT has recorded the streets of Aspen, Colorado, with a special camera that was able to record the surrounding, fitted on top of a car.[95] By combining several shots from different locations, like top of cranes, helicopters and airplanes, a continuous imagery of the town has been gathered. Through a touch-sensitive display, users could indicate the direction they wanted to go by touching the screen and walk around the town at any speed they wanted and could turn to any direction at any point. In a more advanced version of the project, users were surrounded by screens in each side, all of them displaying the corresponding views from the environment.[96] Although the project offered a limited amount of views from specific points of view, it is one of the first projects involving interactivity in cyberspace.

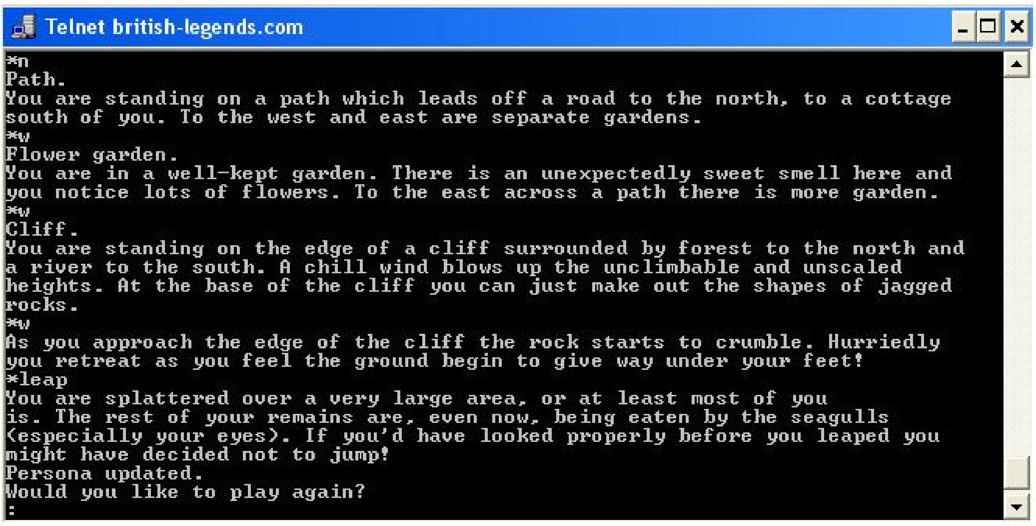

Figure 8: A screen capture from MUD
http://members.gamedev.net/EvilSteve/JournalStuff/MUDHelp.png
Last accessed on August 2007.

---

[95] Scott Fisher, "Virtual Interface Environments," in Multimedia: From Wagner to Virtual Reality, eds. Randall Packer and Ken Jordan, New York: Norton & Company. 2002. p.261

[96] Ibid.

As mentioned before, cyberspace does not necessarily have to be a visually surrounding and a realistic three-dimensional world. First examples of cyberspace that use no graphics at all date back to 1977, called as Multi-User Domains (MUDs).[97] MUD is a kind of program that is connected via distant computers and is composed of a database consisting of information about locations, objects, players and other events.[98] Instead of using graphics and images for representing spaces, objects, characters and actions, only verbal descriptions were used. The reason behind using texts was purely pragmatic. All of the users had to log into the central computer from their personal computers by using a modem. As the connection speeds were really slow, around 300 bps, the only way to sustain simultaneity was through the use of texts instead of graphic elements.[99] Actually, what users experienced was nothing more than reading a novel, only with the exception of being interactive in every action. Users could do anything they wanted by writing the action through their keyboards. The data was sent to the central computer and the response was instantly calculated by the server and sent back to the user as a sentence or a paragraph. The textual world in MUDs is a dynamic one, where new spaces can be added and existing spaces are updated constantly.

---

[97] Peter Anders, Envisioning Cyberspace: Designing 3d Electronic Spaces, New York:McGraw Hill,1999. p.89.

[98] Pavel Curtis, "Mudding: Social Phenomena in Text-Based Virtual Realities," in Multimedia: From Wagner to Virtual Reality, eds. Randall Packer and Ken Jordan, New York: Norton & Company. 2002. p.354.

[99] Peter Anders, "Envisioning Cyberspace," in Virtual Dimension: Architecture, Representation and Crash Culture ed. John Beckmann, New York: Princeton Architectural Press, 1998. p.219.

Figure 9: A screenshot from Habitat.
http://www.fudco.com/chip/lessons.html
Last accessed on August 2007.

In 1986, Lucasfilm Games had created the first two-dimensional graphic based communal cyberspace, namely Habitat.[100] It consisted of real-time animated graphics that responded to the users actions. Intended to be an entertainment medium, Habitat could simultaneously house thousands of users, all of which had to log into Habitat from his/her own personal computer. Each user had an avatar; an image that can be personalized from several different parts to represent self in Habitat, and could see other users who are at the same location through their avatars. The avatars looked like real person with a head, a body and feet and arms. Users could interact with each other by entering texts as in the case of MUDs. The Habitat consisted of 20000 unique locations all of which were connected to each other by one to four connections.[101] The problem of connection speed was still valid at the time of Habitat, so users had to download

[100] Allucquere Rosanne Stone, "Will the Real Body Please Stand Up?: Boundary Stories About Virtual Cultures," in Cyberspace: First Steps, , ed. Michael Benedikt, Cambridge, Massachusetts: The MIT Press, 1991. p.93.

[101] Chip Morningstar and F. Randall Farmer, "The Lessons of Lucasfilm's Habitat," in Cyberspace: First Steps, , ed. Michael Benedikt, Cambridge, Massachusetts: The MIT Press, 1991. p.274.

a package consisting of graphics of the game and the game's working principle was the same with that of MUDs.[102]

Figure 10: A screenshot from a contemporary Massively Multiplayer Online Game.

http://wirelessdigest.typepad.com/photos/uncategorized/world_of_warcraft1.jpg

Last accessed on August 2007.

Technological developments in computer industry have allowed more detailed and realistic three-dimensional graphics and the simultaneous interaction of more users. Whether it is a simple text-based MUD game or a highly detailed Massively Multiplayer Online Game, the worlds created in cyberspace follow a highly physical order.[103] As Gibson notes for cyberspace, the 'consensual hallucination' is at the heart of all these worlds, for it governs both a community and an illusion, where the hallucination strictly mimics the reality.[104] As the

[102] Ibid.

[103] Elaine Chan and Peter Vorderer, "Massively Multiplayer Online Games," in Playing Video Games: Motives, Responses and Consequences, eds. Peter Vorderer and Jennings Bryant, New Jersey: Lawrence Erlbaum Associates. 2006. p83.

[104] Michael Benedikt, "Cyberspace: Some Proposals," in Cyberspace: First Steps.

main aim behind the creation of fantastic worlds is to make them realistic and familiar to users, the notions of space, time and physical laws still persist in virtual environments as in reality.[105] There exists gravity; day and night intervals and you still cannot pass through walls or teleport to another place unless you have magical powers. The ongoing technological studies are also directed towards more realistic experiences in cyberspace; photo-realistic graphics that cannot be told from its real counterpart, more accurate physical simulations or more realistic simulators,[106] whereas cyberspace has a vast potential of offering artificial experiences, adopting alternative rules beyond physical laws and visualizing unique worlds.

3.1.1 The Cartesian Coordinate System

The early examples of cyberspace have been frequently visualized by the Cartesian coordinate system in their spatial formalizations.[107] In Gibson's novel, the Neuromancer, the matrix was consisting of a three-dimensional grid system extending in all three directions. The hierarchic structure of locations in Habitat and MUDs follows a strict two-dimensional Cartesian system where each location is connected up to four neighboring locations from four sides; north, south, east and west. The geometric possibilities cyberspace offers are surpassing the limits of the physical world. Besides being able to represent simple geometric shapes in Euclidean geometry with the precision of infinitesimals, non-Euclidean and hyperspace geometries can also be visualized in cyberspace.[108] The geometric shapes that can be created are only bound with

---

[105] Rob Shields, The Virtual, London: Routledge, 2003. p.60.

[106] Steven Holtzman, Digital Mosaics: The Aesthetics of Cyberspace, New York: Simon & Schuster, 1997. p.45.

[107] Allucquere Rosanne Stone, "Will the Real Body Please Stand Up?: Boundary Stories About Virtual Cultures," in Cyberspace: First Steps, ed. Michael Benedikt, Cambridge, Massachusetts: The MIT Press, 1991. p.104.

[108] Michael Benedikt, "Cyberspace: Some Proposals," in Cyberspace: First Steps, p.122.

the mathematical limitations of the software. Any shape that can be represented as a mathematical equation is likely to be modeled without any restrictions.[109] It should be noted that, the geometries of higher dimensions are not the intrinsic part of cyberspace and that cyberspace cannot offer unique geometrical solids and surfaces; it is yet the ideal medium for representing geometries with higher degrees of parameters.[110] Alternative coordinate systems, like Riemannian or hyperbolic geometries, may be developed and implemented without any limitations or problems.[111] The geometric relationships and rules can be redefined for each spatial arrangement according to the needs.

In other words, cyberspace may be considered as a kind of mould that can be utilized for certain functions ranging from simulating physical worlds to creating unique spaces. Beyond all possibilities cyberspace offers, there are some important aspects of cyberspace that should be mentioned in detail. For the pre-determined physical laws do not have to be applied in cyberspace's autonomous configuration, rules governing the space can be altered and re-defined in each specific case.[112] According to Michael Benedikt, designers should not seek for constant principles for the spatio-temporal logic of cyberspace, but instead build up the formation of rules that are coherent to each other: As there is no rationale in this medium, the autonomous formalization of space and time allows designers to create genuine temporal and spatial qualities. [113]

---

[109] Contemporary drafting and design software allow users to implement custom macros, allowing further and specialized geometric creations.

[110] William J. Mitchell, "Antitectonics: The Poetics of Virtuality," in Virtual Dimension: Architecture, Representation and Crash Culture ed. John Beckmann, New York: Princeton Architectural Press, 1998. p.207.

[111] David Tomas, "Old Rituals for New Space: Rites de passage and William Gibson's Cultural Model of Cyberspace," in Cyberspace: First Steps, ed. Michael Benedikt, Cambridge, Massachusetts: The MIT Press, 1991. p..35.

[112] Michael Benedikt, "Cyberspace: Some Proposals," in Cyberspace: First Steps, p.126.

[113] Ibid. p.128.

3.1.2 The Concept of Scale in Cyberspace

It is found that, in nature, the size of the smallest particle is about 10^{-32}cm, namely Plank length.[114] This means that the distance between two points can be divided into finite amount of points. A similar condition is found in digital images too. The amount of resolution limits the level of magnification to a special point, however in cyberspace the mathematical construct makes it possible to visualize infinite amount of detail.[115] The user can zoom in from the macro scale into the finest details of cyberspace and instantly zoom out without any restrictions, assuming both macro and micro scale data are stored in the virtual environment. Thus the concept of scale is lost in cyberspace.[116] The best outcome showing the possibilities of the absence of scale is the fractal. Fractals, discovered by Benoit Mandelbrot in the 1970's, are formed by repeating a constant rule, so that "if a piece of a fractal is suitably magnified to become of the same size as the whole, it should look like the whole."[117] Therefore the lack of predefined scale and the possibility of infinite amount of zooming allows one to fit infinite amount of points in between two predefined points in cyberspace.

---

[114] Ibid. p.146.

[115] Peter Lunenfeld, Snap to Grid: A User's Guide to Digital Arts, Media and Cultures, Massachusetts: MIT Press, 2001. p.105.

[116] Steven Holtzman, Digital Mosaics: The Aesthetics of Cyberspace, New York: Simon & Schuster, 1997. p.48.

[117] Benoit B. Mandelbrot, "Fractals and an Art for the Sake of Science," in The Visual mind: Art and Mathematics, ed. Michele Emmer, Massachusetts: The MIT Press, 1993. p.12.

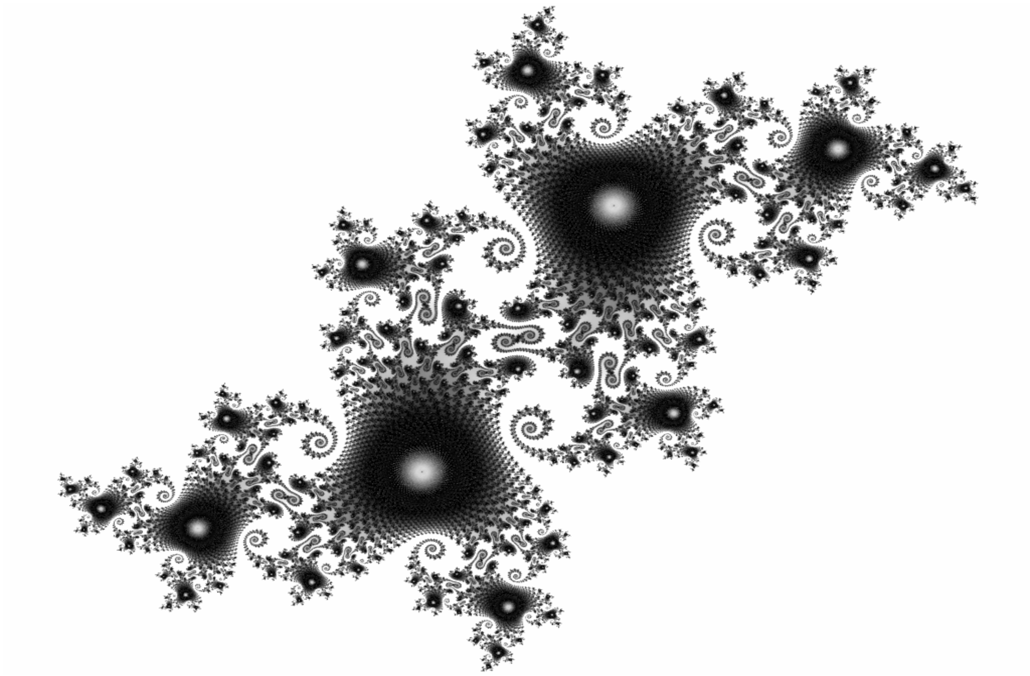

Figure 11: The seahorse fractal.
http://www.geocities.com/salvi1740@sbcglobal.net/Fractal1.png
Last accessed on August 2007.

In 1851, Gottfried Semper classified primordial dwelling into four basic parts: the earthwork denoting the ground, the hearth, which for Semper was the ornament and textile, the framework or the structure and the lightweight enclosing membrane.[118] According to William J. Mitchell, for cyberspace does not have a "ground", and the elements of this medium are not rooted in the "ground", the "earthwork" has lost its meaning. In addition to this, he also states that the second, the hearth, and the third element, the framework, have been also abandoned in the digital medium. One can speak of only the fourth element, the lightweight enclosing membrane, in the medium of cyberspace.[119] The enclosing membrane transforms itself into geometrically formed surfaces. Any

[118] Gottfried Semper, Four Elements of Architecture and Other Writings. trans. Francis Mallgrave and Wolfgang Herrmann. Cambridge: Cambridge University Press, 1989.

