RETHINKING THE ARCHITECTURAL DESIGN PROCESS THROUGH ITS COMPUTABLE BODY OF KNOWLEDGE

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

BY

ESER ERGUN

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

MAY 2008

Approval of the thesis:

RETHINKING THE ARCHITECTURAL DESIGN PROCESS THROUGH ITS COMPUTABLE BODY OF KNOWLEDGE

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ABSTRACT

RETHINKING THE ARCHITECTURAL DESIGN PROCESS THROUGH ITS COMPUTABLE BODY OF KNOWLEDGE

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May 2008, 81 pages

This thesis assumes the architectural design process as a systematic study, in which knowledge is stored, organized and operated on by computational methods. From this perspective, the study explores the efforts for systemizing the architectural design process. Firstly, the focus is on the early approaches of systemizing design in the Design Methods Movement. The thesis identifies and evaluates the use of a number of critical concepts in this movement and in recent architecture practice, in order to see the development and transformation of design methods in terms of computing knowledge in a systematic way.

The thesis evaluates the features that make design systematic within the Design Methods Movement and inquires whether such features like complexity, hierarchy, feedback loops and selection are influential in recent computational design methods of architecture. The thesis looks into two generative design methods, namely evolutionary design and shape grammars, which have been studied by designers since the 1960s, the start of the Design Methods

Movement. These two methods exemplify current systematic approaches to design and according to the thesis these are the instances of how recent architecture employs the features discussed as characteristic in the Design Methods Movement.

Keywords: Architectural Design Process, Systematic, Computational Design, Problem Solving, Generative Design, Evolutionary Design, Shape Grammars.

ÖZ

MİMARİ TASARIM SÜRECİNİN YAPISINDAKİ BİLGİNİN
HESAPLANABİLİRLİĞİ ÜZERİNDEN YENİDEN DÜŞÜNÜLMESİ

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Yüksek Lisans., Mimarlık Bölümü
Tez Yöneticisi: Y. Dç. Dr. Mine Özkâr

Mayıs 2008, 81 sayfa

Bu tez, mimari tasarım sürecini bilginin depolandığı, organize edildiği ve üzerinde işlem yapıldığı sistematik bir çalışma olarak görür. Bu bakış açısıyla tez, mimari tasarım sürecini sistemleştirme çabalarını araştırır. İlk olarak, araştırma, Tasarım Metotları Hareketinin tasarımı sistemleştirme yolundaki erken yaklaşımlarına odaklanır. Tasarım metotlarının bilgiyi sistematik yöntemlerle hesaplama yönünden gelişimini ve dönüşümünü gözlemleyebilmek için, tez bazı kritik kavramlar belirler ve bu kavramların Tasarım Metotları Hareketindeki ve günümüz mimarlık uygulamalarındaki kullanılışını değerlendirir.

Tez, Tasarım Metotları Hareketinde, tasarımı sistematik yapan özellikleri değerlendirir ve kompleksite, hiyerarşi, geri besleme döngüsü ve seleksiyon gibi bu özelliklerin günümüz hesaba dayalı tasarım yöntemleri üzerinde etkili olup olmadığını araştırır. Tez evrimsel tasarım ve şekil gramerleri olmak üzere iki üretken tasarım yöntemine bakar. Bu metotlar Tasarım Metotları Hareketinin başlangıcı olan 1960'lardan beri çalışılmaktadır. Tezde bu iki metot, tasarıma

sistematik yaklaşmanın güncel örneklerini oluşturur. Ayrıca teze göre bu metotlar, günümüz mimarlığının Tasarım Metotları Hareketinin özellikleri olarak ele alınan karakteristiklerini nasıl kullandığına dair örneklerdir.

Anahtar Kelimeler: Mimari Tasarım Süreci, Sistematik, Hesaba Dayalı Tasarım, Problem Çözme, Üretken Tasarım, Evrimsel Tasarım, Şekil Gramerleri.

To my parents

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to my supervisor Assist. Prof. Dr. Mine Özkar for her guidance, advice, criticism, encouragement, patience and insight throughout the research.

I am grateful to my jury members Prof. Dr. Can Baykan, Assoc. Prof. Dr. Zeynep Mennan, Assoc. Prof. Dr. Gülay Hadoğan and Assist. Prof. Dr. Yüksel Demir for their recommendations and valuable interpretations.

I would like to thank all my friends who have been sharing my enthusiasm during the research. I want to express my special thanks to Serdar Aşut for sharing his opinions graciously.

Finally, nothing can be enough to express my thankfulness to my parents and my dear sister who have always encouraged and supported me during the realization process of this thesis and during all my lifetime.

TABLE OF CONTENTS

LIST OF FIGURES

FIGURES

CHAPTER 1

INTRODUCTION

The question of systematic study in architectural design process is gaining significance day by day. In order to deal with the growing scale of architectural design tasks, a systematic study should be supplied. This thesis traces the computational design methods which are invented for systemizing design. The inquiry starts from early proposals for systemizing the design process and explores the influences of early methods on current generative design methods. By establishing a relation between the early proposals and current architecture, the thesis aims to emphasize the common concepts that make design systematic. The study mainly claims that systemizing design is not a new approach. It exists for nearly forty years in architecture, if not more. Moreover, the methods that compute knowledge in order to systemize design have been renewed and transformed throughout this forty years time period.

The complexity of the knowledge required to undertake a design task is organized and operated on through a systematic study. Moreover, through an organizational procedure, members of other disciplines relevant to the design task may contribute to the design process. This collaboration of disciplines in the same system gives them the opportunity to generate their solutions simultaneously. This kind of an organizational study reduces the risk of producing incoherent solutions at independent levels of a separated process. To give an example, when the architectural design and the construction design of a building are solved by different hands, communication errors may occur. Long periods passing in the transfers between the disciplines may cause feedback loss and when the solutions are juxtaposed many incoherent points may occur. This means loss of time, energy and money during the design process. Adhering to the motivation to overcome such inefficiencies, this thesis assumes architectural design as a systematic study that supplies the coherency between all parts of the whole process.

Computational design gives the opportunity to make systematic organizations in a design process. Robert and Rivka Oxman, two contemporary design thinking researchers and architects, claim that "design computing is dependent upon the emergence of a rigorous formulation of knowledge in design." [1] In 1965, long before this assertion, Bruce Archer, from within the Design Methods Movement, expresses the same. He defines design process as "having gathered whatever information is available" about the design problem and organizing it for effective decision making.[2] Early proposals of systemizing design process come from Design Methods Movement in the 1960s. Designers of the movement focus on the systematic organizations of knowledge during the design process in order to reach design goals. Archer defines "systematic" as "pursued according to some plan".[3] Christopher Jones, one of the pioneers of Design Methods Movement, points out the need of developing systematic methods in design. He stresses that systematic study means determining "a logical path" in order to avoid the process from "arbitrary choices". Therefore, the solutions of design problems are "evaluated with all constraints and relationships".[4] Keeping the process away

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[1] Oxman, Robert, Rivka Oxman. "The Computability of Architectural Knowledge." In The Electronic Design Studio Architectural Knowledge and Media in the Computer Era. Ed. Malcolm McCullough. Cambridge, Mass. : MIT Press. 1990. pp. 171-183.

[2] Archer, L. Bruce. "Systematic Method for Designers." In Developments in Design Methods. Ed. Nigel Cross. Chichester: John Wiley & Sons Ltd. 1984. p. 71.

[3] Archer, Bruce. On the Methods of Research. Ankara: ODTU. 1999

[4] Jones, J. Christopher. Seeds of Human Future. London, New York: Wiley – Interscience. 1970. pp. 101-102.

from arbitrary decisions of a pure intuitive process requires transforming design into a more transparent activity than it is usually conceived. Jones claims that Design Methods Movement is supposed to change design understanding in terms of "externalizing design process" which generally starts and finishes in designer's mind. Jones expresses that many languages such as words, mathematical symbols or diagrams are used in order to "combine scientific doubt and rational explanation to design", in other words transforming design process into an understandable form. Therefore, according to Jones, other people besides the designer may add their useful knowledge to the process.[5]

In architecture, new approaches in design thinking may be evaluated with their additive aspects on the transformation and development of architecture. Combining the latest technological developments and architectural design techniques within a functional relationship with the changing history of architecture, may be more effective in solving design problems than only applying the common trends. Narvaez asserts that in order to "overcome ideological paradigms" in design and to serve a better environment with new design solutions, "design knowledge" should include the knowledge of design history. [6] In this study, design knowledge is constructed on the remarkable role of Design Methods Movement in opening a road for contemporary computational design and performing new approaches for systemizing design process, although many proposals of Design Methods Movement are accepted as obsolete today. The fundamental objective of this study is, to explore the significant role of its proposals in developing architectural design. In this respect, the study aims to explore the commonalities and differences between the early design methods and recent generative design methods. In order to exemplify

[5] Jones, J. Christopher. "The state–of–the–art in design methods." In Design Methods in Architecture. Eds. Geoffrey Broadbent and Anthony Ward New York: G. Wittenborn. 1967, pp. 193-197.

[6] Narvaez, Luz Maria Jimenez. "Design's Own Knowledge." In Design Issues. V. 16. No 1. 2000 (Spring) pp. 36-51.

the influential effects of Design Methods Movement in architectural design, some critical concepts, namely complexity, hierarchy, feedback loops and selection, which are firstly proposed within the works of Design Methods Movement in the 1960s, are identified. Use of these concepts in the architecture of the 1960s and in the recent generative architecture is evaluated through a comparative approach considering the similarities and differences of the two eras. The study thus tries to shed light on how design thinking might have evolved since 1960s.

The general tendency in the Design Methods Movement is to consider design as a pure information transmission process. Therefore, the designers' artistry and intuitive abilities of designing are kept outside the design process. Critical approaches to this design understanding of Design Methods Movement have caused changes in design thinking. Hillier, Musgrove and O'Sullivan criticize the static structure of design methods proposed in the 1960s. They claim that there is a need to change design understanding in terms of qualification of design process. According to them the design process should be applied with a new understanding that "reformulates rational and intuitive design". They defend that knowledge cannot be "reduced to homogenized information" and pure "quantification" and according to them Interpretation of the designer should be integrated to the process in order to obtain sufficient solutions. [7]

The changes in design thinking and growing opportunities in technology effect the understanding of the architectural design process. [8] Oxman and Oxman classify knowledge in a design process in two types. First one is the knowledge that defines architectural objects. Second is the knowledge that defines the relations between the architectural object and operations determining these

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[7] Hillier, Bill, John Musgrove, Pat O'Sullivan. "Knowledge and Design." In Developments in Design Methods. Ed. Nigel Cross. Chichester: John Wiley & Sons Ltd. 1984. pp. 251-259.

[8] Oxman, Rivka. "Digital architecture as a challange for design pedagogy: theory, knowledge, models and medium." In Design Studies. V.32 No. 2. March 2008. pp. 99-120.

relations. Oxman and Oxman propose a computational design method in which these two levels of knowledge integrated to each other "in the form of algorithms". [9] This also changes the usual sequential structure of a "conventional" design process according to Rivka Oxman. Oxman claims that this kind of new processes forms in a generative mode. She points out evolutionary design and shape grammars as the "known examples" of generative design models. She expresses that these new design methods include the "understanding of organizational principles". [10]

Geoffrey Broadbent, an architect and design methods researcher, claims that developing new methods is essential in design. New methods integrate new developments of science, technology and philosophy into design and each development is a "hope of some improvement".[11] Before Broadbent, at the very beginning of Design Methods Movement, Morris Asimow stresses the same on the relation of design and new developments in science and says:

> The feature that seems most characteristic of our times is the rapid pace of technological development. Scientific discoveries, multiplying in frequency, become available for technological exploitation. Society, which in the past had tended to abhor rapid change, has become receptive of and eager, and at times even impatient, for new feats of engineering design.[12]

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[9] Oxman, Robert, Rivka Oxman. "The Computability of Architectural Knowledge." In The Electronic Design Studio Architectural Knowledge and Media in the Computer Era. Ed. Malcolm McCullough. Cambridge, Mass. : MIT Press. 1990. pp. 171-183.

[10] Oxman, Rivka. "Digital architecture as a challange for design pedagogy: theory, knowledge, models and medium." In Design Studies. V.32 No. 2. March 2008. pp. 99-120.

[11] Broadbent, Geoffrey. Design in Architecture Architecture and Human Sciences. London, New York: John Wiley & Sons. 1973. pp. 55-56.

[12] Asimow, Morris. Introduction to Design. NJ, Prentice Hall. 1962.

Today, architects still study the integration of scientific methods into design and express that new paradigms in science directly cause new paradigms in design. Charles Jencks, architectural theorist, claims that new research on complexity sciences alters design thinking in architecture. This new way of thinking gives designers a new perspective which is more “creative and free”.[13] Larry Sass, professor of architecture, explains creative design process as a “generative process” produces new ideas and solutions. He claims that genetic algorithms and shape grammars are two rule based systems which generate the new.[14] According to Sass, evolutionary design and shape grammars “have identified the need for design generation with computation and design variation driven by effective rule structures”.[15] Variety of design solutions adds a new creativity understanding to design in terms of obtaining solutions which emerge as “new, original and different from anything else before them” as McCormack expresses.[16] Thus, the thesis also inquiries shape grammars and evolutionary design as two generative design methods seeded by the efforts of finding new problem solving methods in the 1960s and 1970s.The latest interpretations of critical concepts of the 1960s are elaborated through these two methods.

In summary, there is a need for a systematic study in order to obtain a coherency within the whole design process. Designers of the Design Methods Movement propose to solve design problems in a systematic way by computing

[13] Jencks, Charles. “Nonlinear Architecture New Science = New Architecture?” In Architectural Design. No:129. 1997 p.7.

[14] Sass, Larry. “Architectural Design and Design Computation” In Lecture Notes of Introduction to Computation. MIT Department of Architecture

[15] Sass, Larry. “A production system for design and construction with digital fabrication.” MIT; Cambridge, MA/USA, http://ddf.mit.edu/projects/CABIN/cabin_mit_2005.pdf Last access date 01 May 2008.

[16] McCormack, J., Dorin, A. and Innocent, T. (2004) “Generative Design: a paradigm for design research” in Redmond, J. et. al. (eds) Proceedings of Futureground, Design Research Society, Melbourne.
http://www.csse.monash.edu.au/~jonmc/research/Papers/genDesignFG04.pdf
Last access date 01 May 2008.

knowledge. Today designers deal with design process with a more elastic generative approach including intuitive aspect of designers rather than considering it as a rational problem solving process. On the other hand, they still aim to develop methods with organizational procedures. From this perspective, the thesis intends to study Design Methods Movement as an influential era for architectural design today. In order to clarify this approach, many of the terms of early design methods are traced in the recent generative design methods. Through the exploration of the common terms of two design eras the development of design methods understanding is evaluated.

In the second chapter, the thesis firstly focuses on the Design Methods Movement for inquiring the early forms of computations on knowledge in design process. The use of many critical concepts such as complexity, hierarchy and feedback loops is introduced in the second chapter. Later in the following chapters, the recent use of these concepts in generative design methods is introduced in order to underline effective role of Design Methods Movement in development of design thinking. Furthermore, by identifying the recent use of these concepts, observing the evolution of design methods is aimed.

In the third chapter the inquiry explores generative design models, evolutionary design and shape grammars. These are explained as theories rooted in the problem solving tradition in the 1960s and 1970s. Thesis assumes that these two methods are both rule based generative design systems which investigate effective ways of computing knowledge with the use of critical concepts introduced in the second chapter.

After defining main principles of evolutionary design and shape grammars in the third chapter, fourth chapter signifies the current interpretations of the concepts of complexity, hierarchy, feedback loops and selection in terms of design generation. Finally the thesis evaluates the transformations of the proposals of

Design Methods Movement, and argues how these proposals contributed to the development of architectural design. The thesis also explores the additional aspects of design methods today.

CHAPTER 2

RE-EVALUATION OF THE DESIGN PROCESS AS A PROBLEM SOLVING ACTIVITY

2.1. Talking about design as a problem

The first attempts of systemizing design process and treating the process as a scientific operation in the 60's, added a new concept to design literature: "design as problem solving". [17] With this new approach, designers attempted to rationalize design process. They became suspicious about conventional acceptances of design. They developed methods to base design process on a structure and formula similarly solving a problem in mathematics. The efforts of accepting design process as a problem solving procedure were also the efforts of searching for new solutions, and therefore the efforts of demolishing the constant claims of conventional design.[18]

A problem is a situation in which someone needs something but does not know the way to reach it.[19] Similarly, problem solving in design means creating a way

[17] Rowe, Peter G. Design Thinking. London: The MIT Press. 1987, p. 39

[18] Cross, Nigel. "A History of Design Methodology." In Design Methodology and Relationships with Science. Eds. M. J. Vries, N. Cross and D. P. Grant. Dordrecht, Boston, London: Kluwer Academic Publishers. 1993, pp. 15-29.

[19] Newell, Allen, Herbert A. Simon. Human Problem Solving. Englewood Cliffs, New Jersey. : Harvard University PressPrentice-Hall, Inc. 1972, p. 72

to reach the needed thing.[20] There are different kinds of problems in problem solving. Herbert Simon and Alan Newell, both renowned in the fields of computer science and cognitive psychology, state one kind to be well-defined problems.[21] In well-defined problems, solutions are known beforehand or are explicit in the definition of the problem itself. Peter Rowe, professor of architecture and urban design and former Dean of Harvard Faculty of Design, explains this kind of problems with daily life examples such as "crossword puzzles, and making moves in checkers or chess." Rowe asserts that from an architectural perspective, well-defined problems are such problems that may give clues to satisfactory solutions at the very early stages of problem solving process, just like producing the satisfactory combinations of a "space planning problem" with no more effort than using the given data for the building space and site relations, and redefining the problem according to the desired solution.[22] If a designer aims to obtain a square planned bedroom with two beds and one wardrobe, then this is a well-defined problem which depends solely on arranging the furniture according to the place of the entrance, and some other issues such as heating and lighting conditions of the room.

Another kind of problem in design literature is ill-defined problems proposed by Newell and Simon. Ill-defined problems have insufficient input to reach a satisfactory solution. The problem definition and requirements of the problem determined at the beginning of the design process are usually weak input for a designer to develop a solution. Rowe capitulates that designers usually deal with ill-defined problems.[23]

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[20] Mitchell, William J. The Logic of Architecture: Design, Computation, Cognition. Cambridge, MA: The MIT Press. 1994. p. 64

[21] Newell, Allen, Herbert A. Simon. Human Problem Solving. Englewood Cliffs, New Jersey.: Harvard University Press Prentice-Hall, Inc. 1972, p. 73

[22] Rowe, Peter G. Design Thinking. London: The MIT Press. 1987, p. 40.

[23] Ibid.

2.2. Problem Solving in Design

Design Methods Movement considers design as a "rational problem solving activity."[24] Bruce Archer, an industrial designer, proposes that "unsatisfactory conditions" in design require to be solved as a problem. Each problem solving activity is applied in order to reach a design goal. Therefore design is a goal-directed problem solving activity. Problem solving activity aims to transform an unsatisfactory condition into a satisfactory one. Archer claims that, designers firstly define a "problem space" in order to start the process.[25]

Newell and Simon simply explain the problem space as "a space in which problem solving activities take place."[26] Being inspired from the working principles of human mind; they propose this space as an "encoding" system which includes "defining goals, rules, and other aspects of the problem situation." According to Newell and Simon, problem solving requires to gather knowledge such as "what is desired, under what conditions, by means of what tools and operations, starting with what initial information, and with access to what resources." The problem solver classifies this knowledge according to its content defining the "goal" or "side conditions" or other relevant topics about the problem situation.[27] During the design process, designer continuously re-formulates the problem and changes the initial arrangements of the problem.

[24] Dorst, Kees. "The Problem of Design Problems." University of Technology Sydney, Research. http://research.it.uts.edu.au/creative/design/papers/23DorstDTRS6.pdf
Last access date 02 May 2008.

[25] Archer, Bruce. "The Structure of the Design Process." In Design Methods in Architecture. Eds. Geoffrey Broadbent and Anthony Ward New York: G. Wittenborn. 1967, pp. 76-77.

[26] Newell, Allen, Herbert A. Simon. Human Problem Solving. Englewood Cliffs, New Jersey:Harvard University PressPrentice-Hall, Inc. 1972, p. 59.

[27] Ibid. p. 73.

Restrepo and Christiaans assert that “new goals, specifications, ideas” cause this continuous change in a process.[28]

In a combinatorial approach, Simon defines the re-formulation of the problem as “computing the implications of initial assumptions (of a problem) and combinations of them.” [29] From within the design world, William Mitchell introduces the computational design process as a “sequence of operations” that depends on “rules” which are determined in order to satisfy the problem requirements.[30] Archer states that during the process referred to as design computation, in a general sense, knowledge integrated into the process and operated on is called the "input", and produced knowledge is called the "output" and the interactions between inputs and outputs make a "system" to solve the problem. [31] The inputs of a system are the problem requirements, designer's own knowledge about the subject, and “client demands”.[32]

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[28] Restrepo, John, Henri Christiaans. “Problem Structuring and Information Access in Design.” University of Technology, Sydney,http://research.it.uts.edu.au/creative/design/papers/25RestrepoDTRS6.pdf Last access date 02 May 2008.

[29] Simon, Herbert A. “Problem Forming, Problem Finding, and Problem Solving in Design.” In Design & Systems: General Application of Methodology. Eds. Arne Collen and Wojciech W. Gasparski. Transaction Publishers. 1995. p. 247.

[30] Mitchell, William J. The Logic of Architecture: Design, Computation, Cognition. Cambridge, MA: The MIT Press. 1994. p. 179.

The concept of “information” gained importance after World War II, and “information processing” theories have emerged since then. The mathematical expressions of information, namely computation, got more common in the 60s with the studies of “mathematical logic”, “mathematical linguistics” and “numerical analysis (algorithms, computational complexity)”. Investigations on storing and organizing information followed these studies.
Mahoney, Michael S. “The History of Computing in the History of Technology” in Annals Hist. Comput. No: 1 (1988) pp.113-125

[31] Archer, L. Bruce. “The Structure of The Design Process.” In Design Methods in Architecture. Eds. Geoffrey Broadbent and Anthony Ward New York: G. Wittenborn. 1967, p. 84

[32] Guerra, G. “A Geometrical Method of Systematic Design in Architecture.” In Design Methods in Architecture. Eds. Geoffrey Broadbent and Anthony Ward New York: G. Wittenborn. 1967, p. 48.

These new systems and formulations within the systems introduced a new approach to design in terms of computation of knowledge. Pursuing these early attempts, architects today still search for new methods in order to formulate knowledge, and transform it into a product.

2.2.1 Early models of problem solving processes in design

In the 1960's, designers, system designers and engineers were not satisfied with current design techniques. Christopher Jones claims that according to them, those techniques were insufficient for solving complex design problems. [33] Furthermore, they were repeating previous design solutions in the name of "tradition".[34] Christopher Alexander claims that cultures using the same design solutions again and again, keep their imaginations within the limits of those same solutions and same forms. These kinds of cultures, who do not develop design thinking because of being devoted to "traditions", are "unselfconscious cultures." [35] Alexander puts forward a contrary proposal, "self-conscious cultures." In self-conscious cultures designers are supposed to be responsible for explaining "why things get their shape" and they are supposed to have a progressive decision making method.[36] In a self-conscious culture, the designer knows that s/he may not always have enough capacity to solve the problem, therefore the methods s/he produces to solve the problem also means a method to "overcome her incapacity." [37]

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[33] Jones, J. Christopher. Design Methods seeds of human futures. London, New York, Sydney: Wiley – Interscience. 1970. pp. 27-41.

[34] Alexander, Christopher. Notes On The Synthesis of Form. Cambridge, Mass. : Harvard University Press. 1967, p. 53.

[35] Ibid. p. 46.

[36] Ibid. pp. 34-36.

[37] Ibid. pp. 59-60.

In the period following the Second World War, designers, in order to develop more effective design techniques, paid attention to technological developments and the studies on the problem solving behavior. They gained a scientific point of view and took their design tasks as design problems. Therefore, the process gained priority than the product. Producing new solutions by scientific methods have brought new design theories into existence and have instigated the proposal of new design theories. In 1962, these theories were firstly introduced in Design Methods Conference.[38] Nigel Cross, a key figure in design studies, claims that each theory was another systematic approach to design as the products of the idea that "design is a scientific activity" but "not just the utilization of scientific knowledge of artifacts."[39] According to Geoffrey Broadbent, an architect and design methods researcher, these theories depend on organizing knowledge and computing it in such a systematic way that mostly includes stages which require making decisions in sequences.[40]

Design Methods Movement started in 1962 with the Design Methods Conference, but its initial momentum diminished quickly. In the 70s, there already were responses expressed against it. The most striking rejections to design methodology came from Christopher Alexander and Christopher Jones, who are known as its pioneers. Alexander claimed that design methodology was nothing more than an "intellectual game" and it started to hinder the novelty in design. After Alexander, Jones, one of the organizers of the Design Methods Conference, expressed that he was against "fixing all life into logical frameworks." Horst Rittel, a designer and a design methodologist, made an evaluation of the situation of design methods argument and claimed that those

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[38] For a brief history of Design Research, see Bayazit, Nigan. "Investigating Design: A Review of Forty Years of Design Research" In Design Issues, n.1, v.20 (Winter 2004)

[39] Cross, Nigel. "Designerly Ways of Knowing: Design Discipline versus Design Science" In Design Issues, n.3, v.17 (2001): p. 50

[40] Broadbent, Geoffrey. Design in Architecture Architecture and Human Sciences. London, New York, Sydney, Toronto: John Wiley & Sons. 1973, p. 256

arguments were the end of an era at design methodology. He complained about the "simple" and "immature" structure of design methods which cannot be efficient enough to correspond to the "real-world complex problems."[41]

Archer claims that with the rejections to Design Methods Movement design methods arguments continue in a new body called "design research." The concern of design research is also developing new systems of problem solving in design. Archer expresses that "Design research is a systematic inquiry whose goal is knowledge of, or in, the embodiment of configuration, composition, structure, purpose, value, and meaning in man-made things and systems."[42] One of the researchers of this -then new- design research paradigm is Donald Schön. He also stresses that the systematic methods and scientific knowledge are only used for well-defined problems but not for the real world "problematic situations."[43] He emphasizes the role of artistry in design and says that "artistry is an exercise of intelligence, a kind of knowing." According to Schön, proposals of Design Methods Movement raise difficulties for designers in using their artistry and this situation takes the design process away from being realistic.[44]

Nigel Cross states that despite the rejections of Alexander and Jones to design methodology in the 1970s and other rejections that followed them, design methodology continued getting stronger especially in engineering and some

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[41] Alexander,Jones and Rittel cited in,
Bayazit, Nigan. "Investigating Design: A Review of Forty Years of Design Research" In Design Issues, n.1, v.20 (Winter 2004)

[42] Archer, Bruce. "Design, innovation, agility" in Design Studies, n.6, v.20 (November 1999): 565-571.