[119] William J. Mitchell, "Antitectonics: Poetics of Virtuality," in The Virtual Dimension, ed. Beckmann, John Princeton Architectural Press, New York. 1998. p.207.

object, whether it is a two-dimensional shape or a volumetric form, can be formed by a number of surfaces.[120]

Within the intrinsic nature of cyberspace, there does not exist any physical materials. Instead, colors and textures are applied to the surfaces. Objects are diversified from each other through their colors, textures, locations or dimensions. Also, the concept of gravity is not found in cyberspace, unless it is defined through artificial forces.[121] The absence of gravity and materials in cyberspace allows the designers to decide on the relations between elements without any limitations. The loss of scale in cyberspace also eliminates the restrictions in dimensioning the elements for structural necessities.[122] Therefore according to Mitchell, "the structural expression and honesty" has been vanished in cyberspace.[123]

The New York Stock Exchange 3-Dimensional Trading Floor project by Hani Rashid and Lise Anne Couture, demonstrates the immateriality of cyberspace to its full extent. The project aimed to visualize all the data that is related with the Stock Exchange and map the transactions in the market through "a navigable multi-dimensional world" that can be accessed through the World Wide Web.[124] The need to visualize a vast amount of rapidly changing data for the virtual hall of NYSE resulted in purely geometric elements. Flying flow charts, three-dimensional value graphs and latest news shown by texts and videos on surfaces have developed a new graphic language formed from different colors and information.[125] The multi-dimensional space adapts itself according to the

---

[120] Greg Lynn, Animate Form, New York: Princeton Architectural Press, 1998. p.18.

[121] Yehuda E. Kalay, Architecture's New Media: Principles, Theories, and Methods of Computer-Aided Design, p.467.

[122] William J. Mitchell, "Antitectonics: Poetics of Virtuality," in The Virtual Dimension, p.207.

[123] Ibid.

[124] Hani Rashid and Lise Anne Couture, Asymptote: Flux, London: Phaidon Press, 2002. p.37.

[125] Ibid.

changes in stock market in real time by representing them through volumetric organizations.

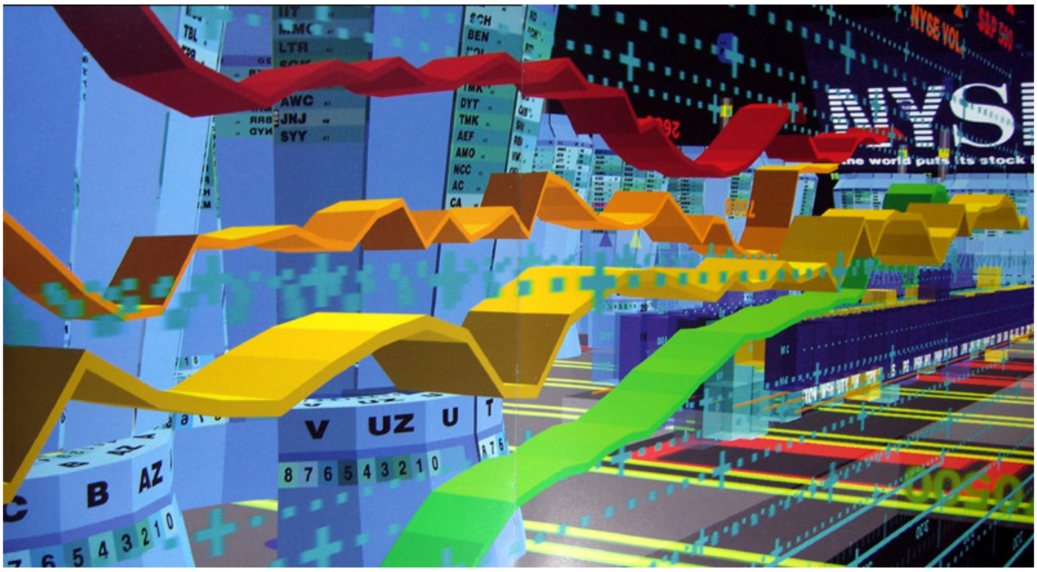

Figure 12: NYSE 3DTF Virtual Reality Environment
Hani Rashid, Lise Anne Couture, <u>Asymptote: Flux</u>, London:Phaidon Press, 2002. p.42.

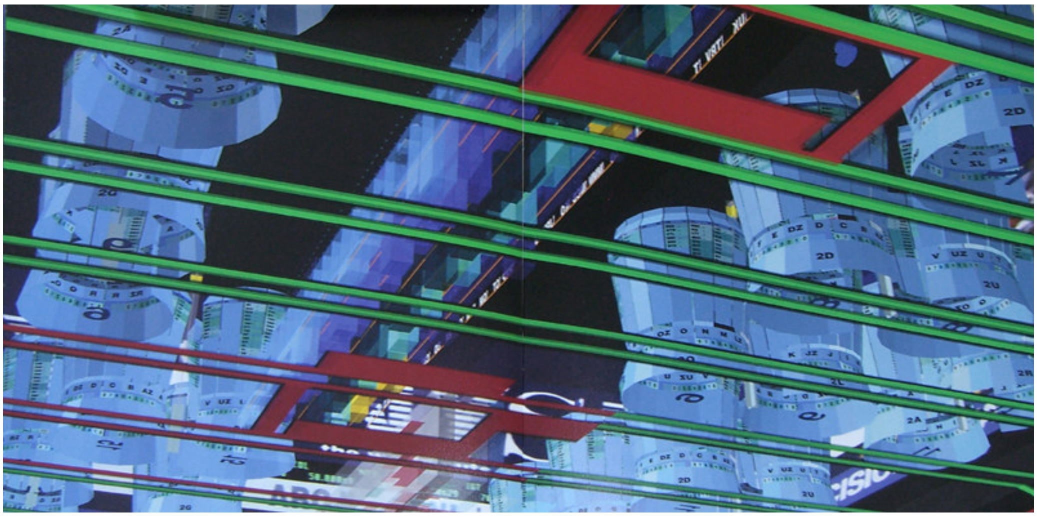

Figure 13: NYSE 3DTF Virtual Reality Environment
Hani Rashid, Lise Anne Couture, <u>Asymptote: Flux</u>, London:Phaidon Press, 2002. p.42.

One of the first architectural projects designed for cyberspace was the Liquid Architectures project designed by Marcos Novak.[126] Novak describes himself as a "trans-architect," for his designs adopt the extra-physical properties of the virtual realm. Novak describes Liquid Architectures as,

> Liquid Architecture is more than kinetic architecture, robotic architecture, an architecture of fixed parts and variable links. Liquid architecture is an architecture that breathes, pulses, leaps as one form and land as another. Liquid architecture is an architecture whose form is contingent on the interest of the beholder; it is an architecture that opens to welcome me and closes to defend me; it is an architecture without doors and hallways, where the next room is always where I need it to be and what I need it to be. Liquid architecture makes liquid cities, cities that change at the shift of a value, where visitors with different backgrounds see different landmarks, where neighborhoods vary with ideas held in common, and evolve as the ideas mature or dissolve.[127]

For Novak, the important aspect is the possibility of adaptation of the spaces and the logic behind the creation of them. He claims that an architectural project should adapt itself to changing needs in time and the themes that are controlling these changes should also evolve according to further conditions.[128] He symbolizes his projects as a symphony in space, which never repeats itself, but "smoothly or rhythmically" regenerates and evolves in time.[129] The formal

---

[126] Peter Zellner, Hybrid Space: New Forms in Digital Architectures, New York: Rizzoli Publications, 1999. p.128.

[127] Marcos Novak, "Liquid Architectures in Cyberspace," originally published in 1991, in Multimedia: From Wagner to Virtual Reality, eds. Randall Packer and Ken Jordan, New York: Norton & Company. 2002. p.283.

[128] Ibid., p.284.

[129] Ibid.

creation of the projects depend on algorithms that are dynamically transformable, so the design process heavily depends on the process of designing algorithms running in the background.

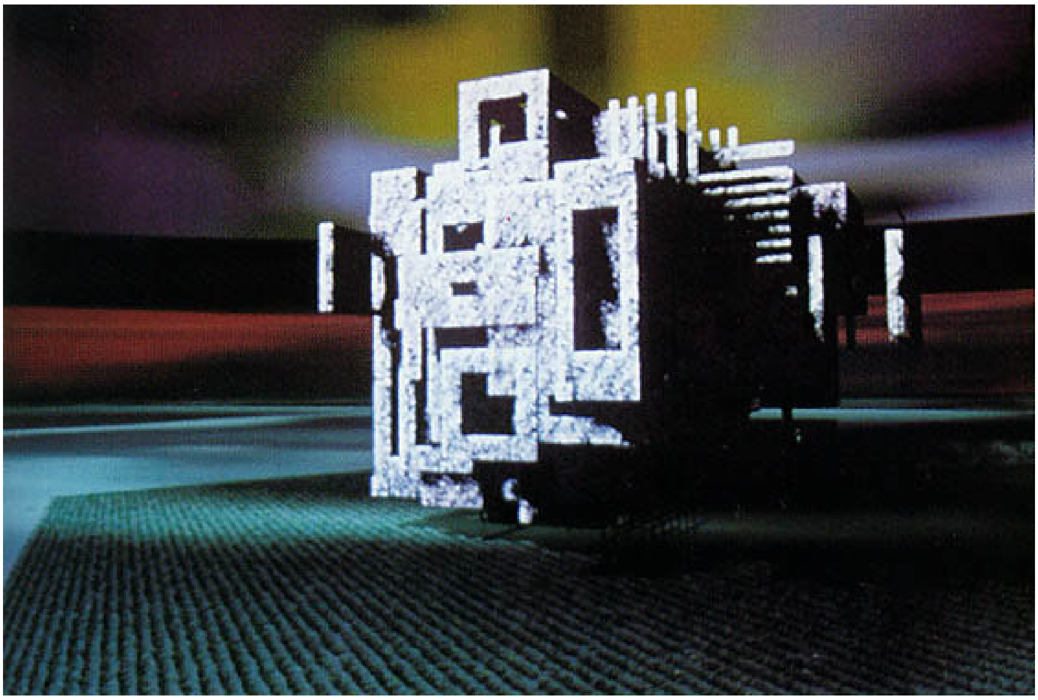

Figure 14: A screenshot from Marcos Novak's "Liquid Architectures."
http://www.zakros.com/liquidarchitecture/liquidarch25.jpeg
Last accessed on August 2007.

Figure 15: A screenshot from Marcos Novak's "Liquid Architectures."
http://www.archilab.org/public/2000/catalog/novak/novak01g.jpg
Last accessed on August 2007.

3.2 Algorithmic Design Tools

> *"For the first time in history the architect is called upon to design not the object but the principles by which the object is generated* and varied *in time."*[130]

Algorithm is a term from mathematics, which denotes a finite set of instructions for achieving a specific purpose in a clear and deterministic way.[131] The instruction sheets of an origami duck or a recipe from a cookbook are the most

[130] Ibid.

[131] Yehuda E. Kalay, Architecture's New Media: Principles, Theories, and Methods of Computer-Aided Design, p.47.

common examples of algorithms.[132] An algorithm may be varied and used numerous times for similar problems leading to the same result every time it is run. Algorithmic design denotes the possibility of objectively recording and re-applying the procedures of the design process or form generation. It is not a concept directly related to computer technology, many algorithmic procedures were used in architecture and other sciences throughout the history.[133] The mathematical processing quality of the computer-aided drafting and design software recently made algorithmic design an integral part of architecture. As all of the actions in any computer-aided design software are done through algorithms running in the background, a project can be represented as a set of algorithms. By re-running the algorithms in the same software, the project can be reproduced in exactly the same way. For this reason, any computational design may be regarded as an algorithmic design, however it is not what algorithmic design denotes.

Algorithmic design mostly implies the use of scripts in the design process that are specialized for a specific purpose. The recursive quality of scripts is the main quality of scripting. The architect can obtain various alternatives of a design by changing the script's minute details and running the modified script again. The resulting forms are unexpected in most cases. Therefore the architect chooses the final form from a set of alternatives, and re-transforming it through further scripting operations.[134] Branko Kolarevic defines this quality of design as "unpredictable, uncertain and indeterminate", becoming a part of design with scripting, opening new possibilities to the production of forms. [135] Scripting has

---

[132] Ibid.

[133] For more detailed information about the history of algorithms and computation, see Yehuda E. Kalay, Architecture's New Media: Principles, Theories, and Methods of Computer-Aided Design, pp.63-74.

[134] Branko Kolarevic, "Digital Morphogenesis," in Architecture in the Digital Age: Design and Manufacturing, ed. Branko Kolarevic, New York: Spon Press, 2003. p.26.

[135] Branko Kolarevic, "Digital Morphogenesis and Computational Architectures," in Cumulative Index of Computer Aided Architectural Design web page, cumincades.scix.net/data/works/att/fbc9.content.pdf. Last accessed on August 2007.

transformed the whole process of design. Instead of working on visual data, architects and designers have started to work on abstract data. The non-visual quality of scripts has shifted the visual and formal processes of design to the numerical and the textual.[136]

Considered as a special case of scripting, parametric design is one of the most common types of algorithmic design. Allowing the architect to formalize the project through associations in the design process, parametric design gives out a set of alternatives with different values of parameters. The possibility of changing the relations among elements or parameters results in main alterations in the final form. There is a misconception that algorithmic design is synonymous with parametric design, however an algorithmic design does not have to be parametric at all while a parametric design is always an example of algorithmic design. It is the algorithm that forms the parametric relations between geometric elements.

To give a basic example, in the design process of an office tower, for it is formed from repeating floor plans, an algorithm may be used to copy the typical floor plan times the number of floors. If the floor plan is modified, the algorithm will change the rest of the floors and the model by updating the plans. Similarly, the model can be formed through a similar algorithm. If a parameter is added to the algorithm that is controlling the number of floors, or number of offices in the plan, the number of stories or offices can be changed instantly through parameters.[137] The first part of the example remains as an algorithm, whereas with the introduction of parameters the algorithm becomes parametric.

---

[136] Zeynep Mennan, "Non-Standardization through Non-Visualization: Scripting the Dom-ino House," in Game, Set and Match II: On Computer Games, Advanced Geometries, and Digital Technologies, eds. Kas Oosterhuis, Lukas Feireiss, Delft: Episode Publishers, 2006. p238.

[137] William J. Mitchell, "Design Worlds and Fabrication Machines," in Architecture in the Digital Age: Design and Manufacturing, ed. Branko Kolarevic, New York: Spon Press, 2003. p.75.