[43] Schön, Donald A. Educating the Reflective Practitioner. San Francisco: Jossey-Bass. 1987. pp.3-4.

[44] Ibid. p. 13.

branches of industrial design. He adds that the design-science arguments are re-gaining their importance in the 2000s.[45]

2.2.2 The critical concepts in Design Methods

The Design Methods Movement proposes to develop design processes similar to solving a problem. This brings forth the definition of a computational process that organizes and operates on the knowledge stored in the process structure. During developing such kind of methods, designers of the movement integrated many concepts into design. The thesis identifies four of them, complexity, hierarchy, feedback loops and selection. These are the concepts that are still strikingly used in contemporary design approaches. These are very adaptable concepts of Design Methods Movement to reinterpretations of design thinking. These concepts were actually developed for other types of disciplines such as economics, mechanical engineering and industrial design. However, in order to operate on the knowledge within a system, designers employed these concepts. Today designers still investigate new ways of computing knowledge with the effective use of these concepts. Therefore, these concepts appear to be the common concepts that relate early and recent approaches of computational design in the ambience of continuously transformation design thinking.

2.2.2.1 Complexity

Functional problems are getting more and more complex day by day. Alexander claims that this condition makes it harder for designers to perceive what the problem is. Therefore, the designers, who are not completely aware of the

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[45] Cross, Nigel. "Designerly Ways of Knowing: Design Discipline versus Design Science" In Design Issues, n.3, v.17 (2001): p. 49.

problem, may not be able to reach the solution of the problem. [46] Jones states that growing populations of societies, changing and improving aspects of information technologies, economical, cultural and educational features, life style preferences and many other features of societies cause design problems to get larger scales and to gain more complexity each time.[47]

In 1967, Alexander exemplifies a complex problem with a task of “designing a complete environment for a million people”.[48] He determines the constraints of the problem as “ecological balance, good health conditions, opportunities for individuals to lead their own lives in their own ways, no condition which let criminal delinquency, good economic conditions, transportation system”. According to Alexander, a problem of this scale is hard for a designer to solve with intuitive methods. The problem requirements have a high level of interrelation. This interrelation causes the problem to have a complex structure. Controlling the flowing knowledge between the requirements is a very hard task for an individual. Alexander proposes that in order to cope with this complexity, designer should apply such a process that depends on “writing the problem down by breaking it into smaller problems.”[49] Alexander claims that this is not very different from producing “a way of setting out an arithmetical problem” which doesn’t allow an individual to solve it by using only mental activities. By setting out the sub-problems, the main problem gains an organized structure and finding the solution gets easier. Alexander stresses that there is no intuitive way of solving a design problem, which has the resembling principles of solving an arithmetical problem, and adds: “the way of representing design problems is

[46] Alexander, Christopher. Notes On The Synthesis of Form. Cambridge, Mass. : Harvard University Press. 1967, p. 1

[47] Jones, J. Christopher. Design Methods seeds of human futures. London, New York, Sydney: Wiley – Interscience. 1970. p.31.

[48] Alexander, op.cit. pp. 2-3.

[49] Ibid.

a way of reducing the gap between the designer's small capacity and the great size of his task."[50]

Instead of a totally intuitive process, Alexander proposes to integrate mathematics and logic into the problem solving in design. The concepts of "order" and "relation" are subjects of modern mathematics and therefore when designers make use of mathematics, they have the opportunity to determine new orders and relations in the problem. Additionally "representing the design problems with logical structures" gives designer the chance of understanding the problem in a clear way.[51]

2.2.2.2 Hierarchy

Alexander claims that in order to cope with the complexity of the design problem and to overcome designer's condition of incapacity, problem is re-organized in a hierarchic structure.[52] Simon explains hierarchical systems in "The Sciences of The Artificial" as "complex systems". Complex problem solving systems include "interrelated subsystems" and each "subsystem" includes other "elementary subsystems."[53] Alexander also decomposes the problems into smaller problems and each sub-problem becomes an independent problem. He uses diagrams for representing the problem abstractions (Fig.2.1). By this kind of a hierarchic organization, designer does not have to deal with the whole complexity of the problem at once. S/he finds solutions for separated but interrelated sub-

[50] Alexander, Christopher. Notes On The Synthesis of Form. Cambridge, Mass. : Harvard University Press. 1967, p. 62.

[51] Ibid. pp. 7-8.

[52] Ibid. p. 61.

[53] Simon, Herbert Alexander. The Sciences of the Artificial. Cambridge: M.I.T. Press. 1969, p. 184

problems. By the interrelation of sub-problems solutions emerge parallel to each other. The final product is the integration of all these sub-solutions.[54]

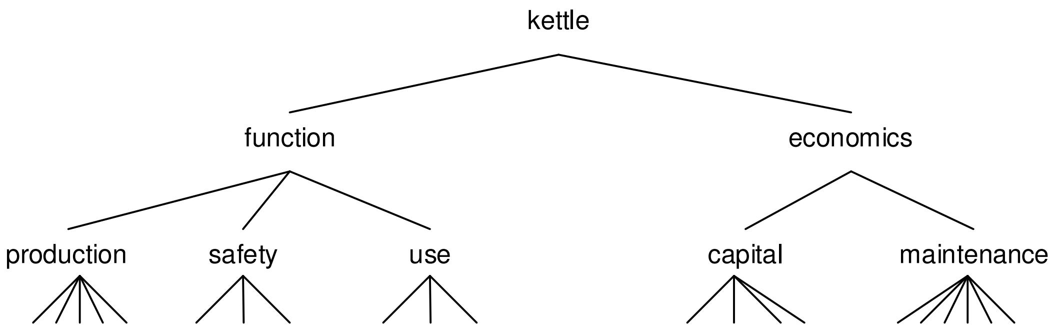

Fig.2.1 A hierarchical model for a kettle design

Alexander, Christopher. Notes On The Synthesis of Form. Cambridge, Mass. : Harvard University Press. 1967, p. 62.

2.2.2.3 Feedback loops

Archer claims that in a problem solving process, the system is defined with the interactions between input, output and feedback. In order to be operational, a system should include sub-systems and these sub-systems should be in relation to each other and the "real world problem" with a feedback flow.[55] In other words, knowledge transfers are established between the systems. This knowledge flow supplies the systems to be progressed interrelated to each other. According to Archer, with a feedback flow between the stages of the process "after each decision, all previous decisions are reappraised in the light of the late decision."

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[54] Alexander, Christopher. Notes On The Synthesis of Form. Cambridge, Mass. : Harvard University Press. 1967, pp. 61-62.

[55] Archer, Bruce. "The Structure of the Design Process." In Design Methods in Architecture. Eds. Geoffrey Broadbent and Anthony Ward New York: G. Wittenborn. 1967, pp. 95-96.

Unless feedback loops are supplied in a process, the loss of knowledge in the process is unavoidable. Thus, in such kind of a process the solutions are not "feasible".[56]

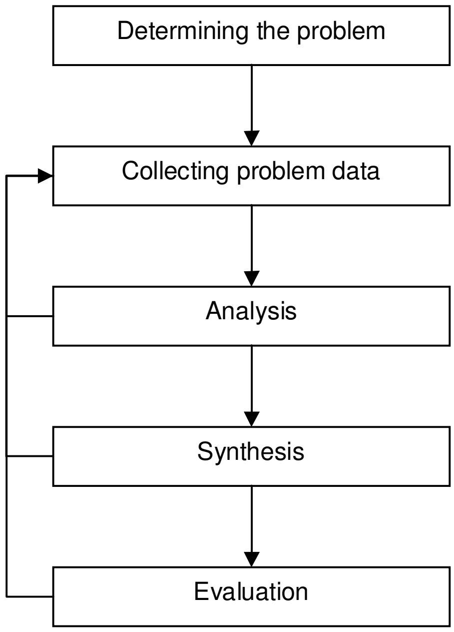

Fig.2.2 Archer's staged design process model

This diagram is an abstraction of Archer's model. For more detailed one see Archer, L. Bruce. "Systematic Method for Designers." In *Developments in Design Methods.* Ed. Nigel Cross. Chichester: John Wiley & Sons Ltd. 1984. p. 64.

Archer's operational model emerges with a sequence of activities. The stages of the model are related to each other with feedback loops. Therefore, the stages are not completely independent activities. In his model, the outputs of the stages in the linear order of operations are integrated into the system again at the "data collection" phase.[57] In Fig.2.2, feedback loops between data collection phase

[56] Archer, L. Bruce. "Systematic Method for Designers." In Developments in Design Methods. Ed. Nigel Cross. Chichester: John Wiley & Sons Ltd. 1984. p. 70.

[57] Rowe, Peter G. Design Thinking. London: The MIT Press. 1987, p. 49.

and the following phases are seen. Archer's method is distinctive because of the concept of feedback. Stages of the process are not discrete parts. They follow each other in an intense relation with a small probability of loss in feedback.

2.2.2.4 Selection

Alexander expresses that solving a design problem means searching for the match between the concepts of "form" and "context." "Form" responds to the "solution" of a design problem and "context" responds to the "definition" of the problem. Therefore, design not only focuses on the solution, but focuses on the process, as well. If form emerges in a proper way, which is determined by the interrelation with context, this condition is introduced as "good fit" by Alexander.[58] In order to have good fit, Alexander proposes to make a "list of all possible relations between a form and its context", in other words "the requirements list." Each item is treated as a unique problem. For each problem the the best solution, the solution which fits the requirements properly, is selected.[59]

Newell and Simon explain how problems are solved in human mind.[60] They claim that finding out the working principles of a human problem solving process may cause many artificially similar ways to be produced in order to solve design problems. In this approach, human mind is assumed to work as an "information processing system" while solving problems. In this system, knowledge, stored in the human memory, is represented with symbols. These symbols are re-organized in a new structure. Human mind organizes the symbols depending on

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[58] Alexander, Christopher. Notes On The Synthesis of Form. Cambridge, Mass. : Harvard University Press. 1967, p. 15.

[59] Ibid. p. 24.

[60] Newell, Allen, Herbert A. Simon. Human Problem Solving. Englewood Cliffs, New Jersey. Harvard University Press Prentice-Hall, Inc. 1972, pp. 5-6.

the relations of the sub-parts of the problem. According to this new structure, the sequence of the decisions on the problem is determined, in other words, this structure represents the order of the decisions of the path followed for solving the problem.[61]

Newell and Simon use diagrams of decision trees in order to represent the sequence of decisions. Each node, in a decision tree, represents a sub-problem, and at each node, a decision is made in order to shift to a new sub-problem and to make a new decision. In decision trees all the possible solutions, the alternatives, are shown. Newell and Simon propose to establish this kind of a system artificially, and adapt it to problem solving in design.[62] The process depends on decomposing the design problem into sub-problems, and goes forward problem by problem following a decision sequence.[63] Simon claims that while determining the alternatives, the question "Does this alternative satisfy all the design criteria?" is asked and the the best one is selected.[64] Newell and Simon, just like Alexander, make a fitness measurement in order to select the final solution among the others.

In Fig.2.3, a decision tree is exemplified with a problem which has a concern of designing a house with three bedrooms. At the first phase the problem is determined as designing a house with tree bedrooms. At the second phase, the number of storeys is decided. The possible solutions are shown in the figure and after evaluating the results of all the alternatives - if it responds to the user's needs, in which condition it is possible to set the building onto the site, in which

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[61] Newell, Allen, Herbert A. Simon. Human Problem Solving. Englewood Cliffs, New Jersey. Harvard University Press Prentice-Hall, Inc. 1972, p. 23.

[62] Ibid. p. 125.

[63] Rowe, Peter G. Design Thinking. London: The MIT Press. 1987, p. 55.

[64] Simon, Herbert Alexander. The Sciences of the Artificial. Cambridge: M.I.T. Press. 1969, p. 121.

condition the rooms have the opportunity to benefit from the natural ventilation, and so on - the one which responds to all criteria is chosen. Here, the two storey option is chosen. At the third phase, the organization of the rooms is decided. Here, the possibilities are also evaluated in order to respond the user needs. And at the forth phase, the number of bedrooms in the first floor is determined in order to obtain an efficient living space. For this example, each phase responds to a very abstract sub-problem of a house planning problem. These sub-problems may be set according to the technical details of the building such as materials of the building and the construction options, whether it is concrete or steel construction. Then alternatives may be chosen after evaluating the constraints of cost and time or other constraints about problem. Surely, real design problems are much more complex than this example. Decisions on real problems depend on largely varied parameters and constraints related to each other. Each decision requires to be evaluated with its results and effects of those results on other decisions. To give an example, the decision of the construction system of a building is not an independent decision from the height of the building. Each decision is a part of a whole. Therefore each decision has to be made considering the whole.

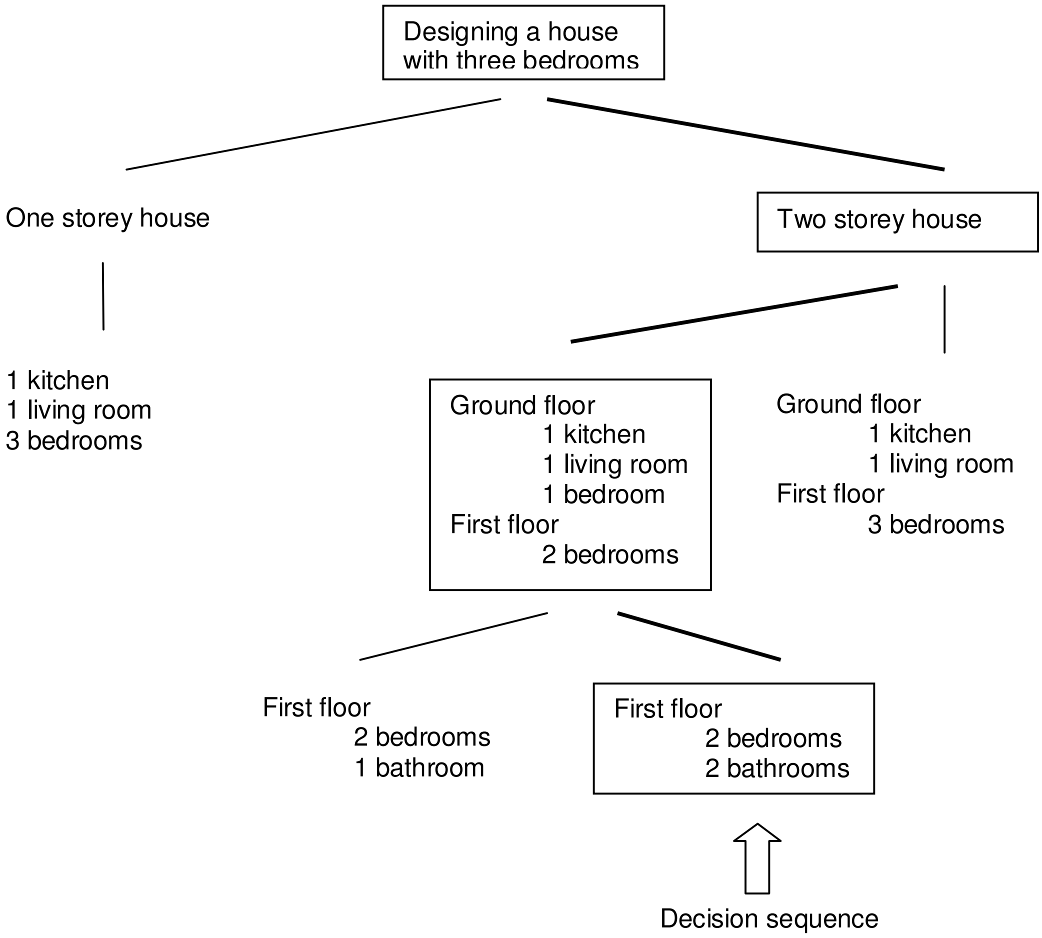

Fig.2.3 A decision tree of planning a house with tree bedrooms
Diagram by Eser Ergun.

Following this inquiry on analytical ways of problem solving in Design Methods Movement, the thesis will introduce generative design methods. Thesis will explore recent generative design methods as the followers of the idea of computing knowledge in order to reach the design goal through a systematic study. Celestino Soddu, an architect and generative design researcher, expresses that generative design is an “organized idea of ‘how to run’ a design process".[65] In this organizational approach design is pursued within a systematic process composed of computational principles. In the admission of these new techniques propose entirely different methods to operate on knowledge, the thesis will trace the influences of early methods on recent architecture by looking at the use of critical concepts. The use of critical concepts complexity, hierarchy, feedback loops and selection in recent generative design techniques will be inquired in the following chapters.

[65] Soddu, Celestino. "Generative Design. A swimmer in a natural sea frame" In GA2006 Papers, p. 1. ,
www.generativeart.com/
Last access date in 18 February 2008

CHAPTER 3

GENERATIVE DESIGN SYSTEMS

Generative design systems are rule-based creative design systems generally result in large quantities of design solutions.[66] Generative design processes are dynamic structures composed of smaller systems and processes with a dynamic interrelation. [67] Mechanical engineer Shea, industrial designer Aish and computer scientist Gourtovaia claim that the interrelating components of a generative process are the contributions of different disciplines, in other words different "performances". They call generative systems as "incorporating performance models". In a generative design model different performances may be exemplified as "engineering performance, spatial performance, fabrication and cost." [68]

As Fischer and Herr, industrial designers, explain, in a generative design system, problem requirements, constraints of the problem, and the rules which determine the new relations and the transformations of the components of the system are represented by a vocabulary. Fischer and Herr claim that the

[66] Fischer, Thomas, Christiane M. Herr. "Teaching Generative Design." In GA 2001 Papers www.generativeart.com/
Last access date 18 February 2008

[67] McCormack, J., Dorin, A. and Innocent, T. (2004) 'Generative Design: a paradigm for design research' in Redmond, J. et. al. (eds) Proceedings of Futureground, Design Research Society, Melbourne.
http://www.csse.monash.edu.au/~jonmc/research/Papers/genDesignFG04.pdf
Last access date 01 May 2008.

[68] Shea, Kristina, Robert Aish, Marina Gourtovaia. "Towards integrated performance-driven generative design tools." In Automation in Construction 14 (2005) pp.253 – 264.

vocabulary is set with the use of symbols. An efficient generative system is firstly supposed to organize these symbols and generate new variations of solutions by generating new relations of the symbols. Then, the system is supposed to "interpret" these new variations whether they fit the expectations of the designer or the user needs well enough. After eliminating the not fitting ones, the others remain for producing new generations or for another selection process for the final product. Fischer and Herr express that this final selection may be done either by the system with a random selection method, or "intentionally" by the designer.[69]

Generative systems are practiced in many ways in architectural design. The thesis inquires into "evolutionary design" and "shape grammars" as generative design methods. Shape grammars and evolutionary design are debated methods in contemporary academic and practical studies. These methods both come from the arguments in problem solving in the 1960s. Moreover, these methods share the common terminology with Design Methods which are introduced as the critical concepts in Design Methods in the second chapter.

3.1 Evolutionary design

3.1.1 Background

Evolutionary computation in design has its roots in complexity arguments in the 1960s. [70] In 1966, in *Complexity and Contradiction in Architecture*, Robert Venturi discusses a relation between complexity sciences and architectural

[69] Fischer, Thomas, Christiane M. Herr. "Teaching Generative Design." In GA 2001 Papers www.generativeart.com/
Last access date 18 February 2008

[70] Broadbent, J. A., S. Harfield "Design and evolution." In Proceedings of "Doctoral Education in Design: Foundations for the Future" Conference, La Clusaz, France. 2000. p. 8.

design. [71] Venturi quotes from Alexander and claims that architecture faces more complexity day by day because of increasing quantities of problem requirements and proposes an architectural design aims to “promote complexity within the whole”. [72] Simon is another researcher who proposes to set up complex systems that organize knowledge in order to solve problems of design in general. In *The Sciences of the Artificial*, Simon states that “creative evolution” became popular with complexity arguments after World War II.[73] He states that evolutionary systems are effective problem solving methods. Holland’s discovery of genetic algorithms enabled exploring “computational models of the process of evolution”.[74]

Kenneth A. De Jong, professor of science and technology, states that one of the branches of the increasing research on computational problem solving in 1960s is evolutionary computation. [75] In 1962, John Holland signifies evolutionary design as a “key element in of problem solving paradigm in design.”[76]Holland investigates the ways of developing “mechanisms” of adapting natural evolutionary systems to the artificial problem solving models.[77] He states that the “control” mechanism in natural systems establish a coherent whole composed of the input and output of the system. Controlling avoids the process

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[71] Jencks, Charles. The architecture of the jumping universe. A polemic: How complexity science is changing architecture and culture. New York: Academy Editions. 1993. p. 26

[72] Venturi, Robert. Complexity and Contradiction in Architecture. New York: The Museum of Modern Art. 1966. p. 19.

[73] Simon, Herbert Alexander. The Sciences of the Artificial. Cambridge: M.I.T. Press. 1969, p. 169.

[74] Ibid. p. 180.

[75] De Jong, Kenneth A. Evolutionary Computation A Unified Approach. Cambridge, Massachusetts: The MIT Press. 2006. p. 24.

[76] Holland cited in,
Ibid. p. 24.

[77] Holland, John H. Adaptation in Natural and Artificial Systems. Cambridge, Massachusetts: The MIT Press. 1992. p. 2.

from being an unorganized system. This “theory of controlling” is adapted to artificial systems by “algorithms” and “strategies”. [78]

Evolutionary design was firstly applied in aircraft design in 1960s.[79] In 1970s and 1980s, problem solving with evolutionary computation became more matured and problem solvers worked for developing more effective use of evolutionary computation in problem solving.[80] Firstly in 1991, WM Jenkins, civil engineer, used evolutionary strategies for structural problems of building design.[81]

John Frazer, an architect who has been working on evolutionary algorithms since 1970s, states that they employ Holland’s principles to solve ill-defined design problems. In 1993, Frazer firstly applied evolutionary design to an architectural element, Tuscan Column (Fig. 3.1). [82]

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[78] Holland, John H. Adaptation in Natural and Artificial Systems. Cambridge, Massachusetts: The MIT Press. 1992. p. 3.

[79] Rafiq, Yaqub, Martib Beck, Ian Packham, Sue Denhan. “Evolutionary Computation and Visualisation as Decision Support Tools for Conceptual Building Design.” In Innovation in Civil and Structural Engineering, Chapter 3. Ed. B. H. V. Topping. Saxe-Coburg Publications, pp. 49-74.

[80] De Jong, Kenneth A. Evolutionary Computation A Unified Approach. Cambridge, Massachusetts: The MIT Press. 2006. p. 24.

[81] Yaqub, Beck, Packham, Denhan. op. cit.

[82] Frazer, John. An Evolutionary Architecture. London: Architectural Association. 1995. pp. 59-60.

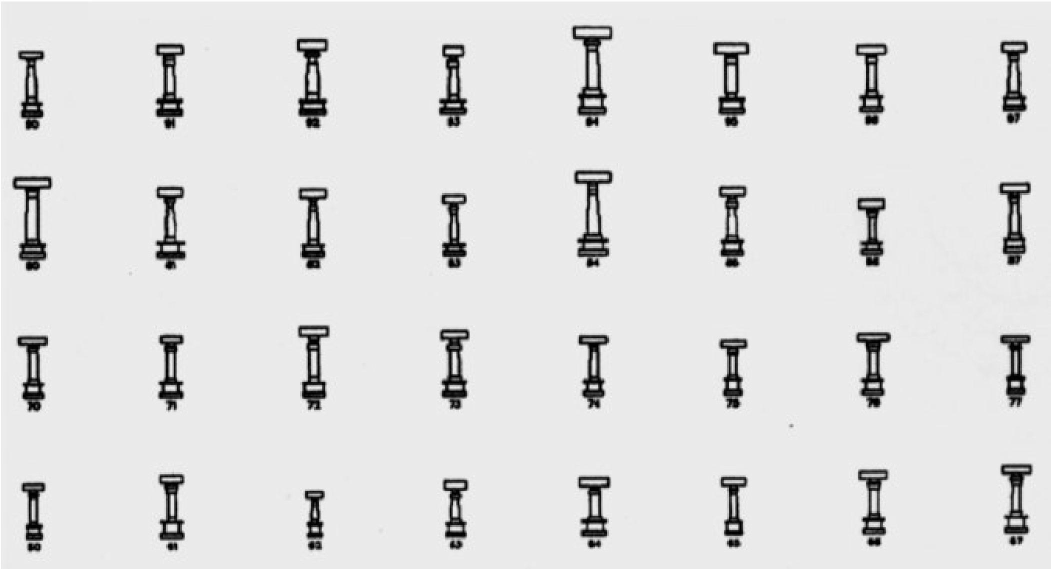

Fig.3.1. Different variations of Tuscan Column obtained by evolutionary design principles

Frazer, John. An Evolutionary Architecture. London: Architectural Association. 1995. p. 62

3.1.2 Evolutionary computation in design

In evolutionary design, designers aim to generate design solutions by imitating natural evolution. Kalay, a frequently cited author on digital design techniques in architecture, states that as natural evolution results with creative, novel and supposedly fit products, designers aim to mimic the nature for this aspect of evolution.[83]

John Frazer states that in evolutionary design process, firstly the "concept" of design should be transformed into a "genetic code" by using "rules" and architectural design concepts may also be represented as genetic codes in computer simulations. In this kind of simulations producing a high amount of generations, therefore a high amount of unpredictable creative forms, in a very

[83] Kalay, Yehuda E. "Architecture's New Media. Principles, Theories, and Methods of Computer-Aided Design" Cambridge, Massachusetts: The MIT Press. p. 282

short time is possible. Frazer adds, at the end of the process, according to the "selection criteria", the best solution is selected.[84] Simon states that natural evolution depends on generating solutions randomly. On the other hand, according to Simon, the selective aspect of evolutionary problem solving does not let the process be a random, in other words "blind" activity. Selecting proper solutions for the goal and then operating on those solutions results in the the best final products.[85] In consequence, as Bentley explains in *An Introduction to Evolutionary Design by Computers,* evolutionary design is a method of "searching" the solutions of a design problem. All "possible solutions" are stored in the "solution space" and the main goal of the "search" is to find the best solutions among the others. At each generation, "better solutions" are picked, and "worse solutions" are left to "death". The solutions selected are again integrated into the process in order to generate child solutions.[86] This process continues until the best solution is selected. In evolutionary design, deciding whether a solution is good or bad depends on the "fitness function".[87]

John Holland, who firstly talked of genetic algorithms in order to adapt the principles of natural evolution to artificial systems, explains "fitness" as the "performance measure" of genetics. If a structure performs well in its environment, it is a "fit" solution.[88] Yehuda Kalay, states that the "fitness" is the

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[84] Frazer, John. An Evolutionary Architecture. London: Architectural Association. 1995, p. 65

[85] Simon, Herbert Alexander. The Sciences of the Artificial. Cambridge: M.I.T. Press. 1969, p. 193.