3.2.1 Development of CAD/CAM Software and Non-Euclidean Geometries

Starting from the 1980's, computers were initially used as a drafting device in architecture.[138] They were used as a representation device for translating the drawings or sketches on paper to the medium of computer.[139] With the ability of computer-aided design software to represent complex curvilinear forms and the introduction of computer-aided manufacturing techniques to the field of architecture in 1990's, new formal and spatial opportunities have been opened up in architecture.[140] With the transition of computers from a drafting device to a design medium, architects have utilized computers as a generative tool instead of a representational medium.[141]

Prior to the introduction of computer-aided design software to architecture, the buildings were constructed from a set of drawings each representing a small portion of the building. Therefore the design process was a "virtual construction" of orthographic drawings representing the actual building.[142] With computer-aided design software, architects started to work on the exact model of the project, which allowed the generation of an orthographic set of drawings from the same model.[143] Stan Allen describes this situation as the breakdown of

---

[138] Yehuda E. Kalay, Architecture's New Media: Principles, Theories, and Methods of Computer-Aided Design, p.69.

[139] Bernard Cache, "Framing the Fold: Furniture, Architecture, Geography, and the Pursuit of the Virtual," in Virtual Dimension: Architecture, Representation and Crash Culture ed. John Beckmann, New York: Princeton Architectural Press, 1998. p.302.

[140] Branko Kolarevic, "Introduction," in Architecture in the Digital Age: Design and Manufacturing, ed. Branko Kolarevic, New York: Spon Press, 2003. p.7.

[141] Branko Kolarevic, "Digital Morphogenesis," in Architecture in the Digital Age: Design and Manufacturing, p.13.

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

[143] Andreas Ruby, "Architecture in the Age of Digital Producibility," in Digital / Real Blobmeister : First Built Projects, ed. Peter C. Schmal, Basel: Birkhauser, 2001.

the distance between the "real" and the "representation," for the three-dimensional model can generate infinite number of representations.[144]

Another important aspect of computer-aided manufacturing is the process called as "file-to-factory," which enables the production of the elements of the project by directly sending the data sets of the computer model to manufacturing companies.[145] Although the "file-to-factory" process allows the production of the parts of a building without any drawings, a set of information is still needed for the manufacturing machines.[146] Therefore the model "constructed" in the digital medium should be capable of generating the required data. The parallel relation between the necessity of representing all of the surfaces with mathematical equations in the computer software and the only possibility of manufacturing through a set of data in CAM processes, made it possible to produce an object whose specific form or amount of curvature is not known prior to manufacturing.

3.2.1.1 Non-Uniform Rational B-Splines (NURBS)

One of the most important things computers have introduced to the field of architecture are Non-Uniform Rational B-Splines (NURBS). Formerly used in the ship industry for shaping the hulls of the ships, NURBS now allow architects to design and control curves in an efficient and easy way. [147] Each NURBS is formed from a set of control points, weights and knots, allowing the

---

[144] Stan Allen, Terminal Velocities: The Computer in the Design Studio, in Virtual Dimension: Architecture, Representation and Crash Culture p.247.

[145] Andreas Ruby, "Architecture in the Age of Digital Producibility," in Digital / Real Blobmeister : First Built Projects.

[146] William J. Mitchell, "Constructing an Authentic Architecture of the Digital Era," in Disappearing Architecture: From Real to Virtual to Quantum, eds. Georg Flachbart and Peter Weibel, Berlin: Birkhauser, 2005. p.85.

[147] Branko Kolarevic, "Digital Morphogenesis," in Architecture in the Digital Age: Design and Manufacturing, p.15.

creation of various different curves. Therefore a curve is controlled not by points on the curve but through indirect control elements. By controlling the control points, any shape can be attained varying from straight lines to double-curved surfaces. A NURBS curve is represented as a mathematical formula, i.e. a polynomial equation. The possibility of producing any NURBS curve through computer numerically controlled machinery by using the equation makes the NURBS a powerful tool for modeling.[148] What is so significant about NURBS curves and surfaces is the introduction of local coordinate systems. In a NURBS curve extending in all three-dimensions, there is a one-dimensional local coordinate system that ranges from 0 to 1. The first local dimension is mostly named as “U.” All the points on the curve are parameterized with a value from 0 to 1. In a similar fashion, in NURBS surfaces, there exists a two-dimensional coordinate system, “U” and “V.” Both ranging from 0 to 1, a point on the surface is denoted by two values. The parameterization of the surface by “U” and “V” coordinates allows finding the precise location of any point on a highly complex curvilinear surface.

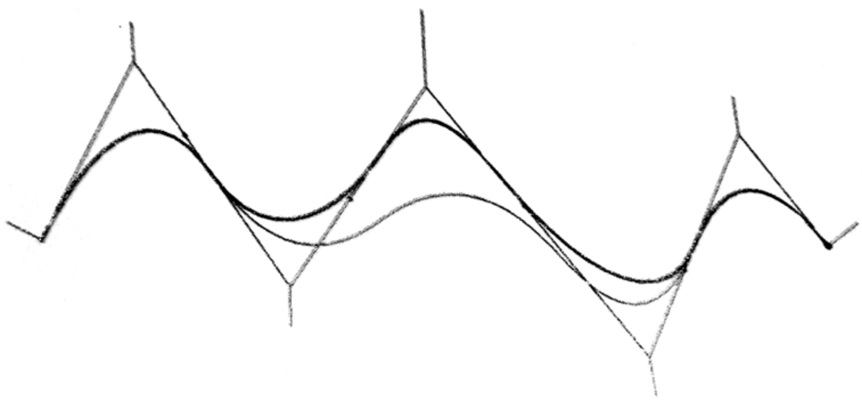

Figure 16: A NURBS Curve.
ed. Branko Kolarevic, Architecture in the Digital Age: Design and Manufacturing, New York: Spon Press, 2003. p.16.

3.2.1.2 Non-Euclidean Geometry

Non-Euclidean geometry became an integral part of computer-aided design and manufacturing. The possibility of representing non-Euclidean geometry or the geometry of higher dimensions, and manufacturing these forms through computer-aided manufacturing machines allowed architects to design curvilinear forms easily.[149] With the advent of NURBS geometries, any surface could be represented and produced with high accuracy through CAM techniques. It should be noted however that, even though computer-aided design software is capable of representing non-Euclidean geometries, these are still working in a Cartesian coordinate system.[150] By defining local coordinate systems, the software can visualize new geometries. While producing these complex forms, manufacturing machines require data belonging to the Cartesian coordinate system as well. By using the global coordinate values of non-Euclidean geometries, machines produce through three-dimensional Cartesian coordinate system with precision.[151]

The introduction of computer-aided manufacturing tools also replaces mass production by mass customization. Varying amounts of differentiations in the parameters will result in customization in final products without increasing the cost of manufacturing.[152] The total cost will not differ in computer numerically controlled machinery to produce any number of different products or a same number of identical objects. To create diversity, only the differentiation in the set of data for manufacturing is required. By setting the alterations in the

---

[148] Ibid.

[149] William Massie, "Remaking in a Post-Processes Culture," in Versioning: Evolutionary Techniques in Architecture, ed. ShoP / Sharples Holden Pasquarelli, London: John Wiley & Sons, 2002. p.58.

[150] Bernard Cache, "Towards a Fully Associative Architecture," in Architecture in the Digital Age: Design and Manufacturing, ed. Branko Kolarevic, New York: Spon Press, 2003. p.142.

[151] Ibid.

[152] Kas Oosterhuis, "A New Kind of Building," in Disappearing Architecture: From Real to Virtual to Quantum, eds. Georg Flachbart and Peter Weibel, Berlin: Birkhauser, 2005. p.92.

parameters of data to zero, a potential mass customization project can become a mass product.[153]

3.2.2 Parametric Design

A parametric equation stands for a group of results that can change with the differentiations in the variables of the equation.[154] The equation y=ax+b is a parametric equation and represents all of the possible first-degree line equations in two-dimensional coordinate system with different values of “a” and “b.” Parametric design implies the definition of relations among entities through certain variables creating a potential for various design alternatives.[155] As the parametric design implies the design of the geometric and mathematical relations between objects, the geometry it uses is also called “associative geometry.”[156] Parametric design tools have introduced new geometries to architecture, however it is not the new geometries parameters mainly offer, but it is the chance to control the design process. Mark Burry names this concept as “designing the design” or “metadesign.”[157] Instead of designing the final shape, the designer defines the parameters and seeks for associations among objects.[158] The design of the process has become more important than the object, for it is the process that creates the final form.

---

[153] Ibid. p.93.

[154] James D. Foley et. al., Introduction to Computer Graphics, Massachusetts: Addison-Wesley Publishing Company, 1993. p.325.

[155] Branko Kolarevic, “Digital Morphogenesis,” in Architecture in the Digital Age: Design and Manufacturing, p.17.

[156] Mark Burry, “Between Intuition and Process: Parametric Design and Rapid Prototyping,” in Architecture in the Digital Age: Design and Manufacturing, ed. Branko Kolarevic, New York: Spon Press, 2003. p.149.

[157] Ibid. p.151.

[158] Mark Burry, “Paramorph: Anti-accident Methodologies,” in AD: Hypersurface Architecture II, London: Academy Editions, 1999.

An important concept regarding parametric design is topology. It is also called the "geometry of the rubber sheet," for topological equivalence denotes all possible configurations of a figure drawn on a rubber sheet that is deformed without any tears or cuts.[159] Instead of the momentary shape of an object, topology deals with the relations among its geometric constituents.[160] For that reason, changing the size or shape of an object or twisting and stretching it, does not change the object's topologic quality. Greg Lynn defines topology as "a continuous stream of relative values" and "multiplicity without points," denoting the formless character of the topologic entities.[161] Topology is closely related with parametric design. The variation of forms produced by different values of parameters result in topologically equivalent forms, which are called "homeomorphic forms."[162]

In parametrics, geometry is controlled through parameters or control geometries. Control geometries are never built but used during the design process. A surface can be defined through a set of points, a group of curves or from the intersection of a volume with another surface, which are all control geometries. In each case the surface is dependent on the initial set of data, a phenomenon called as "geometric dependency."[163] By changing the coordinates of one or more points, the form of the surface can be modified, or decreasing the amount of curvature on each curve will result in a less curvilinear surface or one can change the initial volume with another and obtain a completely different surface. All of these operations can be done after the creation of the surface, as

---

[159] Giuseppa Di Cristina, "The Topological Tendencies," in Architecture and Science, ed. Giuseppa Di Cristina, London: John Wiley & Sons, 2001. p.7.

[160] Branko Kolarevic, "Digital Morphogenesis," in Architecture in the Digital Age: Design and Manufacturing, p.13.

[161] Greg Lynn, Animate Form, p.20

[162] Branko Kolarevic, "Digital Morphogenesis," in Architecture in the Digital Age: Design and Manufacturing, p.13.

[163] Robert Aish, "Exploring the Analogy that Parametric Design is a Game," in Game, Set and Match II: On Computer Games, Advanced Geometries, and Digital Technologies, eds. Kas Oosterhuis, Lukas Feireiss, Delft: Episode Publishers, 2006. p203.

modification tools. Control geometry can also be dependent on another set of data. The hierarchic structure of parametrics allows any number of steps of parameterization. At the end, all data becomes implicitly or explicitly dependent to each other. Any change in the initial set of data modifies all the subsets automatically, for all of the parameters and geometries are dependent on each other. One can also modify lower levels of hierarchy of design without changing the upper levels.

Parametric design offers a wide range of possibilities. Besides the possibility of forming geometrical associations, parameters can also have mathematical relations.[164] A function can control the geometry of a shape or the results of a structural analysis may be used to decide on the dimensions of structural elements. This kind of mathematical control data cannot be seen as a geometric entity in the model but it takes place in the hierarchic structure of parameters and modifying the mathematical data will result in a different configuration of the design.

The following project is a proposal for two monorail stations at the Middle East Technical University. The project was designed for the Summer Practice of first year undergraduate students at the Middle East Technical University, Department of Architecture by Assistant Professor Berin Gür, Research Assistant Gökhan Kınayoğlu and Research Assistant Onur Yüncü and the scripting was realized by Kınayoğlu. The project was designed in Autodesk Maya using MEL script. The script is composed of various parameters that are controlling the width and length of the station, the height of the shelter, the dimensions of the unit element and the number and width of the seating. The final shape of the shelter is formed from timber elements with standard length. By different amount of rotations in each joint detail, the shelter can deform its

---

[164] Branko Kolarevic, "Digital Morphogenesis," in Architecture in the Digital Age: Design and Manufacturing, p.18.

shape. The script uses a control curve for determining all of the positions of the elements. Each point on curve determines the actual rotational value of the corresponding element of the shelter. Therefore every element's value of rotation is determined from the shape of the curve. Afterwards, each joint detail is generated from the rotational values between neighbouring elements by using the script.

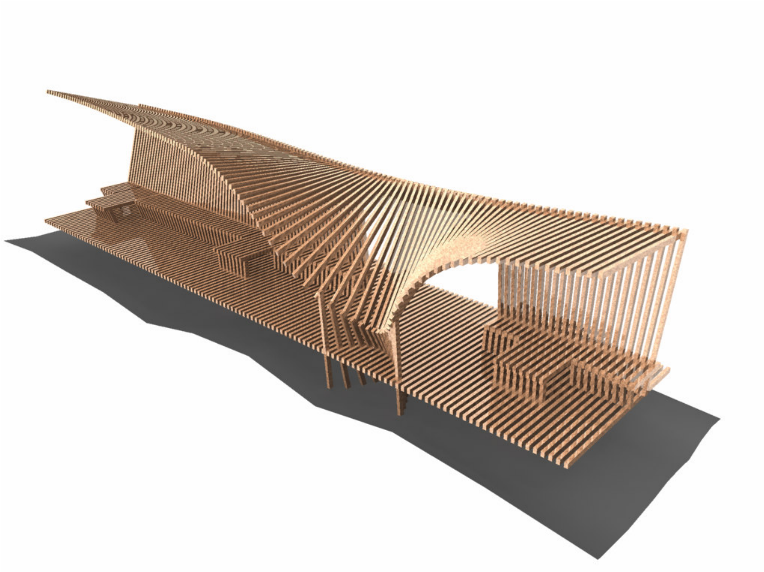

Figure 17: Parametric Monorail Station.
Image courtesy of Gökhan Kınayoğlu.