[86] Bentley, Peter. "An Introduction to Evolutionary Design by Computers" In Evolutionary Design by Computers. Ed. Peter Bentley. San Francisco, California: Morgan Kaufmann Publishers. 1999, p. 5.

[87] Ibid., 7.

[88] Holland, John H. Adaptation in Natural and Artificial Systems. Cambridge, Massachusetts: The MIT Press. 1992. p. 5.

“harmony between form, function and context” and this harmony causes the evolutionary process to result with unique solutions.[89]

3.1.2.1 Genetic algorithms

Bentley states that genetic algorithms (from here on, GA) depend on the idea of “adapting processes of natural systems” to the artificial systems. According to Bentley GAs are more similar to the natural evolution than other evolutionary algorithms such as evolutionary programming, evolution strategies and genetic programming. Therefore, designers prefer genetic algorithms rather than the others. [90]

In GA, the “genotypes” correspond to the codes of the problems and the “phenotypes” correspond to the “population of solutions.”[91] In biology genotype means the stored information in cells, in other words genetic codes of cells. Phenotype means physical corresponding of genetic codes.[92] Kalay explains “problem space” in an evolutionary problem solving process as “genotypes” and the solution space as “phenotypes”. According to the fitness function the “fittest” phenotypes are chosen in order to generate new children solutions from their genotypes. The remaining genotypes are “discarded.” These operations occur in

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[89] Kalay, Yehuda E. "Architecture's New Media. Principles, Theories, and Methods of Computer-Aided Design" Cambridge, Massachusetts: The MIT Press. p. 282.

[90] Bentley, Peter. “An Introduction to Evolutionary Design by Computers” In Evolutionary Design by Computers. Ed. Peter Bentley. San Francisco, California: Morgan Kaufmann Publishers. 1999, p. 8.

[91] Kalay, op. cit. pp. 282-283.

[92] Blamire, John. “Genotype and Phenotype Definition.” Department of Biology, Brooklyn College,
http://www.brooklyn.cuny.edu/bc/ahp/BioInfo/GP/Definition.html
Last access date 10 May 2008.

a computer memory in a very short time and in this short time millions of solutions may be generated.[93]

3.1.2.2 Genetic operators

In natural evolution, there are many genetic processes such as mutation, crossover, inversion, dominance modification, translocation, and deletion, in order to create new generations from the parents.[94] In the artificial evolution studies, these processes are adapted to different kinds of problem solving models. Some of these are copied from nature by the genetic algorithms in the name of genetic operators. The most common genetic operators in GA in design are mutation and crossing-over.[95]

3.1.2.2.1 Mutation

Holland states that: “In genetics mutation is a process wherein one allele of a gene is randomly replaced by (or modified to) another to yield a new structure.”[96] But this process rarely happens in nature. In the artificial design systems, the parameters are coded by using “ones” and “zeros” in the computer memory.[97] Bentley exemplifies the mutation of an allele of an individual in a

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[93] Kalay, Yehuda E. "Architecture's New Media. Principles, Theories, and Methods of Computer-Aided Design" Cambridge, Massachusetts: The MIT Press. pp. 282-283.

[94] Holland, John H. Adaptation in Natural and Artificial Systems. Cambridge, Massachusetts: The MIT Press. 1992. p. 33.

[95] Bentley, Peter. “An Introduction to Evolutionary Design by Computers” In Evolutionary Design by Computers. Ed. Peter Bentley. San Francisco, California: Morgan Kaufmann Publishers. 1999.

[96] Holland, op. cit. p. 109.

[97] Angesleva, Jussi. “Evolutionary computation in creative design.” Computer related design, Royal College of Art. 2001. p.17
http://angesleva.iki.fi/projects/dissertation/evolution.pdf
Last access date 12 February 2008.

computer simulation with the code of the individual,"111111". When the random replacement happens, the individual possibly mutates into "110111".[98]

Ming Tang and Dihau Yang, professors at Savannah College of Art and Design, stress that in an evolutionary design process in its normal proceeding, where the determined rules are applied to emerging generations, members from each generation are selected. In order to obtain new generations the same rules are applied again and again. This kind of a normal process may come to end with no mutation. As the evolution in an artificial system happens through simulation, if it is desired, the mutation may also be simulated. Tang and Yang, set an evolutionary design system in the Maya software, in order to experiment the mutation operator in a design process. Rules of the software do not include noise. They add random noise to the system and make the noise to grow by "accumulating" it in the process body, during several generations. When the noise reaches a high level of frequency for the members of the generations, many of them react with extraordinary mutations. [99] Fig.3.2 shows the extraordinary flow of the process.

[98] Bentley, Peter. "An Introduction to Evolutionary Design by Computers" In Evolutionary Design by Computers. Ed. Peter Bentley. San Francisco, California: Morgan Kaufmann Publishers. 1999.

[99] Tang, Ming, Yang. D. "Genetic Evolution: A Synthetic Approach in Form Generation." Pp. 3-4. http://genetic.ming3d.com/GE_FEIDAD3.pdf
Last access date 03 May 2008.

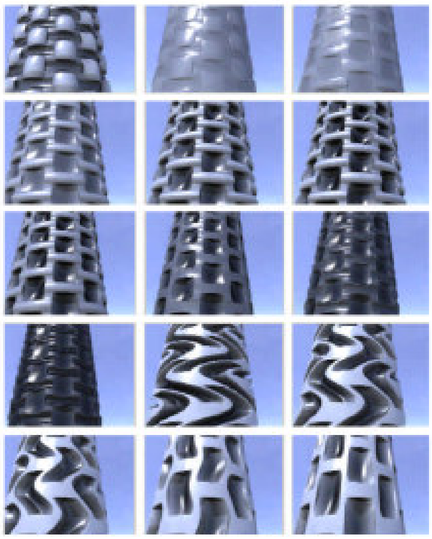

Fig.3.2 The members before the noise and after the noise

Tang, Ming, Yang. D. "Genetic Evolution: A Synthetic Approach in Form Generation."
http://genetic.ming3d.com/GE_FEIDAD3.pdf
Last access date 03 May 2008.

3.1.2.2.2 Crossing-over

Genes are the coded versions of the features, in other words the parameters of the problem and the "alternative forms of the genes" are called the "alleles". [100] Crossing-over is the "exchanging segments between pairs of chromosomes" in order to make new "combinations of alleles" in nature. [101] In the genetic algorithm strings, the crossing-over occurs between the strings of codes randomly just like in the natural systems. In a crossing-over process, firstly two parents are selected randomly, and then the segments, which will pass to the other string, are also selected randomly, and finally the crossing-over occurs

[100] Holland, John H. Adaptation in Natural and Artificial Systems. Cambridge, Massachusetts: The MIT Press. 1992. p. 9

[101] Ibid., 97.

and new individuals, the child solutions, emerge.[102] Fig.3.3 shows an example of crossing-over between two parent strings.

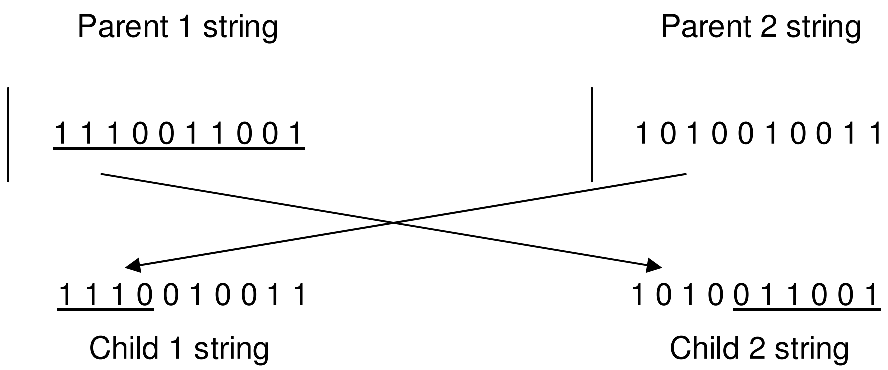

Fig.3.3 The crossing-over operator

Holland, John H. Adaptation in Natural and Artificial Systems. Cambridge, Massachusetts: The MIT Press. 1992. p. 9

Tang and Yang explore how crossing over exists during an evolutionary design process in architecture. They select architectural elements of a building as parent generations. After mating them, they observe the emergence of the new generations. The parents' many features pass to the new generations by heritance or by crossing-over. They simulate this mating event in Maya with two roof structures as parent-A and parent-B. They run the process until 100 children solutions are generated.[103] In Fig. 3.4 some selected child solutions are shown. They note that:

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[102] Holland, John H. Adaptation in Natural and Artificial Systems. Cambridge, Massachusetts: The MIT Press. 1992. p. 98.

[103] Tang, Ming, Yang. D. "Genetic Evolution: A Synthetic Approach in Form Generation." p.3. http://genetic.ming3d.com/GE_FEIDAD3.pdf
Last access date 03 May 2008.

The first child is identical to parent-A, and the 100th child is identical to parent-B. The other 98 children are just the mixture of parent-A and parent-B with different weight combination. For instance, the second child had 99% affluence from A and %1 affluence from B, the third children had 98% affluence from A and 2% from B.[104]

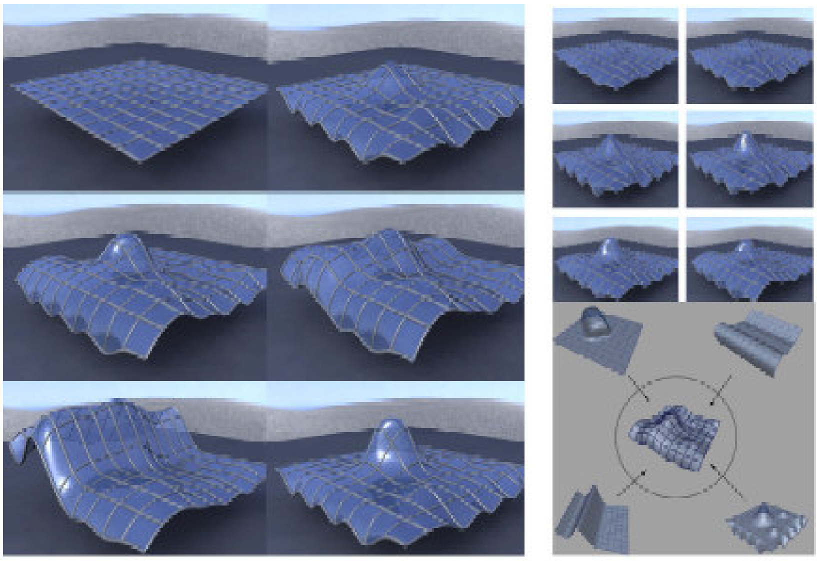


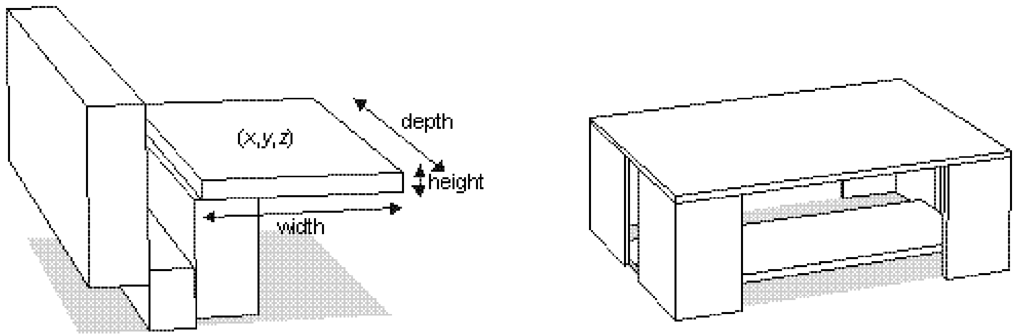
Fig. 3.4 Generated roof structures

Tang, Ming, Yang. D. "Genetic Evolution: A Synthetic Approach in Form Generation." p.3.
Genetic Evolution, http://genetic.ming3d.com/GE_FEIDAD3.pdf
Last access date 03 May 2008.

[104] Tang, Ming, Yang. D. "Genetic Evolution: A Synthetic Approach in Form Generation." p.3.
http://genetic.ming3d.com/GE_FEIDAD3.pdf
Last access date 03 May 2008.

3.1.2.3 Designing with evolutionary algorithms: Bentley's evolving table

Fig.3.5. shows Peter Bentley's example of an "evolving table" with the Generative Evolutionary Design System. The 3D figure is the representation of the design which corresponds to the phenotype. On the left side of the figure, the randomly shaped parts of a table is shown, the parts of the table continue evolving and generating alternative forms until the size of the table gets fitter for a functional table. The final product of this process is shown on the right side as a table with proportional parts. The genotypes are shown in the table below the figure. They are the codes of the size of the table. In this model, seeing the form evolution simultaneously with the interaction between the parameter changes and the genotypes is possible. [105]



[105] Bentley, Peter. "Aspects of Evolutionary Design by Computers" Intelligent Systems Group, Department of Computer Science, University College London, http://www.cs.ucl.ac.uk/staff/P.Bentley/wc3paper.html
Last access date 16 February 2008.