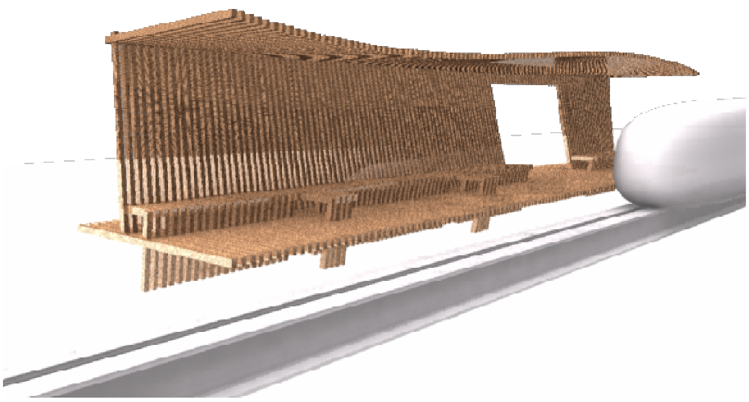

Figure 18: Variation of the Parametric Monorail Station.
Image courtesy of Gökhan Kınayoğlu.

```
// creates BankYan
            polyCube -ch off -o on -w 8 -h 12 -d $banksidedepth -cuv 4
                        -n ("bankyan" + $functioncounter);
            move -r ($functioncounter+8) 0 (-1 * $depth/2 + 270);

// creates BankYan Locator
            spaceLocator -p 0 0 0;
            rename "locator1" ("lby" + $functioncounter);
            move -r ($functioncounter+8) 0 (-1 * $depth/2 + 150 + 60 + 95);
            parent ("bankyan" + $functioncounter) ("lby" + $functioncounter);

// creates BankUst Locator
        spaceLocator -p 0 0 0;
        rename "locator1" ("lbu" + $functioncounter);
        move -r ($functioncounter+8) 0 (-1 * $depth/2 + 90 + $banksidedepth + 90);

// creates BankUst
        polyCube -ch off -o on -w 8 -h 12 -d 1 -cuv 4 -n ("bankust" + $functioncounter);
        move -r $functioncounter 0 0;

expression -s ("bankust" + $functioncounter + ".scaleZ = 50
                / tan(deg_to_rad(lz" + $functioncounter + ".rotateX)) * 2 + 180")
            -o ly0 -ae 1 -uc all ;


expression -s ("bankust" + $functioncounter + ".translateZ = 60
                * cos(deg_to_rad(lby" + $functioncounter + ".rotateX)) + 80")
            -o ly0 -ae 1 -uc all ;

        parent ("bankust" + $functioncounter) ("lbu" + $functioncounter);
        parent ("lbu" + $functioncounter) ("lby" + $functioncounter);

//keeps BankUst levelled
        expression -s ("lbu" + $functioncounter + ".rotateX = 180 - lby"
                + $functioncounter + ".rotateX")  -o ly0 -ae 1 -uc all ;


//inverse the BankYan locator
        select -r ("lby" + $functioncounter);
        rotate -r 0 0 180;

//counter increment
        $parameter2 = ($counter2 / 2000);
```

Figure 19: Partial script of Parametric Monorail Station.

Script courtesy of Gökhan Kınayoğlu.

3.3 The nth Dimension in Cyberspace

Similar to the initial approaches in trying to achieve higher dimensions in hyperspace through n-dimensional geometries, architects have tried to represent higher dimensions in the medium of computers with the introduction of cyberspace.[165] Instead of trying to reach higher dimensions through geometries beyond intuition, architects have visualized the upper dimensions by utilizing parameters into their designs. The tremendous visualization and computation capability of computers and the spatial possibilities of cyberspace have enabled architects to design projects with complex relations, apply force fields and dynamic simulations to projects for morphogenetic purposes.

As Branko Kolarevic states, to the first three dimensions, a new dimension may be added in a project as a temporal dimension, for showing the deformations of the object through time that are created by various forces or alterations in parametric values.[166] From a set of keyframes consisting of topologically equal but formally different instances of the project, animation software will produce a smooth transformation in the fourth dimension through interpolation of discrete forms.[167] The resulting set of forms can be considered as an extension in the fourth dimension, that can now be represented.

Greg Lynn made one of the early attempts as taking time as an integral part of the design process.[168] He aimed to create an architecture of motion by taking into consideration "motion and force at the moment of formal conception."[169] For Lynn, form is the total immersion of internal and external forces. Rather

---

[165] Greg Lynn, Animate Form.

[166] Branko Kolarevic, "Digital Morphogenesis," in Architecture in the Digital Age: Design and Manufacturing, p.22.

[167] Ibid.

[168] Greg Lynn, Animate Form. p.20.

[169] Ibid. p.11.

than producing alternatives to a specific form, Lynn searched for the properties of animate design by implementing physical properties, external forces or gradient fields.[170] The project consists of simulated forces like friction, gravity, mass or wind; each acting as generators of form. The final form is an instance of the implementation of all forces upon the project, however it also promotes variations for different force fields and simulations.

Michael Benedikt proposes a kind of space for representing n-dimensional systems, called "data space."[171] According to Benedikt, in data space for every object there are up to four extrinsic dimensions -spatio temporal qualities of the object- and any number of intrinsic dimensions -color, shape, weight, size or other similar properties. The intrinsic dimensions are considered as a part of data space if an alteration is observed among that dimension. Each object in data space has an address for denoting its exact position, as in the Cartesian coordinate system. Data space is consisting of points, where each point represents an instance of the object and it is capable of showing all possible formations.[172]

3.3.1 Higher Dimensions Through Multiple Variables

The parametric design enabled integration of multiple variables into the design. Alterations in the value of each parameter produce a new form of the project. Higher dimensions are represented as parameters extending between their local minimum and maximum values. The family of variations generated through the differentiation of the parameter, creates one of the possible higher dimensions. In other words, each parameter has the capacity to form a unique dimension.[173]

---

[170] Branko Kolarevic, "Digital Morphogenesis," in Architecture in the Digital Age: Design and Manufacturingp.20.

[171] Michael Benedikt, "Cyberspace: Some Proposals," in Cyberspace: First Steps, p.135.

[172] Ibid.

[173] Marcos Novak, "Transmitting Architecture: transTerraFirma/TidsvagNoll v2.0," in Architectural Design: Architects in Cyberspace, v.65 No: 11 / 12, 1995. p.47.

Consequently, by adopting “n” parameters in a project, architects can reach the n^{th} dimension.[174] Although it may seem illogical at first, the potential of each parameter to create unique formal alternatives of the project is the crucial point here. In n-dimensional projects, the project becomes a topological entity rather than an instance. The parametric existence of an object turns it into a formless geometry because of the fluctuating values of its parameter.

Another alternative for reaching higher dimensions is a technique called “versioning,” which mainly deals with cooperating all processes of design.[175] Opposed to traditional techniques of design, where an idea is developed through stages of design to reach into a built form; versioning depends on data-design capable of responding to multiple influences with a non-linear formation of the design process.[176] The history of design process is recorded, so previous versions can be reached at any time of the process and the evolution of the project can be observed. Therefore both previous versions and alternatives may occur simultaneously.[177] The outcomes of the project also help to revive the process, resulting in a continuous deformation and reformation of the project. As a result, “the final building is comprised of numerous derivative of the digital data and is therefore in its sum only one possible image of the reality extracted from the master geometry as seen in the nth derivation.”[178]

---

[174] Michael Benedikt, “Cyberspace: Some Proposals,” in Cyberspace: First Steps, p.133.

[175] Ingeborg Rocker, “Versioning: Evolving Architectures – Dissolving Identities ‘Nothing is as Persistent as Change,” in Versioning: Evolutionary Techniques in Architecture, ed. ShoP / Sharples Holden Pasquarelli, London: John Wiley & Sons, 2002. p.11.

[176] Ibid.

[177] Ibid. p.13.

[178] Ibid. p.17.

3.3.2 Family of Forms: Form Finding vs. Form Making

The set of formal outcomes of a parametric design through different values of parameters is called a "family of forms."[179] A family of forms covers all possible forms of a parametric design, in other words all possible points in a data space. The possibilities presented by the family of forms allow the architect to focus on the design process. Instead of creating a form, designers benefit from extrinsic forces allowing the self-organization of the system. Again, architects analyze and determine the forces acting on the design, which lead to the emergence of the shape. The technique is called "form-finding" and was first used by Frei Otto for his tensile or pneumatic structures.[180] Form-finding in digital medium has the potential of "analyzing dynamic, highly non-linear, indeterministic systems of organization."[181] "Family of forms" and form-finding procedures have allowed architects to decide on the final form of the project from a group of alternatives. In form finding, designing the design gains more importance, for the outcomes of the parametric variation solely depends on the design of parameters.

---

179 Branko Kolarevic, "Digital Morphogenesis," in Architecture in the Digital Age: Design and Manufacturing, p.26.

180 Achim Menges, "Polymorphism," in Architectural Design: Techniques and Technologies in Morphogenetic Design, Vol. 76, No.2, p.79

181 Branko Kolarevic, "Digital Morphogenesis," in Architecture in the Digital Age: Design and Manufacturing, p.26.

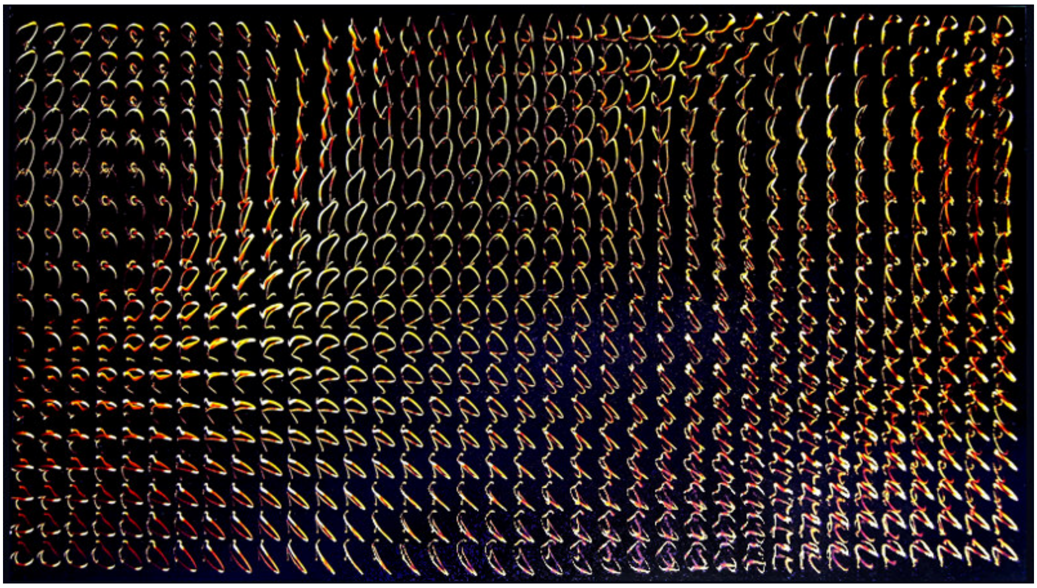

Figure 20: "Hystera Protera," a family of forms.
Mark Goulthorpe, "Scott Points: Exploring Principles of Digital Creativity," in Architecture in the Digital Age: Design and Manufacturing, New York: Spon Press, 2003. p.171.

In most cases the formal library of a design is represented through matrices with various dimensions. If the variations are achieved through a single parameter an animation showing the process of transformation will include all formal possibilities. Every single frame of the animation will compose the "family of forms." Representing higher numbers of parameters will require two or three-dimensional matrices, in some cases also requiring transformation through time. The ideal quality of computer medium allows designers to increase or decrease the amount of increments in parameters, resulting in less or more number of instances.

In the design process of Kas Oosterhuis and Marcos Novak's' "transPORTs2001," a parametric design approach is taken. The project was designed to create an interface between the physical and virtual worlds. A parametric model was created using computer-aided design software, which was designed as a "performing structure."[182] Parametric relations allow users to interact with the structure initiating variations on the form. Inputs from the website together with the data collected from the building alter the shape of the structure, which is composed of pneumatic bars. Oosterhuis compares the structure to an "organism" for it reacts to its environment and the pneumatic bars act like filaments in a muscular bundle.[183] The process allowed the architects to implement the design without an exact form, but instead the structure finds its form through time.

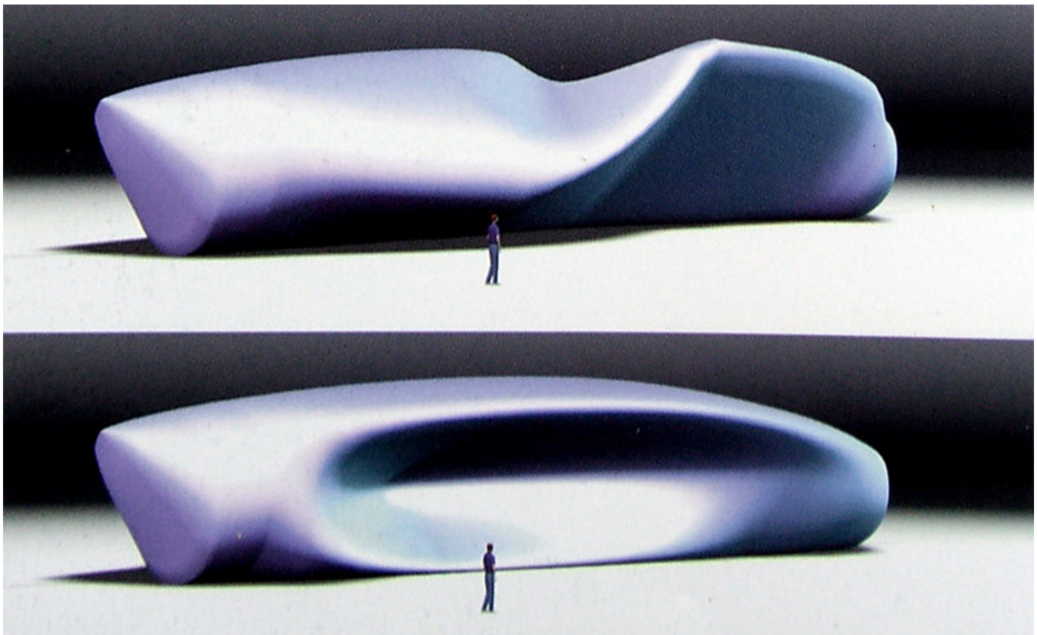

Figure 21: Interactive computer model of transPORTs2001.
Peter Zellner, Hybrid Space: New Forms in Digital Architectures, New York: Rizzoli Publications, 1999. p.72.

[182] Peter Zellner, Hybrid Space: New Forms in Digital Architectures, New York: Rizzoli Publications, 1999. p.72.

[183] Ibid.

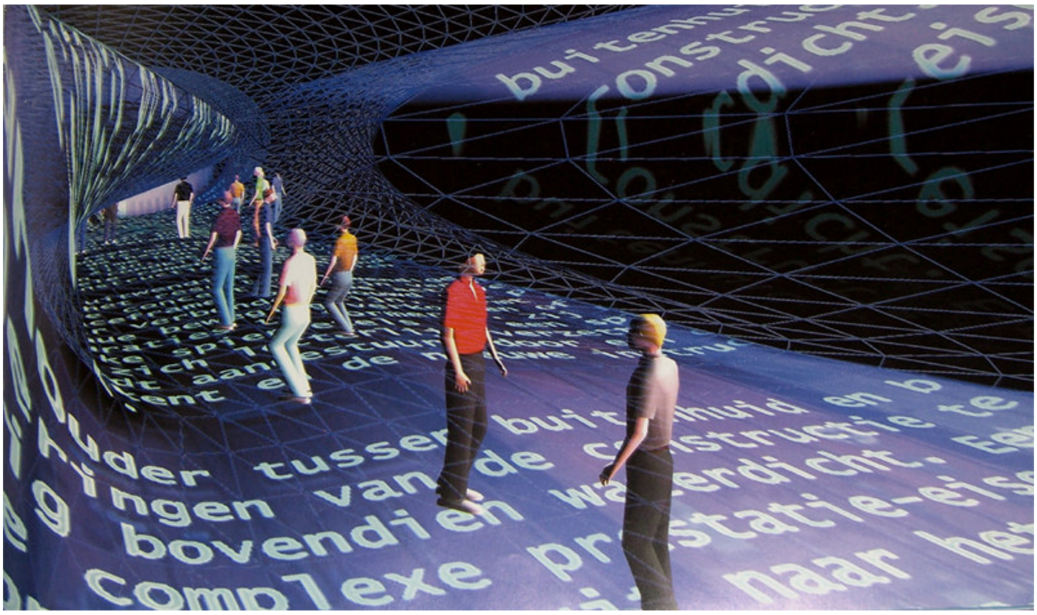

Figure 22: Computer rendering of the physical model.

Peter Zellner, Hybrid Space: New Forms in Digital Architectures, New York: Rizzoli Publications, 1999. p.72.

CHAPTER 4

HYPOSPACE
PARAMETERIZATION – MATERIALIZATION

The unique design methods and computational tools offered by cyberspace and computer-aided design have allowed architects to design projects using new geometries along with algorithms, parameters and associative design techniques. Extending the discussion about the effects of cyberspace on the design techniques and methods elaborated in previous chapter, this chapter will mainly focus on the concept of surface, which comes as a consequence of parameterization and materialization. As mentioned in the previous chapter, parameterization allows architects and designers to design through a set of variables, resulting with a set of possible implementations of the project. Although the process of computer-aided design covers a wide range of explorations of relations and formal experimentations, the final product has to be represented or manufactured through an instance of all possible variations. As manufacturing processes need an instance of the project for construction, or as a project realized in cyberspace has to be represented through a possible set of variations, the architect has to decide on the final form of the building as a part of the design process, a process called as form-finding. The contradicting demands of parameterization and materialization create a conflicting situation between the two: While parameterization allows reaching higher dimensions through associative geometries, materialization requires a reductionist representation of the project as its construction in the physical world needs a single occurrence of the project as well as any representation in cyberspace.

4.1 The Formal Shift From Space to Surface in Virtual Realm

> "Today we search for the meaning of surface on surface. That is why we are changing our style of perception: instead of reaching into the depth, we are surfing on the crests of the waves."[184]

Giedion notes that the concept of surface has been the subject of architecture for many centuries, whereas it is during the Modern Movement that it transformed from a purely aesthetic element into a crucial constructive element.[185] As stated by Mark Taylor, surfaces were formerly regarded as a base for applying ornaments, in other words they were entities that should be "dressed" and not to be used as "naked" forms.[186] Architects and artists like Theo van Doesburg, Kasimir Malevich, Cornelis van Eesteren, Gerrit Rietveld and Mies van der Rohe have utilized the rectangular walls as purely constructive elements in the first quarter of the 20th century.[187] As previously mentioned in the second chapter, in architecture, a parallel approach was taken by using organic forms, where the concept of surface was taken as a non-planar entity and curvilinear forms were designed with the impact of the discovery of non-Euclidean geometries. This two-fold development of the concept of surface in the 20th century is revitalized with the introduction of cyberspace and computer-aided design tools into architecture. In the digital medium, surfaces have found a completely geometric and autonomous formation, freed from both physical and

---

[184] Norbert Bolz, "Design des Immateriellen in Sehnsucht," 1995, cited in Dagmar Richter, "Armed Surfaces: Towards a New Topology," in Architectures Non Standard, eds. Fréderic Migayrou and Zeynep Mennan, Paris: Editions du Centre Pompidou, 2003. p.80.

[185] Sigfried Giedion, Space, Time and Architecture: The Growth of a New Tradition, 5th ed., Massachusetts: Harvard University Press, 1971. p.li.

[186] Mark Taylor borrows the terms "dressed" and "naked" from Leone Battista Alberti's De Re Aedificatoria, in "Surface-Talk," in Surface Consciousness, ed. Mark Taylor, London: John Wiley & Sons, 2003. p.32.

[187] Sigfried Giedion, Space, Time and Architecture: The Growth of a New Tradition. p.li.

material restraints within the medium of computers. In other words, the concept of surface has been reshaped as a purely constructive geometrical element.

Throughout history, structure and surface have been regarded as two distinct entities. According to Mark Taylor, Alberti and Gottfried Semper have produced two opposing but similar views related to the surface-structure relation.[188] Alberti stated that surface was the cladding or the ornament on the structure, and that by removing the surface one could reach to the "true, inner architectural surface."[189] It can be said that the ornament applied onto the structure is a surface with a certain thickness masking the inner surface. The separation of structure and surface can also be found in Semper's view, but in reverse order: Semper claimed that surface has priority over the solid structure.[190] Although each view governs different orders of surface and structure, both regard surface as a separate entity from structure, thought as a natural outcome of the application of ornament. Surface is not a unique architectural element of the design process but comes as a product of this process. It is with the Modern Movement that surface and structure are completely detached and both gain their own formal characteristics.[191] Within the context of cyberspace, as structural necessities have vanished, the duality between surface and structure has disappeared and surface has become capable of governing the structural quality on itself. Although there is no need to adopt any structural property, surface becomes structure itself, for it is the only constructive element in cyberspace.[192]

---

[188] Mark Taylor, Surface Consciousness. p.32.

[189] Ibid.

[190] Gottfried Semper, Four Elements of Architecture and Other Writings. trans. Francis Mallgrave and Wolfgang Herrmann. Cambridge: Cambridge University Press, 1989.

[191] Branko Kolarevic, "Digital Production," in Architecture in the Digital Age: Design and Manufacturing, p.39.

[192] Peter Wood, "Sticks and Stones: Skins and Bones," in Surface Consciousness, ed. Mark Taylor, London: John Wiley & Sons, 2003. p.67.

Figure 23: Conceptual model of "Dynaform" by Bernhard Franken, an example of a monocoque structure.

http://www.dam-auktion.de/auktionimage/4.jpg

Last accessed on August 2007.

Contrary to the absence of structural constraints in cyberspace, contemporary material technologies have allowed the production of surfaces with structural qualities.[193] Therefore while the structural necessities vanish in the digital medium, the possibility of manufacturing complex structural skins is evolving the concept of surface to the opposite extreme. Unlike previous conceptions of structure and skin, monocoque structures allow the binding of the two, attributing a structural role to the skin of the building, which becomes capable of bearing all or most of the loads.[194] Although monocoque structures and

[193] Şulan Kolatan and William MacDonald (Kol/Mac Studio,) "MUTualistic ENvironmentality," in Architectures Non Standard, eds. Fréderic Migayrou and Zeynep Mennan, Paris: Editions du Centre Pompidou, 2003. p.103.

[194] Branko Kolarevic, "Digital Production," in Architecture in the Digital Age: Design and Manufacturing, p.39.

structural skins are a new subject for architecture, they have been used in automotive, aerospace and shipbuilding industry long before architecture.[195] Monocoque structures owe their existence to new materials that can resist a great amount of stress while taking on various curvilinear forms.[196] As Joseph Giovanni notes,

> "In some ways the search for a material and form that unifies structure and skin is a counterrevolution to Le Corbusier's *Domino House*, in which the master separated structure from skin. The new conflation is a return to the bearing wall, but one with freedoms that Corb never imagined possible."[197]

The essential point of the use of surfaces in virtual projects and monocoque structures in construction is the unification of structure and surface for the first time. In the former case, the lack of structural constraints evolve surface to structure, while in the latter, the capability of having structural qualities unify surface and structure. The traditional massive load-bearing wall has now turned into structural surfaces. Departing from the views of Alberti and Semper, structure has become the outcome of surface with the advent of new materials and computer-aided design software. Şulan Kolatan and William MacDonald's Project MUTEN – Mutualistic Environment – Istanbul can be noted as an example of the unification of structure and surface. The project's continuous curvilinear surfaces take on the structural role by adopting the role of structural skin.

---

[195] Ibid. p.40.

[196] In 2003, Nexia Bio Technologies has produced Bio-Steel, a biopolymer, by implementing a gene responsible for the protein that gives the strength of the spider web into genes of a goat that are responsible from producing milk, resulting with a structural material, that is lightweight, elastic and 20 times stronger than steel.
www.nexiabiotech.com
Last accessed on August 2007.

[197] Joseph Giovanni, "Building a Better Blob," in Architecture, vol.89, no.9, 2000. p.126.

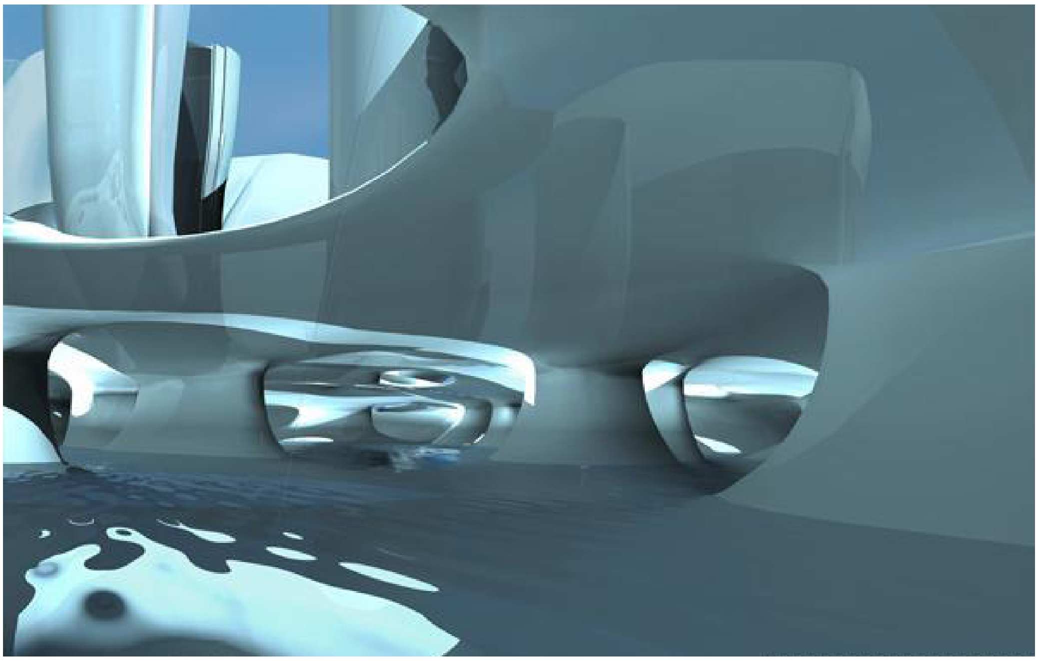

Figure 24: A view from MUTEN Istanbul Project (2006).
http://www.arkitera.com/tools/watermark.php?src=UserFiles/Image/ig/Proje/2006/muten/106.jpg
Last accessed on August 2007.

Mark Taylor notes further that a fundamental differentiation in the formal characteristic of surfaces through the transition from the physical world to the virtual realm is the absence of thickness within surfaces.[198] The absence of thickness has transformed surface into a sole geometric constituent of architecture. For the mathematical necessities and geometrical properties of computer-aided design software, surfaces in computer medium do not have any thickness. The design software adopt surfaces as their main constituent and a surface with thickness can only be denoted by two distinct surfaces close to each other. Through the process of design, architects utilize surfaces without any thickness and even for manufacturing purposes, the computer model of the project does not necessarily require a thickness, for the computer-numerically controlled machinery deals with the traces among surfaces and not with their thickness. Although the manufactured parts of the building are composed of

[198] Mark Taylor, "Surface-Talk," in Surface Consciousness, p.31.

physical materials with certain dimensions, the computer model rarely contains the thickness data of parts.

The loss of materiality and depth of surfaces has opened new potentials for the geometric capabilities of surface. Previously limited with the physical and material constraints, surfaces can now take any shape with the mathematical precision of computers. The governing of surface in computer-aided design software has resulted with the introduction of new geometries into the field of architecture. Although new geometries were used in architecture long before the virtual realm,[199] the possibilities offered by cyberspace are much beyond the geometric explorations of the former applications. Non-Euclidean geometries, which are unattainable with common physical materials, have been introduced to the formal library of architecture.[200]

Another important aspect related with surfaces is the achievement of smoothness. Smoothness may be defined as the continuity of curvilinear forms through various surfaces.[201] It can be noted, especially in recent built projects, that architects want to end up with smooth and continuous surfaces. As Branko Kolarevic states, aiming for smoothness may be an attempt to hide connection details between surfaces that interrupts the appearance of the overall forms, or it can be the geometrical quality of the final building.[202] Kolarevic notes,

> "To some extent that smoothness and seamlessness provided for only one scale that mattered: it was the overall form and

[199] See "Reflections of the Debate in the Artistic and Architectural Realm" in Chapter 2.

[200] Mark Burry, "Between Surface and Substance," in Surface Consciousness, ed. Mark Taylor, London: John Wiley & Sons, 2003. p.14.

[201] Branko Kolarevic, "Digital Production," in Architecture in the Digital Age: Design and Manufacturing, p.37.

[202] Branko Kolarevic refers to Bernhard Franken's Dynaform project for BMW pavilion also as an attempt of achieving smoothness.

> shape that were primary – nothing was allowed to distract from the expressive and atypical geometry of the exterior skin."[203]

In addition to concerns related with smoothness, architects also give importance to the surface quality of their buildings. To achieve unique tactile surfaces, architects devise ornaments and surface operations. Therefore, the so long repressed use of ornaments has found a new approach in the virtual medium with this new primacy of the surface. In 1908, Adolf Loos had criticized the use of ornament in architecture, regarded as "crime" in his essay "Ornament and Crime."[204] Ornament and texture have reemerged with the development of manufacturing technologies and the possibility of implementing design in the digital medium.[205] In contemporary architectural projects, ornament is also used to give a sense of scale and tactility. Especially in the virtual realm, with the use of bare geometric elements, the loss of scale and tactility hardened the spatial and visual perception of users. In order to solve this problem, architects have devised ornaments and reliefs on surfaces.[206] Kolarevic also claims that aside from pragmatic reasons, aesthetic concerns are also valid in the use of ornament.[207] Whether it is used for functional reasons or for aesthetic considerations, ornament and texture have turned into an integral part of surfaces in contemporary design processes.

---

[203] Branko Kolarevic, "Surface Effects: Ornament in Contemporary Architecture," in Game, Set and Match II: On Computer Games, Advanced Geometries, and Digital Technologies, eds. Kas Oosterhuis, Lukas Feireiss, Delft: Episode Publishers, 2006. p.172.

[204] Adolf Loos, "Ornament and Crime" (1908), in Ornament and Crime: Selected Essays, trans. Michael Mitchell, Riverside: Ariadne Press, 1998.

[205] Branko Kolarevic, "Surface Effects: Ornament in Contemporary Architecture." p.172.

[206] Ibid. p.173.

[207] Ibid. p.172.