Phenotype:

x, y, z, width, height, depth of block 1 x, y, z, width, height, depth of block 2

x, y, z, width, height, depth of block 3 x, y, z, width, height, depth of block 4

x, y, z, width, height, depth of block 5 .... x, y, z, width, height, depth of block 16

Genotype:

11010110	10101101	10101110	10011010	01101010	...	10001010	10001010	10001010
desired xpos 1	desired ypos 1	desired zpos 1	desired width 1	desired height 1	...	desired width 4	desired height 4	desired depth 4

Fig.3.5.

Generative Evolutionary Design of a table.

Bentley, Peter. "Aspects of Evolutionary Design by Computers" Intelligent Systems Group, Department of Computer Science, University College London,
http://www.cs.ucl.ac.uk/staff/P.Bentley/wc3paper.html
Last access date 16 February 2008.

Such an evolutionary system like Bentley's evolving table example, involves a high interrelation between the problem space and solution space, the inputs and the outputs. This interaction unifies the system and prevents feedback loss. On the other hand, Simon explains natural complex systems with their hierarchic structures "evolve from simplicity".[106] Simon exemplifies this with an evolution of a biological system starts from a cell and then evolves into an organ.[107] In the artificial systems mimicking natural evolution, this evolution from simple to complex happens in order to get more useful solutions at each time just like in the Bentley's example. In this example, we can express that codes correspond

[106] Simon, Herbert Alexander. The Sciences of the Artificial. Cambridge: M.I.T. Press. 1969, p. 216.

[107] Ibid. 186.

to the chromosomes of cells and table correspond to the organ. The solutions which are more appropriate for the desired one are selected.

3.2 Shape grammars

3.2.1 Background

Mitchell expresses that starting from Modern Architecture, attributing design quantitative aspects such as “order, complexity, unity” and “variety”, caused many attempts of “measuring aesthetic values”. In 1933, a mathematician George Birkhoff, developed a mathematical formula relating “aesthetic value, order and complexity.” During the 60s, efforts of “analyzing aesthetics” continued in more reasonable ways by the exploration of “information theories” and the integration of algorithms to design. [108] In 1972, Stiny and Gips, engineering undergraduate students at MIT[109], proposed the theory of shape grammars following the studies on quantifying design in Design Methods.[110]

Stiny, expresses that after reading Birkhoff’s Aesthetic Measure and learning about his formula on aesthetics, he understood that he could compute on shapes.[111] Stiny adds reading Chomsky’s influential studies on the topic of the structure of language made him to decide developing shape grammars.[112]

[108] Mitchell, William J. The Logic of Architecture Design Computation and Cognition. Cambridge, Mass. : The MIT Press. 1990. p. 33

[109] Knight, Terry, George Stiny. “Classical and Non-classical Computation” In Information Technology. Vol.5, No. 4, 2001. p. 362.

[110] Mitchell, op. cit.

[111] Stiny, George. Shape. Cambridge, Mass. : The MIT Press. 2006. p.14

[112] Ibid., 17

Chomsky states that in order to obtain “a method for describing language”, he “formalizes the notions of phrase structures” and adds,

> We study the formal properties of a set of grammatical transformations that carry sentences with phrase structure into new sentences with derived phrase structure, showing that transformational grammars are processes of the same elementary type as phrase-structure grammars. [113]

Chomsky, summarizes the aim of linguistic theory as clarifying how a “speaker produces and understands new sentences.” [114] Stiny takes Chomsky’s proposition as a model for design. He defines shape grammars as the language of design. Shape grammars are “systems of rules” similar to Chomsky’s “generative grammars which show how words go together and make sentences.” Stiny asserts that by using “a finite number of rules”, “generating indefinite number of things” is possible. [115] Thus, computational design explored by Design Methods, gained a visual aspect with Stiny’s proposition.

Scott C. Chase, states that shape grammars integrate logic and design in order to “generate and analyze languages of design” and they have been used since 1980s in “fine arts, architecture and landscape design.” Chase expresses that “use of logic in design is not new” in design. [116] On the other hand integrating shape grammars and logic “provide a natural intuitive method of generating

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[113] Chomsky, Noam. “Three Models for the Description of Language.” 1956 p.113

[114] Ibid.

[115] Stiny, George. Shape. Cambridge, Mass. : The MIT Press. 2006. p. 17

[116] Ibid.

precise definitions of parametric shapes and high level spatial relations." [117] Chase states that this feature distinguishes shape grammars from other "traditional procedural programming methods" and he adds,

> The use of logic can facilitate a top-down method of development, from the abstract to the specific. This is possible because the symbolic abstractions of logic formulations enable one to denote entire classes of data structures and procedures while ignoring their details. This can be a more natural method of development than having to deal with often unintuitive formulations.[118]

3.2.2 Designing with shape grammars

Shape grammars propose a mathematical foundation for the analysis of shapes and the generation of new shapes by computing with parts of shapes and as well as with visual rules that designate spatial relations of multiple shapes.[119]

Shape grammars are distinct from the evolutionary design in the previous section. In evolutionary design, the whole process depends on codes and fitness function. On the other hand shape grammars consider design as a computation in a visual way. Stiny and Knight emphasize the difference of shape grammars from other computational methods. They state that shape grammars are "purely

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[117] C. Chase, Scott. "Using logic to specify shapes and spatial relations in design grammars" In Workshop Notes, Grammatical Design, Fourth International Conference on Artificial Intelligence in Design. Stanford University, USA,1996

[118] Ibid. p. 2.

[119] See Knight, Terry. "Applications in architectural design, and education and practice." Report for the NSF / MIT Workshop on Shape Computation, 1999. for a short and accurate synopsis of the field of shape grammars and its basic applications in education and design practice.

visual" computational design methods depending on "computations on shapes" instead of "texts" or "symbols" [120] Stiny, separately, emphasizes that "visual reasoning" is about seeing the embedded parts.[121] "Practicing visual reasoning" is possible by the application of shape rules to the embedded parts.[122] Therefore, in order to generate new shapes from a given shape, the designer firstly should be able to see relevant parts in the shape using the embedding part relation.

3.2.2.1 Embedding Relations

Shapes are not as definite as they seem as Stiny explains,

1) Some shapes can look different and be the same,
2) Other shapes can look the same and be different.[123]

They do not have certain parts in their structures; they instead display ambiguities to the eye. The embedded parts in the shape change from person to person because of perceiving different things from what they see in a shape. [124] Ambiguity in shapes makes the designer curious about the arrangements in shapes. Designers search for alternative ways of making new arrangements in the shape. Stiny expresses that this property in shapes removes the limits in the shape. Therefore a designer is free to see whatever s/he wants to see in the shape. Stiny's proposal with the theory of shape grammars is that design rules

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[120] Knight, Terry, George Stiny. "Classical and Non-classical Computation" In Information Technology. Vol.5, No. 4, 2001. p. 362.

[121] Stiny, George. Shape. Cambridge, Mass. : The MIT Press. 2006. p. 61.

[122] Ibid. p. 65.

[123] Ibid. p. 70.

[124] Ibid. p. 6.

vary as much as shapes do. Ambiguity in shapes is a very prolific situation for creating new shapes. [125]

The designer has the opportunity to see many different embedded parts in one shape (Fig.3.6). The point is to be able to see them by making efficient rules and finding the embedding relations in the shape. New embedding relations let the designer to have novel solutions through a solution which seems to be definite and “stable”.[126]

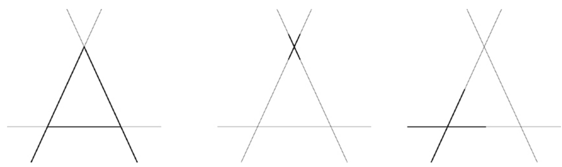


Fig. 3.6 Embedded shapes in the intersecting lines

Stiny, George. Shape. Cambridge, Mass. : The MIT Press. 2006. p. 8.

Stiny describes the embedding relations in a shape as:

> - Every basic element is embedded in itself.
> - Two basic elements, each embedded in the others are identical.
> - If three basic elements are such that each is embedded in the new, then the first basic element is embedded in the last.[127]

[125] Stiny, George. Shape. Cambridge, Mass. : The MIT Press. 2006. p. 301.

[126] Ibid. p. 125.

[127] Ibid. p. 167.

3.2.2.2 Calculating with shapes

Stiny considers design as a "calculation". Calculating with shapes is a kind of "mathematics" that includes "no equations or number" but shapes. Additionally, he employs rules for calculating with shapes. His mathematics combine "seeing and doing". [128] This gives computational design a new aspect of visual perceiving. Designer computes on the parts of the shapes that he identifies visually.

Stiny claims that applying a series of "calculations" on a shape means, picking new embedding relations again and again as long as "calculating" is continuously applied. Each calculation transforms the shape into a new shape. Designer may have the ability of producing new shapes via choosing the embedding relations and applying rules to them without knowing the history of the shape. [129]

Calculating with shapes is a visual activity.[130] Stiny asserts that rules are applied to see the existence of the emergent shapes in the whole shape. Making calculations on the emergent shapes makes the design product to have an interrelated body with the designer's mind as the designer determines the rules. The designer may change the applied rules, and therefore, may change the embedding relations. It is not possible to see a part independent from the rules applied to the shape, the limits of the design depends on the applied rules and then "seeing." In addition, the attempts of seeing new constituents give a shape

[128] Stiny, George. Shape. Cambridge, Mass. : The MIT Press. 2006. p. 14.

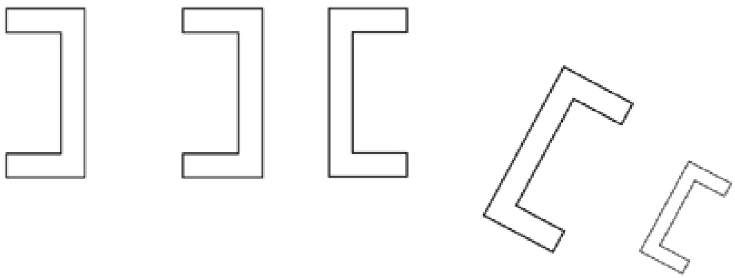
[129] Ibid.p. 163.

[130] Ibid. p. 125.

a dynamic body, open to change at each calculation applied on its changing constituents. [131]

3.2.2.3 Shape transformations

Stiny uses various shape rules in order to have interrelation between the parts of the shapes. New shapes are defined with new relations. Shape rules are constructed with “shape transformations.” These transformations are a set of operations such as “rotating, scaling, reflecting and translating” the shape or the subparts of the shape. [132] In Fig. 3.7 the transformations are exemplified.



translation reflection rotation scale

Fig. 3.7 Shape transformations
Shapes by Eser Ergun.

3.2.2.4 Spatial relations

Spatial relations define the combinations of shapes, how they come together and interact with each other. Decomposing a shape is a way of determining the

[131] Stiny, George. Shape. Cambridge, Mass. : The MIT Press. 2006. p. 167.

[132] Ibid., 194

spatial relations in the shape. It helps to conceive the arrangements in the shape and the interaction between the parts of the shape.[133]

In Fig.3.8 (a), The Hearst Headquarters Building, designed by Foster & Partners, is shown.[134] The facade of the building has a pattern which is constructed by combining triangles. In Fig.3.8 (b), one of the modules of the pattern is highlighted.

Fig.3.8 (a) Hearst Headquarters

Business Week, Architectural Wonders,
http://images.businessweek.com/ss/05/11/wondersoftheworld/source/11.ht
Last access date 04 May 2008.

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133 Stiny, George. Shape. Cambridge, Mass. : The MIT Press. 2006. pp. 245-248.

134 Foster&Partners, http://www.fosterandpartners.com
Last access date 04 May 2008.

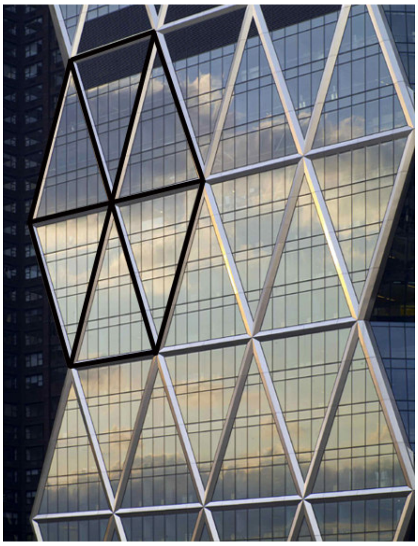


Fig.3.8 (b) The highlighted module in the facade

Foster&Partners, http://www.fosterandpartners.com/Projects/1124/Default.aspx
Last access date 04 May 2008.

In Fig.3.9 (a), one of the modules on the facade of the Hearst Headquarters, is studied apart. It is decomposed to its sub-shapes. In Fig.3.9 (b), the module is re-constructed by applying rules to the selected sub-shape, the triangle.