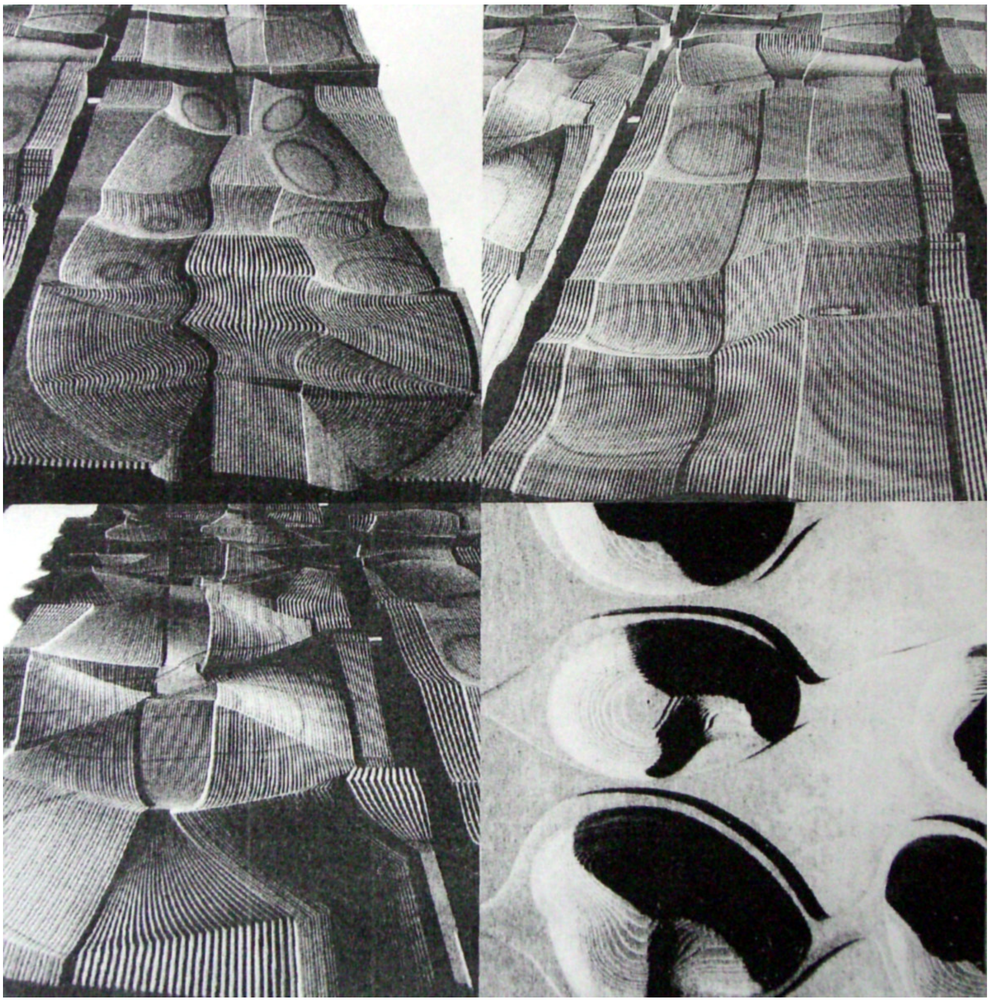

Figure 25 : CNC-milled formworks of Embryo House, by Greg Lynn. (1998). Peter Zellner, Hybrid Space: New Forms in Digital Architectures, New York: Rizzoli Publications, 1999. p.139.

Besides the capability of surfaces adopting ornaments in the virtual realm, physically manufactured surfaces are also capable of taking ornament. It can be said that the main reason beyond the return of ornament is the ease of applying ornament by computer-aided manufacturing techniques. The laborious craftsmanship once required has turned into mere technical application of computer-aided manufacturing processes. Computer driven production techniques allow implementation of reliefs and textures on surfaces without any difficulties, as in the case of Greg Lynn's "Embryo House" project.[208] Lynn uses computer numerically controlled machinery to produce individual composite panels for formworks. By devising a parametric formation of formworks more than two thousand unique panels were manufactured, attaining an embedded ornament and texture on all concrete surfaces of the house. Another similar approach was taken by Jacques Herzog and Pierre de Meuron in Eberswalde Library. The building utilizes silk-screened glass and photo-engraved concrete panels on its façade to produce an effect, which Herzog and de Meuron call "ornamented minimalism," denoting minimalist geometry with a highly decorative skin.[209]

Figure 26: Eberswalde Library by Jacques Herzog and Pierre de Meuron
http://www.pushpullbar.com/forums/attachment.php?attachmentid=10609&stc=1&d=1138630387
Last accessed on August 2007.

---

[208] Peter Zellner, Hybrid Space: New Forms in Digital Architectures, New York: Rizzoli Publications, 1999. p.139.

[209] Ibid. p.173.

As Dagmar Richter notes, there has been a shift in the subject of architectural design from "depth of construction and material" to ever changing and constantly visualizing surface with the introduction of computer software from animation and movie industry.[210] The possibility of adopting new geometries using non-Euclidean geometries and achieving further dimensions through parameters with nonlinear design techniques whose outcomes cannot be foreseen prior to visualization; the capability of surfaces to adopt structural roles in designs with advances in material technologies; the ease of applying ornament to surfaces in the computer medium along with the concerns for smoothness of surfaces and remaining as the single constructive element in the virtual realm, the concept of surface has become an important aspect of architecture within the computer-aided design medium. In other words, it can be said that the main interest throughout the design process in the medium of computers has shifted from spatial quality to the novel surface qualities of geometries. It is however certain that spatial concerns have not been left completely, but instead issues relating to surface have become superior to the spatial quality of the architectural projects.

4.1.1 Effects of Algorithmic Design on the Concept of Surface

Algorithmic design allows architects to analyze various data and forces related with the design decisions, and architects can design logical relations among these entities resulting with a formal library of possible implementations of the project.[211] Algorithmic design allows architects to design through immense amounts of data sets and analyses, which are capable of creating several formal instances of the project through computer-aided design software.[212] The most

---

[210] Dagmar Richter, "Armed Surfaces: Towards a New Topology," in Architectures Non Standard, eds. Fréderic Migayrou and Zeynep Mennan, Paris: Editions du Centre Pompidou, 2003.

[211] Robert Aish, "Exploring the Analogy that Parametric Design is a Game," in Game, Set and Match II: On Computer Games, Advanced Geometries, and Digital Technologies, eds. Kas Oosterhuis, Lukas Feireiss, Delft: Episode Publishers, 2006. p203.

[212] Ibid.

significant change caused by algorithmic design is the shift from a visual design process to a non-visual one.[213] For algorithmic design implies designing with the aid of scripts, parameters and mathematical relations, the architect has to deal with the non-visual quality of "norms" that create "non standard form."[214] As Zeynep Mennan notes in "Of Non Standard Forms: A 'Gestalt Switch',"

> "Non standard form is an enunciation of non-identity extended to the infinite; it forms a powerful challenge to the entire organization of human experience and philosophical thought always defined between order and chaos, identity and difference, invariable and variable, universal and singular, essence and appearance. These antinomies are generated and controlled by an extraformal normativity defining form as the incarnation of a model implicated by a norm."[215]

According to Mennan, the fluctuation of norm differentiates the process of nonstandardization from customization, where variation is achieved through a limited number of alternatives, whereas the non standard offers endless alternatives to form.[216] Constant variation of norm and form introduces a factor of uncertainty to the design process.[217] The architect cannot foresee the outcomes of the relations among elements that constitute the design while designing. The increasing number of parameters makes it impossible to intuit

---

[213] Zeynep Mennan, "Non-Standardization through Non-Visualization: Scripting the Dom-ino House," in Game, Set and Match II: On Computer Games, Advanced Geometries, and Digital Technologies, eds. Kas Oosterhuis, Lukas Feireiss, Delft: Episode Publishers, 2006. p.238.

[214] Zeynep Mennan, "Of Non Standard Forms: A 'Gestalt Switch'," in Architectures Non Standard, eds. Zeynep Mennan and Fréderic Migayrou, Paris: Editions du Centre Pompidou, 2003. p.34.

[215] Ibid.

[216] Ibid.

[217] Robert Aish, "Exploring the Analogy that Parametric Design is a Game," in Game, Set and Match II: On Computer Games, Advanced Geometries, and Digital Technologies, p202.

the alternatives of design prior to visualization. Instead of dealing with surfaces, architects have to deal with associations among geometries that build up the project. It is not the surface that is designed, but surface is the outcome of the process of design. Therefore the concern has shifted from visual to non-visual, from surface to algorithms and associative geometry throughout the process of design. The primary concern is still on the surface for it is the final product of the design process but the main part of the design process is occupied with non-visual design elements.

In contrary to the shift from visual to non-visual design process, architects still have to represent their projects to users through visual elements. For algorithmic design processes lead to infinite variations of a project, nonstandard forms become an integral part of the projects. Therefore, users cannot intuit the formal capacity of the paramorphs through discrete visualizations of the project but can only intuit a limited part of the project. Also, it is not possible for one to understand the parametric relationship between elements through the final geometry of the design process. There is a one-directional perceptual relation between geometry and parametrics, which is towards the final product of algorithms, parameters and geometric relations. It can be said that, algorithmic design has parted the fields of interest of architects and users to opposite extremes. While architects deal with non-visual design elements, users can only experience the formal characteristics of the projects through geometries.

Figure 27: "Tables Projectives" by Objectile (Patrick Beaucé, Bernard Cache) (exhibited at "Architectures Non Standard", Centre Pompidou, 2003-2004.)

http://architettura.supereva.com/extended/20060305/09.jpg

Last accessed on August 2007.

Bernard Cache designs through parameters and mathematical relations. Instead of using sketches or drawings, Cache designs through algorithmic procedures and parametric modeling of objects.[218] "Tables Projectives" is designed by Bernard Cache and Patrick Beaucé through algorithmic operations. A

[218] Bernard Cache, "Framing the Fold: Furniture, Architecture, Geography, and the Pursuit of the Virtual," in Virtual Dimension: Architecture, Representation and Crash Culture ed. John Beckmann, New York: Princeton Architectural Press, 1998. p.302.

parametric model is constructed and users decide on the final form of their tables. The table has two planar supports and a tabletop. Among alternatives, the tabletop always remains parallel to the ground with differing shapes. The table's supports are calculated and formed according to the center of gravity of the tabletop, guaranteeing the structural unity of the table. The only constraint about the geometry of the supports is that they will always be quadrilateral, with lower sides being coplanar to each other. With all these geometrical constraints and associations, Cache results in a "non standard" object, which is capable of ending with a different product in each manufacturing process.[219] The architect does not deal with the geometry of the table, but the geometric rules defining the geometry.[220] As a consequence, the table can be considered as a topologic multidimensional object. For that reason, the designer and user cannot anticipate the formal limits of multidimensional design, as neither the designer nor the user can intuit all the possible variations of the parametric model.

4.2 The Fold as an Agent

> "If there is a single effect produced in architecture by folding, it will be the ability to integrate unrelated elements within a continuous mixture."[221]

Folding is a technique introduced to the field of architecture from the book "The Fold: Leibniz and the Baroque" by Gilles Deleuze.[222] Michael Speaks notes that folding departs from the deconstructivist approach of conflicting and

---

[219] Ibid.

[220] Bernard Cache, Earth Moves: The Furnishing of Territories, ed. Michael Speaks, Massachusetts: The MIT Press, 1995. p.88.

[221] Greg Lynn, "Architectural Curvilinearity: The Folded, the Pliant and the Supple," in Architectural Design Profile: Folding in Architecture, ed. Greg Lynn, New York: John Wiley & Sons, 1993. p.8.

[222] Gilles Deleuze, The Fold: Leibniz and the Baroque, (1988), trans. Tom Conley, Minneapolis: University of Minnesota Press, 1993.

contradictory logic and finds its way through attaining “a more fluid logic of connectivity.”[223] Folding in architecture implies connectivity, which can be formal, conceptual or parametric, among entities that can be related or unrelated to each other. Every fold is a parametric connection between separate entities. For each entity operates by itself while affecting the other, a “heterogeneous continuous system” is formed via folding. [224]

Folding implies the infinity of the elements that make up an object. Deleuze compares the desert to a labyrinth for explaining the infinite quality of the fold.[225] Although a desert may seem to have an infinite number of sand grains, one can find the last grain in a desert; whereas the labyrinth consists of endless folds, for it is not the matter but the folding operation the labyrinth is made of.[226] Therefore, folding implies a formless architecture, for it deals with the process rather than the final result. It searches for continuity among objects and forms connections between them.

Folding is closely related with topological geometry for it aims for continuous transformation. A folded surface no more implies a single geometric shape in space, but instead it evolves into a temporal, topologic entity, involving numerous formations extending in time.[227] The Cartesian conception of space consisting of discrete points that form the geometric three-dimensional space has turned into a family of forms. As Kolarevic notes,

---

[223] Michael Speaks, “Folding Toward a New Architecture,” in Earth Moves: The Furnishing Territories, by Bernard Cache, ed. Michael Speaks, Massachusetts: The MIT Press, 1995. p.xiii.

[224] Giuseppa di Cristina, “The Topological Tendency in Architecture,” in Architecture and Science, ed. Giuseppa di Cristina, London: John Wiley & Sons. 2001. p.7.

[225] Gilles Deleuze, The Fold: Leibniz and the Baroque, p.6.

[226] Ibid.

[227] Giuseppa di Cristina, “The Topological Tendency in Architecture,” in Architecture and Science, p.8.

> "This new fluidity of connectivity is manifested through "folding," a design strategy that departs from Euclidean geometry of discrete volumes represented in Cartesian space, and employs topological conception of form and the "rubber sheet" geometry of continuous curves and surfaces as its ultimate expression."[228]

Greg Lynn has utilized folding in the Stranded Sears Tower project, consisting of nine office towers that are decomposed from a single high-rise tower.[229] The dissemination of the vertical office tower by elongating it in the horizontal direction is coupled with the multiplication of the tower through interlocking tubular structures. The distinctive geometry of the towers is achieved by external forces acting on the tubes. As Lynn describes,

> "The rigid geometry that dictated the exact parallel relations between tubes was rejected for a more supple description. Through a geometry that is more supple, the nine contiguous tubes accommodate themselves fluidly and flexibly to the multiple and often discontinuous borders of the site. The relations between tubes are not exactly parallel. These supple deflections allow connection to take place, which would have been repressed by a more rigid and reductive geometric system of description."[230]

Although the project consists of many formal relations with the site and itself, the outcome of the project cannot transmit those relations to the user through its final form. For that reason the user can only evaluate the formal quality of the

---

228 Branko Kolarevic, "Introduction," in Architecture in the Digital Age: Design and Manufacturing, ed. Branko Kolarevic, New York: Spon Press, 2003. p.4.

229 Greg Lynn, "Stranded Sears Tower," in Architectural Design Profile: Folding in Architecture, ed. Greg Lynn, New York: John Wiley & Sons, 1993. p.83.

230 Ibid.

project. The multidimensional process of design cannot be represented in the final product. The reductionist approach of parametric and algorithmic design is also valid for the technique of folding.

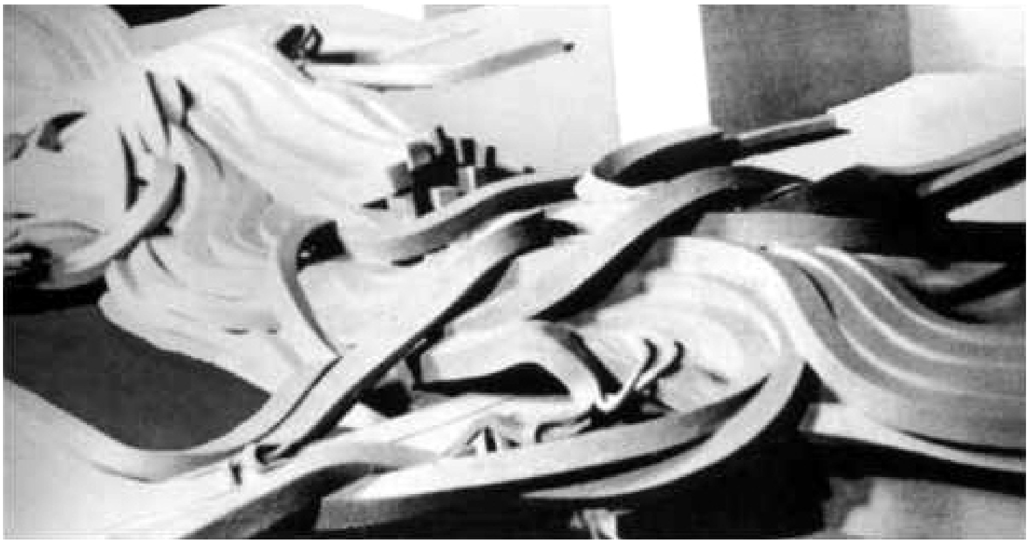

Figure 28: "Stranded Sears Tower," by Greg Lynn, site model.
Greg Lynn, in "Multiplicitous and Inorganic Bodies," in Assemblage, No: 19 (Dec., 1992), pp.32-49.

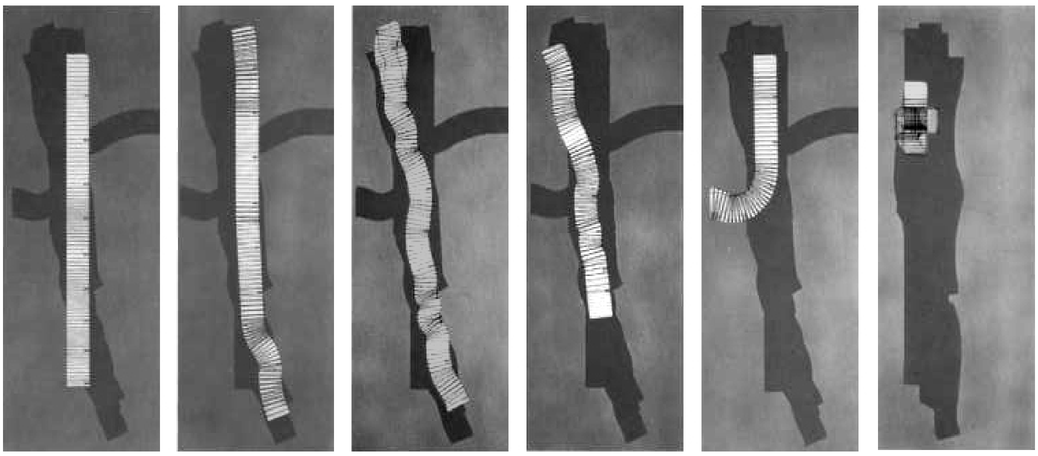

Figure 29: "Stranded Sears Tower," by Greg Lynn, plans of various tubes.
Greg Lynn, in "Multiplicitous and Inorganic Bodies," in Assemblage, No: 19 (Dec., 1992), pp.32-49.

4.3 Hypospace: The Deduced nth Dimension

At the beginning of the 20th century, the concept of hyperspace had initiated attempts to search for ways to represent upper spatial dimensions. The resultant art forms have developed new ways for representing the upper dimensions in two and three-dimensional space. Initially thought as a spatial dimension, the fourth dimension was later accepted as a temporal dimension with Einstein's Theory of Relativity. Unlike hyperspace, cyberspace has expanded the spatial quality to upper dimensions through parametric relations between geometric entities, including time as a parameter.

The multidimensional quality of cyberspace has altered the conception of space in architecture. Dagmar Richter mentions the transformation of space from a mass-produced and standardized character to an ever changing, unstable one, where one re-experiences shape and reforms his/her reference according to each specific variation.[231] The infinite possibility of variation within form through parametric modeling has created the "architecture of formlessness."[232] Besides the former Cartesian understanding of space, which denotes a "container" for objects and subjects, a new understanding of space has become possible where space is thought as a "web" of relations, leading to topologic space.[233] Topological understanding of space implies forms that contain temporal differentiations among themselves and space being able to implement connections and transformations.[234] Unlike Cartesian space that is "metric,

---

[231] Dagmar Richter, "Armed Surfaces: Towards a New Topology," in Architectures Non Standard, eds. Fréderic Migayrou and Zeynep Mennan, Paris: Editions du Centre Pompidou, 2003. p.79.

[232] Greg Lynn, "Architectural Curvilinearity: The Folded, the Pliant and the Supple," in Architectural Design Profile: Folding in Architecture.

[233] Capi Corrales Rodriganez, "From Space as Container to Space as Web," in Mathematics and Culture I, ed. Michele Emmer, Berlin: Springer, 2004. p.123

[234] Stephen Perrella, "Hypersurface Theory: Architecture><Culture," in Architecture and Science, ed. Giuseppa Di Cristina, London: John Wiley & Sons, 2001. p.143.

quantitative, infinite and homogeneous," topological space is dynamic, qualitative and heterogeneous.[235]

As mentioned in the previous chapter, a parametric design project may consist of multiple dimensions, each capable of generating an infinite number of alternatives, and computers and design software have the capability of instantly representing all these alternatives with the same amount of detail regardless of their formal complexity.[236] With the increasing number of parameters involved in the project, the complexity of relations and the contents of family of forms proliferate. For neither the architect, nor the user becomes capable of intuiting the total formal quality of the project, the multidimensional variations of the project are reduced to a limited amount of variation for pragmatic reasons. Furthermore, as the architect reduces these alternatives to a single instance for manufacturing purposes, the project passes through another transformation, compacting upper dimensions into a geometric entity, namely surface. Accordingly, the architect evaluates the formal quality of the project among surfaces and the user also perceives a two-dimensional surface denoting a multi-dimensional design process. With the shift from space to surface in the virtual realm along with the increasing concern on parametric design and its multidimensional characteristics, space is perceived through the complex geometry of surfaces. In other words, there exists a deduction from multi-dimensions of information to two dimensions of geometry.

Under the influence of these developments, cyberspace has produced a new kind of space called "hypospace." Contrary to the multidimensional, topological quality of cyberspace, hypospace is a deduced version of space. Hypospace denotes multiple dimensions by its very own nature for it contains upper

---

[235] Giuseppa di Cristina, "The Topological Tendency in Architecture," in Architecture and Science, ed. Giuseppa di Cristina, London: John Wiley & Sons. 2001. p.9.

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

dimensions with new design techniques, but it can be represented following a deduction process due to the limited representational and perceptual capabilities. Multiple dimensions of the parametric model initially convolute to two dimensions by creating surfaces that still carry the information of upper dimensions, followed by a perceptual expansion, which leads to attaining back the three-dimensionality. The convolution of upper dimensions and expansion of two dimensions concurrently take place in the spatial conceptions of the virtual realm.

4.3.1 The Increasing Perceptual Gap Between Virtual and Real Space

Perception is the awareness of the elements of the environment through physical sensation.[237] Unlike physical space, perception in cyberspace occurs through visual sensation. Perception of environments and objects in cyberspace depends solely on visual data. In the Gestalt theory of perception, it is found that complex forms lead to simplification of geometries by selecting the essential parts and discarding the excess perceived data.[238] The principle was named as “closure” by the Gestalt theorists Max Wertheimer (1880–1943) and Kurt Koffka (1886–1941). Another principle called Prägnanz denotes the perception of the simplest configuration among many possible more complex visual stimuli.[239] Prägnanz and closure generally occur when the visual data excesses the perceptual limits of the viewer, resulting with perceptible forms.

As physical space deals with the body, cyberspace deals with the mind.[240] For complex geometries cannot be perceived instantly and completely, the mind

---

[237] Roy Ascott, “The Architecture of Cyberception,” in Architectural Design: Architects in Cyberspace, v.65 No: 11 / 12, 1995. p.38.

[238] Kurt Koffka, Principles of Gestalt Psychology, New York: Harcourt, Brace and World Inc., 1935. p.110.

[239] Ibid.

[240] Roy Ascott, “Technoetic Structures,” in Architectural Design: Architects in Cyberspace II, v.68, No: 11 / 12, 1998. p.32.

tries to simplify the geometries into simpler forms. It can be said that the mind works topologically in the perception process of complex forms. For, neither the designer nor the viewer completely grasps the formal characteristic of the surfaces; both perceive the surface as topologically equivalent forms of the original shape.

Roy Ascott proposes the term "cyberception" for the perception and cognition of cyberspace.[241] Cyberception transcends the current perceptual abilities, which allows seeing the whole instead of instances or grasping the relational qualities of processes. Ascott states that,

> (Cyberception) is a matter of high-speed feedback, access to massive databases, interaction with a thousand eyes, hearing the earth's most silent whispers, reaching into the enormity of space, even to the edge of time. Cyberception is the antithesis of tunnel vision or linear thought. It is an all-at-once perception of a multiplicity of viewpoints, an extension in all dimensions of associative thought, recognition of the transience of all hypotheses, the relativity of all knowledge, the impermanence of all perception.[242]

The polymorphic quality of the projects of cyberspace requires cyberception for understanding the exact relations or forces that generate the project. As instances of the project cannot represent the essential properties of the project, in order to intuit one should not perceive but "cyberceive."[243]

[241] Roy Ascott, "The Architecture of Cyberception," p.38.

[242] Ibid.

[243] Ibid. p.39.

CHAPTER 5

CONCLUSION

This thesis has stated that architectural space has undergone significant changes from the way it is designed and conceptualized to the way it is perceived by both the architects and the users. Similar to the shifts in the conception of space that occurred at the beginning of the 20^{th} century, alterations in the conception of space have taken place in architecture with the use of computer-aided design software as a design tool instead of a drafting and representation medium. With the shift from a mere drafting device into an integral part of the design process, computers have produced a vast amount of novel qualities to the design process, varying from new geometries to algorithmic and parametric design.

The focus throughout the design process has shifted to process rather than the final form, owing to algorithmic and parametric design techniques along with the introduction of the topological existence of forms. Consequently, the process of design has internalized form-finding processes, leaving aside the form making processes. Architects have started to focus on relational properties of architectural elements, instead of their specific size or position in space. Although the form-finding processes prioritize algorithmic and parametric design methods, the process of algorithmic design is interrupted at the moment of deciding about form among a family of forms. Besides being a necessity for manufacturing the project, deciding on a final form is a must for conveying the formal characteristics of the project to the users, as it is hard to intuit the whole formal quality of family of forms. Once the decision on the final form is made, all other possible configurations of the project are omitted and a single formation of the project is achieved. Alternative formations of the project cannot be expressed through a single instance of the project. Therefore, in the final phase of design, apart from its geometric complexity, the project loses its multi dimensional character and turns into a three-dimensional discrete entity, an Euclidean figure in Cartesian space.

This thesis claimed that the multi dimensional quality of parametric models and the topological existence of forms in cyberspace make it inevitable for projects to pass through a deduction phase in order to exist in cyberspace or manufactured in the physical world. While attempts to reach higher dimensions through algorithmic design procedures and associative geometry lead to topological multi-dimensional projects, the endeavors to achieve higher dimensions are reversed with the utilization of surface as the ultimate geometric unit for representation. The two-dimensional quality of the surface is ideally capable of carrying all the information of higher dimensions and becomes condensed with numerous information, geometric relations, algorithmic procedures and mathematical equations. However, the multidimensional project designed with algorithmic procedures, parameters and associative geometry cannot be perceived from the sole geometric quality of surface. This repression of information and geometric associations leads to an inevitable process of deduction. In other words, a certain convolution of higher dimensions exists through surfaces towards the final phase of the design process, which results in a lower dimension. Therefore, surface can be no more considered as a two dimensional geometry, but only be regarded as a deduced n-dimensional entity, which makes the surface as the main constituent of hypospace. For these reasons, hypospace is considered as the outcome of the parallel existence of bi-directional process of expansion and convolution taking place in relation to the concept of surface.

The convolution phase may be surpassed by the new material technologies in near future. It can be thought that new materials may become capable of changing their forms without losing their structural quality. Therefore, architects would no longer have to decide on a single instance but instead it would be possible to implement a series of instances by using polymorphic materials. The limits of the formal differentiation of materials and architectural elements will become the main responsibility of architects, together with other formal instances of the project. As the realized project becomes a "family of forms," architects would have to design through various "family of forms," finally deciding on a series of possible formal existences of the project. In other words architects will design a second order "family of forms." During the manufacturing and realization phase, the formless quality of materials will free architects from the limitations of the process of deduction. So the project would remain as a multi-dimensional entity after the manufacturing or realization processes, capable of constantly changing its form according to external effects, which were used as morphogenetic factors throughout the design process. Eventually, "formless architecture" may become the architecture itself.

REFERENCES

Aish, Robert. "Exploring the Analogy that Parametric Design is a Game," in Game, Set and Match II: On Computer Games, Advanced Geometries, and Digital Technologies, eds. Kas Oosterhuis, Lukas Feireiss, Delft: Episode Publishers, 2006. pp.202-207.

Allen, Stan. "Terminal Velocities: The Computer in the Design Studio," in Virtual Dimension: Architecture, Representation and Crash Culture ed. John Beckmann, New York: Princeton Architectural Press, 1998. pp.242-255.

Anders, Peter. "Envisioning Cyberspace," in Virtual Dimension: Architecture, Representation and Crash Culture ed. John Beckmann, New York: Princeton Architectural Press, 1998. pp.218-233.

Anders, Peter. Envisioning Cyberspace: Designing 3d Electronic Spaces, New York:McGraw Hill, 1999.

Ascott, Roy. "Technoetic Structures," in Architectural Design: Architects in Cyberspace II, v.68, No: 11 / 12, 1998. pp.30-33.

Ascott, Roy. "The Architecture of Cyberception," in Architectural Design: Architects in Cyberspace, v.65 No: 11 / 12, 1995. pp.38-41.

Banchoff, F. Thomas. Beyond the Third Dimension: Geometry, Computer Graphics and Higher Dimensions, New York: Scientific American Library, 1990.