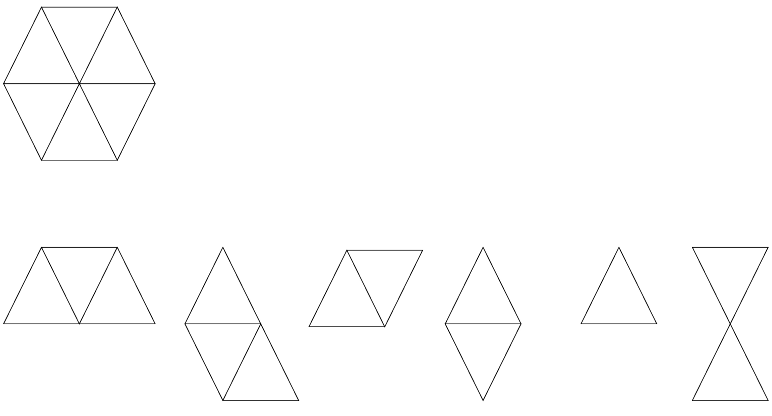
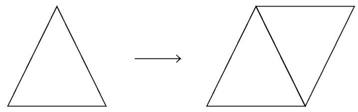
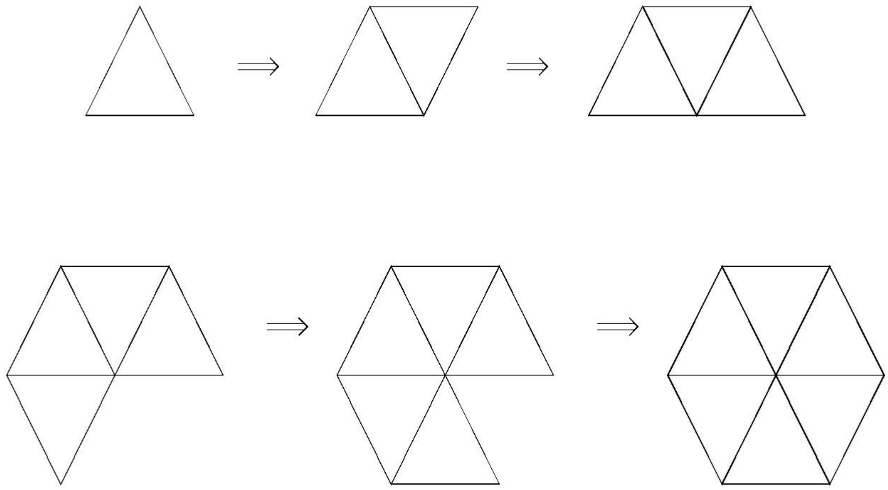


Fig.3.9 (a) Sub-shapes of the module

Analysis by Eser Ergun.



rule



computation

Fig.3.9 (b) Re-constructing the module

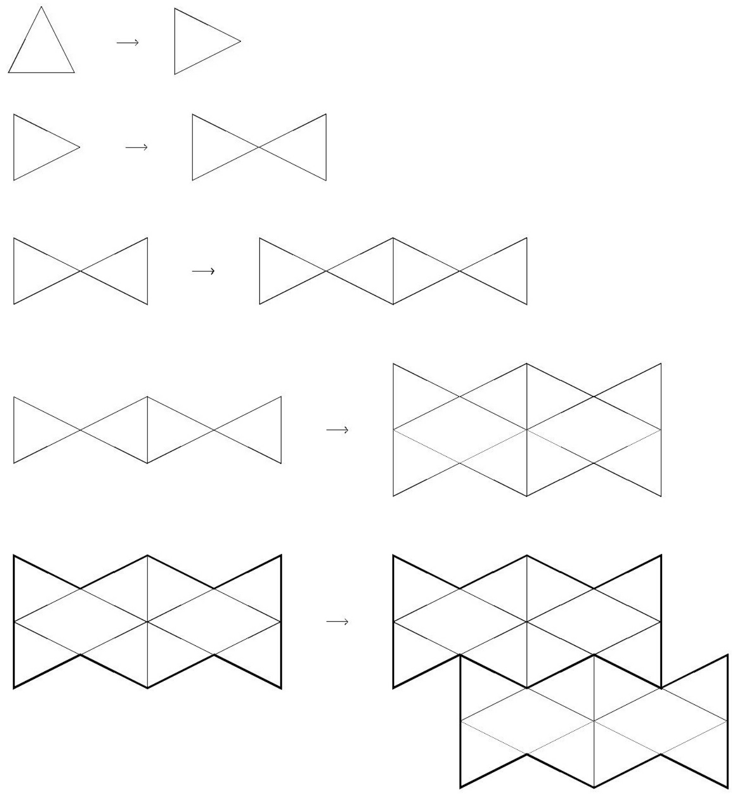
Knight, Terry, George Stiny. "Classical and Non-classical Computation" In Information Technology. Vol.5, No. 4, 2001. p.362

On the other hand, at the beginning of the calculations, determining a "vocabulary", in other words determining the shapes which will take part in the new arrangements, is another way of determining spatial relations. By this method, making arrangements with shapes by applying rules, new shapes may be constructed.[135]

In Fig.3.10, two of the sub-shapes of the module, decomposed above, are selected as the vocabulary for a new computation. Then, by applying addition

[135] Stiny, George. Shape. Cambridge, Mass. : The MIT Press. 2006. pp. 252, 253.

rules, a new pattern, which is different from the pattern of the Hearst Headquarters' facade, is obtained.



rules

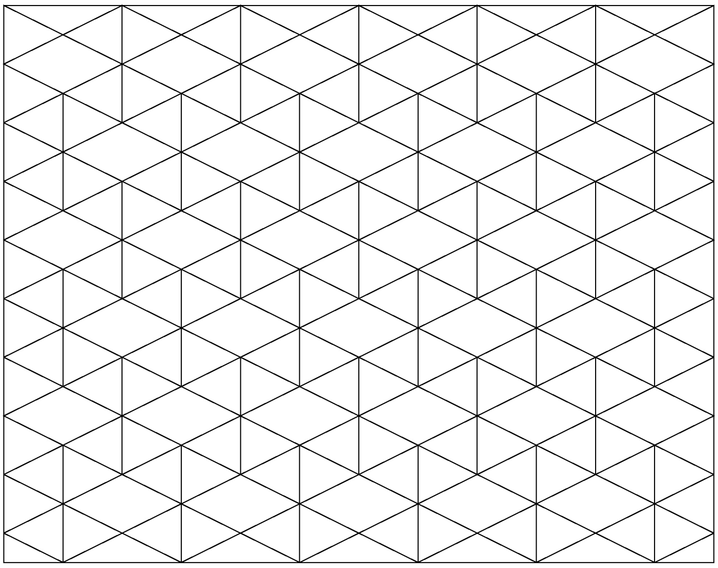


Fig.3.10 Re-constructing a new pattern

Re-construction by Eser Ergun.

CHAPTER 4

Traces of Design Methods Features in Contemporary Practice

Janssen, Frazer and Ming-Xi express that generative design models have their roots in the 1960s. In order to operate on the knowledge, a system based on rules is also developed in generative design methods. But on the other hand, according to Janssen, Frazer and Ming-Xi, current systems aim to "generate and explore alternative design proposals" besides main efforts of Design Methods Movement, "analyzing" and "evaluating". In these alternative proposals generative systems do not separate problem definition and solution with sharp boundaries. Problem formulating and solving progress simultaneously. Therefore problem defining continues during the process. Thus, the relation of problem space and solution space is not as static as it is proposed in the Design Methods. [136]

Recent designers assume computational design process as a more flexible way of operating on knowledge that claims the intuitive aspect of the designer. Designers work with simulations of design environments and design solutions. Therefore, they have the chance of contributing to the computational process with their visual preferences. They have the chance of directing the processes with their artistic choices besides the rules and algorithms they develop in order establish a system. Thus, recent use of the critical concepts of Design Methods Movement, complexity, hierarchy, feedback loops and selection get form in a more dynamic way in generative design methods.

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[136] Janssen, Patrick, John Frazer, Tang Ming-Xi. "Evolutionary Design Systems and Generative Processes" In Applied Intelligence. V.16 2002. pp. 119-128.

4.1 Complexity in generative design

As it is stated before Simon defines complex systems as the systems which are "made up of a large number of parts that have many interactions." The present systems, which deal with complexity, "focus mainly on mechanisms that create and sustain complexity and on analytical tools for describing and analyzing it."[137] Generative design systems are also analytical systems which produce complexity and also offer methods to cope with that complexity. Shea, Aish and Gourtovaia claim that generative design models include generative parameters comprising "the maximum number of structural members in a candidate design, parametric constraints on the structural grammar, and parameters that control the generative and optimization process".[138] The wide range of parameters in a process causes the initial complexity to increase. Soddu stresses this as that increasing complexity of a process "enlarges the memory" of the process. This memory is a "layering of different inputs, needs, references and feelings." [139]

Designers make use of shape grammars in order to "generate new spatial designs and characterizing their style"[140] On the other hand; with the application of rules shapes may get more and more complex. Rules determine the picked parts in a shape, and new operations on them. Applying rules and obtaining different shapes from the same shape and same shape's parts may continue as

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[137] Simon, Herbert Alexander. The Sciences of the Artificial. Cambridge: M.I.T. Press. 1969, pp. 169-184

[138] Shea, Kristina, Robert Aish, Marina Gourtovaia. "Towards integrated performance-driven generative design tools." In Automation in Construction 14 (2005) pp.253 – 264.

[139] Soddu, Celestino. "Generative Design. A swimmer in a natural sea frame" In GA2006 Papers, p. 9
www.generativeart.com/
Last access date in 18 February 2008

[140] Shea, Aish, Gourtovaia. op. cit. pp.253 – 264.

long as the designer wants.[141] Therefore, in shape application of formulations depends on a cognitive aspect. Thus, the complexity in shape grammars causes a difficulty for designers in developing generative design tools.[142]

4.1.1 Hierarchy in generative design

Simon states that the components of complex systems may be organized or disorganized. The artificial systems such as design deal with organized complex systems in order to produce analytical ways for solving problems. The organization in the complex systems requires hierarchy, in other words requires an arrangement of systems. [143] This arrangement includes smaller systems in the larger ones. McCormack, Dorin and Innocent exemplify this with ecosystem in nature: The ecosystem emerges from an atom, the smallest system in the nature, and goes on getting larger and more complex in the sequence of *atom, molecule, organelle, cell, organ, organism* and *ecosystem.* [144]

Michael A. Rosenman, an architect who studies evolutionary design, works on establishing a systematic evolutionary approach "based on a genotype which represents design grammar rules for instructions on locating appropriate building blocks." He point outs the hierarchical organizations in his system. He claims that he aims to keep the "combinatorial problems" at minimum level and to have

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[141] Stiny, George. Shape. Cambridge, Mass. : The MIT Press. 2006. pp. 226, 227.

[142] Chase, Scott C: "Generative desig tools for novice designers: Issues for selection." In Automation in Construction 14 (2005) pp.689 – 698.

[143] Simon, Herbert Alexander. The Sciences of the Artificial. Cambridge: M.I.T. Press. 1969, p. 183.

[144] McCormack, J., A. Dorin and T. Innocent. (2004) 'Generative Design: a paradigm for design research' in Redmond, J. et. al. (eds) Proceedings of Futureground, Design Research Society, Melbourne.
http://www.csse.monash.edu.au/~jonmc/research/Papers/genDesignFG04.pdf
Last access date 01 May 2008.

a harmony in the process by "decomposing" and "aggregating the hierarchical organization of the design object". [145]

Rosenman uses 2D house plans in order to represent the concept of form generating by evolutionary approach. In the work, the zones of a house plan and their smaller parts are represented with "polygonal shapes" constructed by the "closed loops of edge vectors." These polygonal shapes emerge during the application of the design grammar. In Fig.4.1, the first diagram represents a "basic unit" or "cell" for the spatial relations which will emerge during the process. This basic unit is a "polygon," in other words it is the "sequences of edge vectors (W1, N1, E1, S1)." The second and third diagrams in Fig.4.1 show the coming together of sub-shapes and "joining" their edges, and as a result, the emergence of new "polyminoes." [146]

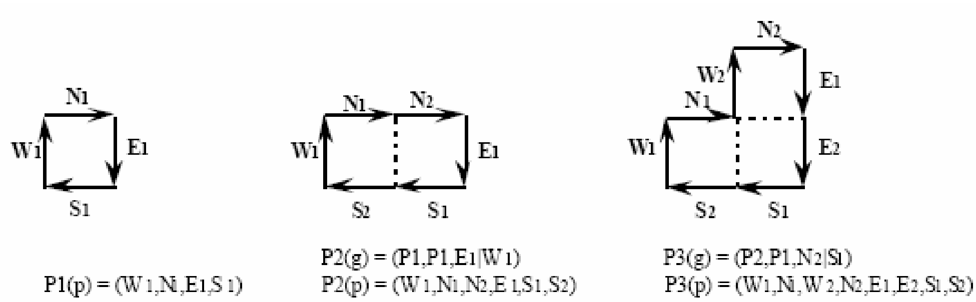

Fig. 4.1 Generation of polyminoes

http://people.arch.usyd.edu.au/~mike/GenForm1.pdf
Last access date 10 May 2008.

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145 Rosenman, M.A. "The Generation of Form Using an Evolutionary Approach." Faculty of Architecture, Design & Planning , The University of Sydney,
http://people.arch.usyd.edu.au/~mike/GenForm.html
Last access date 10 May 2008.