Barile, Margherita. "Cartesian," in MathWorld-A Wolfram Web Resource, created by Eric W. Weisstein, http://mathworld.wolfram.com/Cartesian.html. Last accessed on April 2007.

Benedikt, Michael. "Cyberspace: Some Proposals," in Cyberspace: First Steps, , ed. Michael Benedikt, Cambridge, Massachusetts: The MIT Press, 1991. pp.119-224.

Bolz, Norbert. "Design des Immateriellen in Sehnsucht," 1995, cited in Dagmar Richter, "Armed Surfaces: Towards a New Topology," in

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

Bonola, Roberto. Non-Euclidean Geometry: A Critical and Historical Study of Its Developments, U.S.A.: Dover Publications, 1955.

Burry, Mark. "Between Intuition and Process: Parametric Design and Rapid Prototyping," in Architecture in the Digital Age: Design and Manufacturing, ed. Branko Kolarevic, New York: Spon Press, 2003. pp.147-162.

Burry, Mark. "Paramorph: Anti-accident Methodologies," in AD: Hypersurface Architecture II, London: Academy Editions, 1999.

Burry, Mark. "Between Surface and Substance," in Surface Consciousness, ed. Mark Taylor, London: John Wiley & Sons, 2003.

Cache, Bernard. "Framing the Fold: Furniture, Architecture, Geography, and the Pursuit of the Virtual," in Virtual Dimension: Architecture, Representation and Crash Culture ed. John Beckmann, New York: Princeton Architectural Press, 1998. pp.292-303.

Cache, Bernard. "Plea for Euclid" in http://architettura.supereva.com/extended/19990501/ep07en_01.htm Last accessed on April 2007.

Cache, Bernard. "Towards a Fully Associative Architecture," in Architecture in the Digital Age: Design and Manufacturing, ed. Branko Kolarevic, New York: Spon Press, 2003. pp.139-146.

Cache, Bernard. Earth Moves: The Furnishing of Territories, ed. Michael Speaks, Massachusetts: The MIT Press, 1995.

Chan, Elaine and Vorderer, Peter. "Massively Multiplayer Online Games," in Playing Video Games: Motives, Responses and Consequences, eds. Peter Vorderer and Jennings Bryant, New Jersey: Lawrence Erlbaum Associates. 2006. pp.77-88.

Cornford, Francis Macdonald. "Invention of Space," in The Concepts of Space and Time, ed. Milic Capek, Dordrecht: D. Reidel Publishing Company, 1976. pp.3-16.

Cristina, Giuseppa di. “The Topological Tendency in Architecture,” in Architecture and Science, ed. Giuseppa di Cristina, London: John Wiley & Sons. 2001.

Curtis, Pavel. “Mudding: Social Phenomena in Text-Based Virtual Realities,” in Multimedia: From Wagner to Virtual Reality, eds. Randall Packer and Ken Jordan, New York: Norton & Company, 2002. pp.352-369.

Dahl, Thomas. “The Transformation of Space and the Construction of Engineering Knowledge and Practice – From Renaissance Perspective Thinking to Gaspard Monge’s Descriptive Geometry” in Transforming Spaces, The Topological Turn in Technology Studies. eds. Mikael Hard, Andreas Lösch, Dirk Verdicchio, 2003.

Deleuze, Gilles. The Fold: Leibniz and the Baroque, (1988), trans. Tom Conley, Minneapolis: University of Minnesota Press, 1993.

Evans, Robin. “Architectural Projection,” in Architectural Projection; Architecture and Its Image, eds. Robin Evans, Eve Blau and E. Kaufman, Montreal: The MIT Press, 1989. pp.20-35.

Fisher, Scott. ”Virtual Interface Environments,” in Multimedia: From Wagner to Virtual Reality, eds. Randall Packer and Ken Jordan, New York: Norton & Company. 2002. pp.257-266.

Gibson, William. Neuromancer, New York: Ace Books. 1984.

Giedion, Sigfried. Space, Time and Architecture: The Growth of a New Tradition, 5th ed., Massachusetts: Harvard University Press, 1971.

Giovanni, Joseph. “Building a Better Blob,” in Architecture, vol.89, no.9, 2000.

Harold Scott MacDonald Coxeter. Non-Euclidean Geometry, Washington D.C.: Mathematical Association of America, 1998.

Harris, A. Paul. “To See with the Mind and Think Through the Eye: Deleuze, Folding Architecture, and Simon Rodia’s Watts Towers,” in Deleuze and Space, eds. Ian Buchanan and Gregg Lambert, Edinburgh: Edinburgh University Press, 2005.

Hartshorne, Robin. Companion to Euclid: A Course of Geometry, Based on Euclid’s *Elements* and Its Modern Descendants, Berkeley: American Mathematical Society, 1997.

Heim, Michael. “The Erotic Ontology of Cyberspace,” in Cyberspace: First Steps, ed. Michael Benedikt, Cambridge, Massachusetts: The MIT Press, 1991. pp.59-80.

Henderson, Linda Dalrymple. The Fourth Dimension and Non-Euclidean Geometry in Modern Art, Princeton: Princeton University Press, 1983.

Holtzman, Steven, Digital Mosaics: The Aesthetics of Cyberspace, New York: Simon & Schuster, 1997.

Kalay, E. Yehuda. Architecture’s New Media: Principles, Theories, and Methods of Computer-Aided Design, Massachusetts: The MIT Press, 2004.

Kern, Stephen. The Nature of Time and Space 1880-1918, Cambridge, Massachusetts: Harvard University Press, 2003.

Kitchin, Rob. Cyberspace, New York: John Wiley & Sons. 1998.

Koffka, Kurt. Principles of Gestalt Psychology, New York: Harcourt, Brace and World Inc., 1935.

Kolarevic, Branko. “Digital Morphogenesis and Computational Architectures,” in Cumulative Index of Computer Aided Architectural Design web page, cumincades.scix.net/data/works/att/fbc9.content.pdf. Last accessed on July 2007.

Kolarevic, Branko. “Digital Morphogenesis,” in Architecture in the Digital Age: Design and Manufacturing, ed. Branko Kolarevic, New York: Spon Press, 2003. pp.11-28.

Kolarevic, Branko. “Introduction,” in Architecture in the Digital Age: Design and Manufacturing, ed. Branko Kolarevic, New York: Spon Press, 2003. pp.1-10.

Kolarevic, Branko. “Digital Production,” in Architecture in the Digital Age: Design and Manufacturing, ed. Branko Kolarevic, New York: Spon Press, 2003. pp.29-54.

Kolarevic, Branko. “Surface Effects: Ornament in Contemporary Architecture,” in Game, Set and Match II: On Computer Games, Advanced

Geometries, and Digital Technologies, eds. Kas Oosterhuis, Lukas Feireiss, Delft: Episode Publishers, 2006. pp.172-180.

Kolatan Şulan and MacDonald William (Kol/Mac Studio,) "MUTualistic ENvironmentality," in Architectures Non Standard, eds. Fréderic Migayrou and Zeynep Mennan, Paris: Editions du Centre Pompidou, 2003. pp.102-104.

Krauss, M. Lawrence. Hiding in the Mirror; The Mysterious Allure of Extra Dimensions, From Plato to String Theory and Beyond, New York: Penguin Books, 2005.

Loos, Adolf. "Ornament and Crime" (1908), in Ornament and Crime: Selected Essays, trans. Michael Mitchell, Riverside: Ariadne Press, 1998.

Lorentz, A. Hendrik. "The Einstein Theory of Relativity", originally published on 1920, in http://www.gutenberg.org/files/11335/11335.txt, Last accessed on April 2007.

Lunenfeld, Peter. Snap to Grid: A User's Guide to Digital Arts, Media and Cultures, Massachusetts: MIT Press, 2001.

Lynn, Greg. Animate Form, New York: Princeton Architectural Press, 1998.

Lynn, Greg. "Architectural Curvilinearity: The Folded, the Pliant and the Supple," in Architectural Design Profile: Folding in Architecture, ed. Greg Lynn, New York: John Wiley & Sons, 1993. pp.8-15.

Lynn, Greg. "Stranded Sears Tower," in Architectural Design Profile: Folding in Architecture, ed. Greg Lynn, New York: John Wiley & Sons, 1993. pp.82-85.

Mandelbrot, B. Benoit. "Fractals and an Art for the Sake of Science," in The Visual Mind: Art and Mathematics, ed. Michele Emmer, Massachusetts: The MIT Press, 1993. pp.11-14.

Massie, William. "Remaking in a Post-Processes Culture," in Versioning: Evolutionary Techniques in Architecture, ed. ShoP / Sharples Holden Pasquarelli, London: John Wiley & Sons, 2002. pp.54-59.

Menges, Achim. "Polymorphism," in Architectural Design: Techniques and Technologies in Morphogenetic Design, Vol. 76, No.2. pp.78-87.

Mennan, Zeynep. "Non-Standardization through Non-Visualization: Scripting the Dom-ino House," in Game, Set and Match II: On Computer Games, Advanced Geometries, and Digital Technologies, eds. Kas Oosterhuis, Lukas Feireiss, Delft: Episode Publishers, 2006. pp.234-241.

Mennan, Zeynep. "Of Non Standard Forms: A 'Gestalt Switch'," in Architectures Non Standard, eds. Zeynep Mennan and Fréderic Migayrou, Paris: Editions du Centre Pompidou, 2003. pp.34-41.

Mitchell, J. William. "Constructing an Authentic Architecture of the Digital Era," in Disappearing Architecture: From Real to Virtual to Quantum, eds. Georg Flachbart and Peter Weibel, Berlin: Birkhauser, 2005. pp.80-89.

Mitchell, J. William. "Design Worlds and Fabrication Machines," in Architecture in the Digital Age: Design and Manufacturing, ed. Branko Kolarevic, New York: Spon Press, 2003. pp.73-80.

Mitchell, J. William. "Antitectonics: Poetics of Virtuality," in The Virtual Dimension, ed. Beckmann, John Princeton Architectural Press, New York. 1998. pp.204-217.

Morningstar, Chip and Farmer, F. Randall. "The Lessons of Lucasfilm's Habitat," in Cyberspace: First Steps, ed. Michael Benedikt, Cambridge, Massachusetts: The MIT Press, 1991. pp.273-302.

Newton, Isaac. "On Absolute Space and Absolute Motion," in The Concepts of Space and Time, ed. Milic Capek, Dordrecht: D. Reidel Publishing Company, 1976. pp.97-106.

Novak, Marcos. "Liquid Architectures in Cyberspace," originally published in 1991, in Multimedia: From Wagner to Virtual Reality, eds. Randall Packer and Ken Jordan, New York: Norton & Company. 2002. pp.272-285.

Novak, Marcos. "Transmitting Architecture: transTerraFirma / TidsvagNoll v2.0," in Architectural Design: Architects in Cyberspace, v.65 No: 11 / 12, 1995. pp.42-47.

Oosterhuis, Kas. "A New Kind of Building," in Disappearing Architecture: From Real to Virtual to Quantum, eds. Georg Flachbart and Peter Weibel, Berlin: Birkhauser, 2005. pp.90-115.

Panofsky, Erwin. Perspective as Symbolic Form, New York: Zone Books, 1997.

Perrella, Stephen. “Hypersurface Theory: Architecture><Culture,” in Architecture and Science, ed. Giuseppa Di Cristina, London: John Wiley & Sons, 2001.

Rashid, Hani and Couture, Lise Anne. Asymptote: Flux, London: Phaidon Press, 2002.

Richter, Dagmar. “Armed Surfaces: Towards a New Topology,” in Architectures Non Standard, eds. Fréderic Migayrou and Zeynep Mennan, Paris: Editions du Centre Pompidou, 2003.

Robertson, Howard Percy. “Geometry as a Branch of Physics,” in The Concepts of Space and Time, ed. Milic Capek, Dordrecht: D. Reidel Publishing Company, 1976. pp.409-424.

Rocker, Ingeborg. “Versioning: Evolving Architectures – Dissolving Identities ‘Nothing is as Persistent as Change,” in Versioning: Evolutionary Techniques in Architecture, ed. ShoP / Sharples Holden Pasquarelli, London: John Wiley & Sons, 2002. pp.10-17.

Rodriganez, Capi Corrales. “From Space as Container to Space as Web,” trans. Emmanuela Moreale, in Mathematics and Culture I, ed. Michele Emmer, Berlin: Springer, 2004. pp.123-138.

Ruby, Andreas. “Architecture in the Age of Digital Producibility,” in Digital / Real Blobmeister : First Built Projects, ed. Peter C. Schmal, Basel: Birkhauser, 2001.

Semper, Gottfried. Four Elements of Architecture and Other Writings. trans. Francis Mallgrave and Wolfgang Herrmann. Cambridge: Cambridge University Press, 1989.

Shields, Rob. The Virtual, London: Routledge, 2003.

Slowik, Edward. Cartesian Space-time; Descartes’ Physics and the Relational Theory of Space and Motion, Dordrecht: Kluwer Academic Publishers, 2002.

Smith, Charles Henry. "How the Fourth Dimension May Be Studied," in The Fourth Dimension Simply Explained, by ed. Henry P. Manning, New York: Munn&Company, 1910.

Speaks, Michael. "Design Intelligence: Or Thinking After the End of Metaphysics," in Versioning: Evolutionary Techniques in Architecture, ed. ShoP / Sharples Holden Pasquarelli, London: John Wiley & Sons, 2002. pp.4-6.

Speaks, Michael. "Folding Toward a New Architecture," in Earth Moves: The Furnishing Territories, by Bernard Cache, ed. Michael Speaks, Massachusetts: The MIT Press, 1995. pp.xii-xx.

Stone, Allucquere Rosanne. "Will the Real Body Please Stand Up?: Boundary Stories About Virtual Cultures," in Cyberspace: First Steps, ed. Michael Benedikt, Cambridge, Massachusetts: The MIT Press, 1991. pp.81-118.

Sutherland, Ivan. "The Ultimate Display," in Multimedia: From Wagner to Virtual Reality, eds. Randall Packer and Ken Jordan, New York: Norton & Company. 2002. pp.252-256.

Taylor, Mark. "Surface-Talk," in Surface Consciousness, ed. Mark Taylor, London: John Wiley & Sons, 2003.

Tomas, David. "Old Rituals for New Space: Rites de passage and William Gibson's Cultural Model of Cyberspace," in Cyberspace: First Steps, ed. Michael Benedikt, Cambridge, Massachusetts: The MIT Press, 1991. pp.31-48.

Van de Ven, J. M. Cornelis. Concerning The Idea of Space: The Rise of a New Fundamental in German Architectural Theory and in the Modern Movements Until 1930, Ph.D. dissertation, University of Pennsylvania, 1974.

Wood, Peter. "Sticks and Stones: Skins and Bones," in Surface Consciousness, ed. Mark Taylor, London: John Wiley & Sons, 2003.

Zellner, Peter. Hybrid Space: New Forms in Digital Architectures, New York: Rizzoli Publications, 1999.