146 Ibid.

This process of joining sub-shapes and generating new polyminoes happens in a random way as Rosenman states that:

> The generation of these polyminoes occurs from a random selection of edges in the first shape conjoined with a random selection from equal and opposite edges in the second shape. At each step in the generation, the phenotype is reinterpreted to generate a new edge vector description and the conjoining (sub)rules applied.[147]

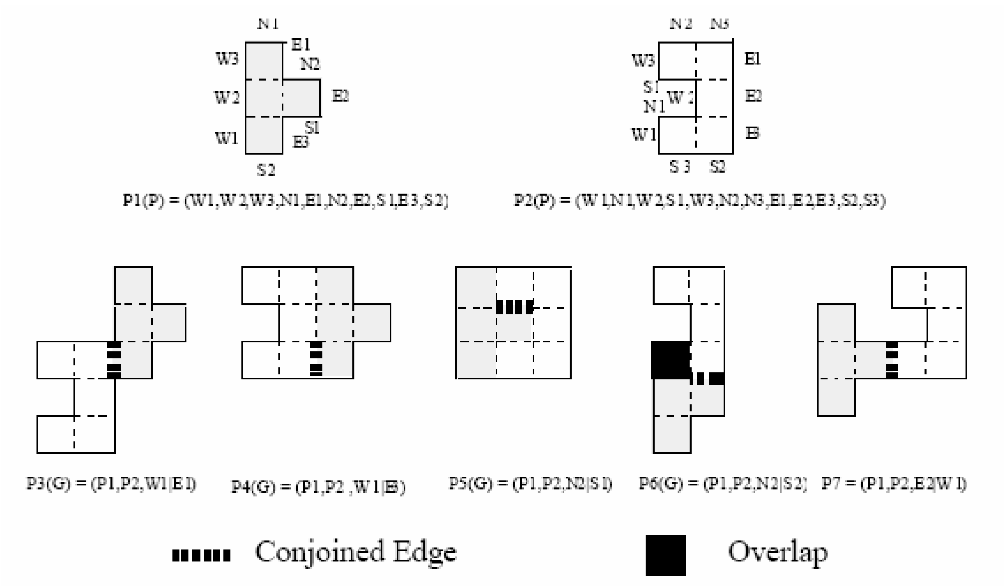

Fig. 4.2 Some Examples of Conjoining Two Polyminoes

Rosenman, M.A. “The Generation of Form Using an Evolutionary Approach” 2006. p.7
Faculty of Architecture, Design & Planning , The University of Sydney

[147] Rosenman, M.A. “The Generation of Form Using an Evolutionary Approach.” Faculty of Architecture, Design & Planning , The University of Sydney, http://people.arch.usyd.edu.au/~mike/GenForm.html
Last access date 10 May 2008.

By establishing different spatial relations of two rooms, to generate various "zone forms" is possible, as it is shown in Fig.4. 2. In Fig.4.2, P1 and P2 are the polygons which represent two different room types and the other diagrams represent the zones which are constructed by combining the two rooms in different relations. By combining these zones in different ways, new house plans may also be generated. [148]

In Rosenman's model, an evolutionary design model is applied in order to transform "genotypes" into "phenotypes", in other words codes into forms. When design grammars are integrated to the evolutionary model, a "grammar rule" represents a "gene." Each diagram represents a phenotype, and the formulas, written below the diagrams, show the genotypes. In this example, "length of the genotype" changes according to the "required room sizes." In this study, "fitness function for the rooms" is determined if the "area ratios" and the number of the angles" are at a minimum level, as possible as they can be, in order to obtain "useful compact forms". The fitness function for the "zone level," aims to "minimize a sum of adjacency requirements between rooms reflecting functional requirements," and finally the fitness function for the "house level" is expected to "minimize a sum of adjacency requirements between rooms in one zone and rooms in other zones." These are the "quantitative" aspects of fitness function and other qualitative aspects will be determined by the "designer or the user, interactively and subjectively." [149] Therefore, the designer has the chance of evaluating the solutions intuitively. The interrelation established between the designer's mind and the process, bends the mechanic aspect of the process comes from the formulations.

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[148] Rosenman, M.A. "The Generation of Form Using an Evolutionary Approach." Faculty of Architecture, Design & Planning , The University of Sydney,
http://people.arch.usyd.edu.au/~mike/GenForm.html
Last access date 10 May 2008.

[149] Ibid.

In this house plan generation example, evolution by “simple crossover” is the method for generating “child members”. In Fig. 4.3(a) both genotypes of the rooms have four sites and in a random way, “crossover” may happen between the sites. [150]Fig.4.3 (b) shows two examples of the possible room types when crossover occurs at the fourth sites of the rooms given in the Fig.4.3 (a).

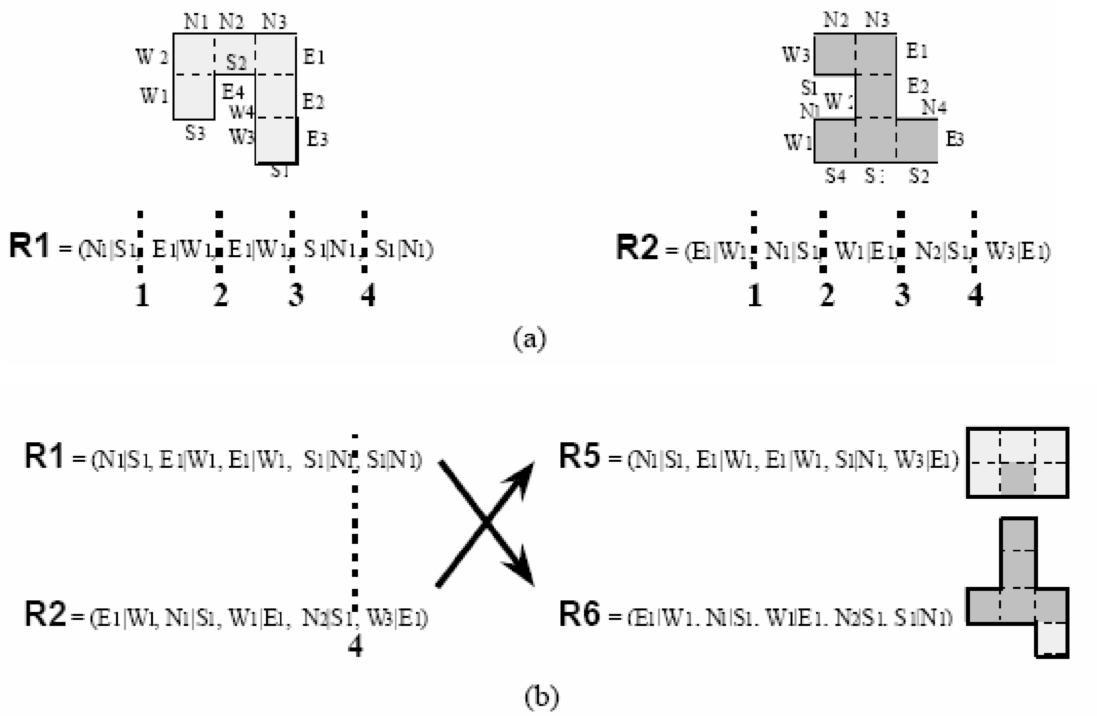

Fig 4.3. Crossover at Room Level; (a) initial rooms R1 and R2 generated from unit square cell U1, (b) crossover at site 4

Rosenman, M.A. “The Generation of Form Using an Evolutionary Approach.” Faculty of Architecture, Design & Planning , The University of Sydney, http://people.arch.usyd.edu.au/~mike/GenForm.html
Last access date 10 May 2008.

[150] Rosenman, M.A. “The Generation of Form Using an Evolutionary Approach.” Faculty of Architecture, Design & Planning , The University of Sydney, http://people.arch.usyd.edu.au/~mike/GenForm.html
Last access date 10 May 2008.

Producing a large number of varieties of solutions (Fig.4.4) within an interacting structure is a very complex task. In order to overcome this difficulty, Rosenman applies evolutionary design in a hierarchic structure. By the hierarchy concept, he manages to keep the "genotypes shorter" and therefore to reduce the complexity. His system lets the designer to solve the sub-problems of a house design problem, simultaneously. He calls this condition "parallelism". Parallelism hinders the "combinatorial problems", which are seen in linear design processes, to emerge. Parallelism establishes a harmony in the system by uniting the solution processes of problems and sub-problems. [151]

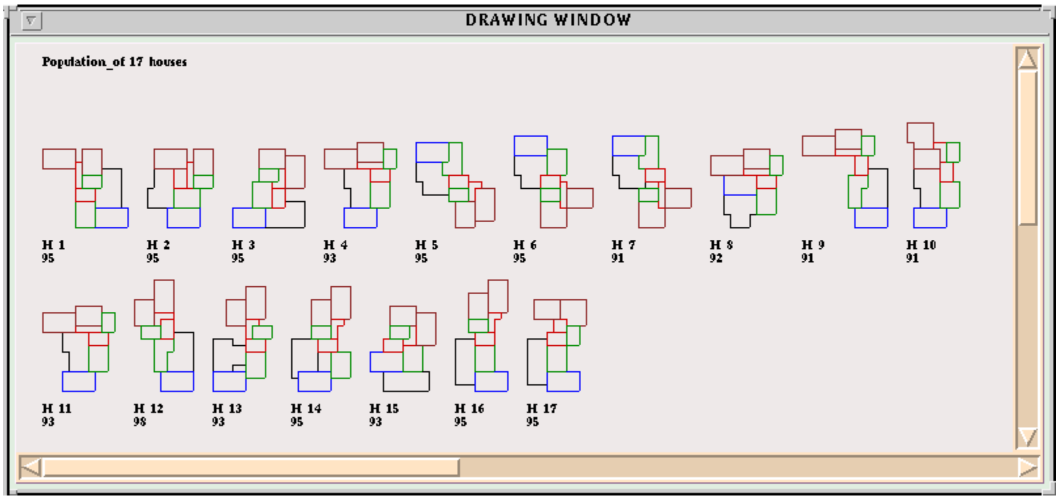

Fig. 4.4 *Final House Designs Selection*

Rosenman, M.A. "The Generation of Form Using an Evolutionary Approach." Faculty of Architecture, Design & Planning , The University of Sydney,
http://people.arch.usyd.edu.au/~mike/GenForm.html
Last access date 10 May 2008.

[151] Rosenman, M.A. "The Generation of Form Using an Evolutionary Approach." Faculty of Architecture, Design & Planning , The University of Sydney,
http://people.arch.usyd.edu.au/~mike/GenForm.html
Last access date 10 May 2008.

Another example in which hierarchy concept may be recognized clearly is Siza's Malagueira houses. Alvaro Siza, a contemporary Portuguese architect, designs thirty-five different plan schemes for a development of 1200 dwellings, which is still being constructed today, in Malagueira. His first house for this dwelling was built in 1978. His effort of preparing unique houses which respond to different user demands and needs is distinctive from the other mass housing proposals. On the other hand, there are many difficulties in the application of this customization of the houses according to each dweller's personal expectations from a house. First of all, it is hard for him to explain this new design approach to the other designers of the Malagueira development, then there are serious problems with finding proper representations of such a large number of design alternatives, and finally the aim of the idea is designing unique houses for each dweller, but the insufficient tools only enable to generate different house alternatives for the users. [152] On the other hand, Jose Pinto Duarte, notices the generative potential of Siza's proposal of customization of houses and decides to make possible the application of the proposal. He proposes the systemization of Siza's design approach by using shape grammars. He expresses that shape grammars are efficient tools for the technical incapacity of Siza's design method for customization of the houses. He develops a computer program which "encodes" Siza's design rules. [153]

Duarte's process also includes a complexity organized through hierarchy. The generation of spatial relations starts from a basic unit, a rectangle and then the house plan schemes gain complexity with the application of rules. Duarte develops rules for "enlarging the space of design solutions" which is composed of the design alternatives of Siza. He sets rules in order to run the process in the

[152] Duarte, Jose P. "Towards the mass customization of housing: the grammar of Siza's Houses at Malagueira" In Environment and Planning B, v. 32. 2005.

[153] Ibid.

sequence of defining the first floor”, “defining the second floor” and finally “defining the terrace”. These events happen in an interrelation. Rectangle is used as the initial shape of the Malagueira grammar and the rules for generating new solutions depends on the actions of “dissecting”, “connecting”, and “extending” the rectangles. There are also rules developed for “assigning and changing the functions associated with them”.[154] Some selective rules are shown in Fig.4.5.

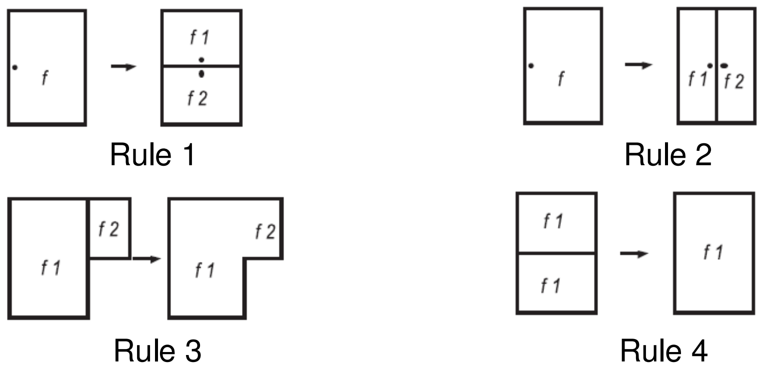

Fig. 4.5 Four of the grammar rules

Duarte, Jose P. “Towards the mass customization of housing: the grammar of Siza’s Houses at Malagueira” In *Environment and Planning B,* v. 32. 2005, p. 356.

By using such rules given above, the process is progressed in a hierarchic organization. Firstly, the “lot”, the initial shape, is divided into four “functional zones”: “patio, living, service and sleeping.” Before dividing the zones into rooms, a staircase is added. Fig.4.6 shows an exemplary hierarchic tree diagram which involves a partial generation of the house plans in the whole process. The dark shaded areas in the plans correspond to the staircases.[155]

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[154] Duarte, Jose P. “Towards the mass customization of housing: the grammar of Siza’s Houses at Malagueira” In Environment and Planning B, v. 32. 2005.

[155] Ibid.

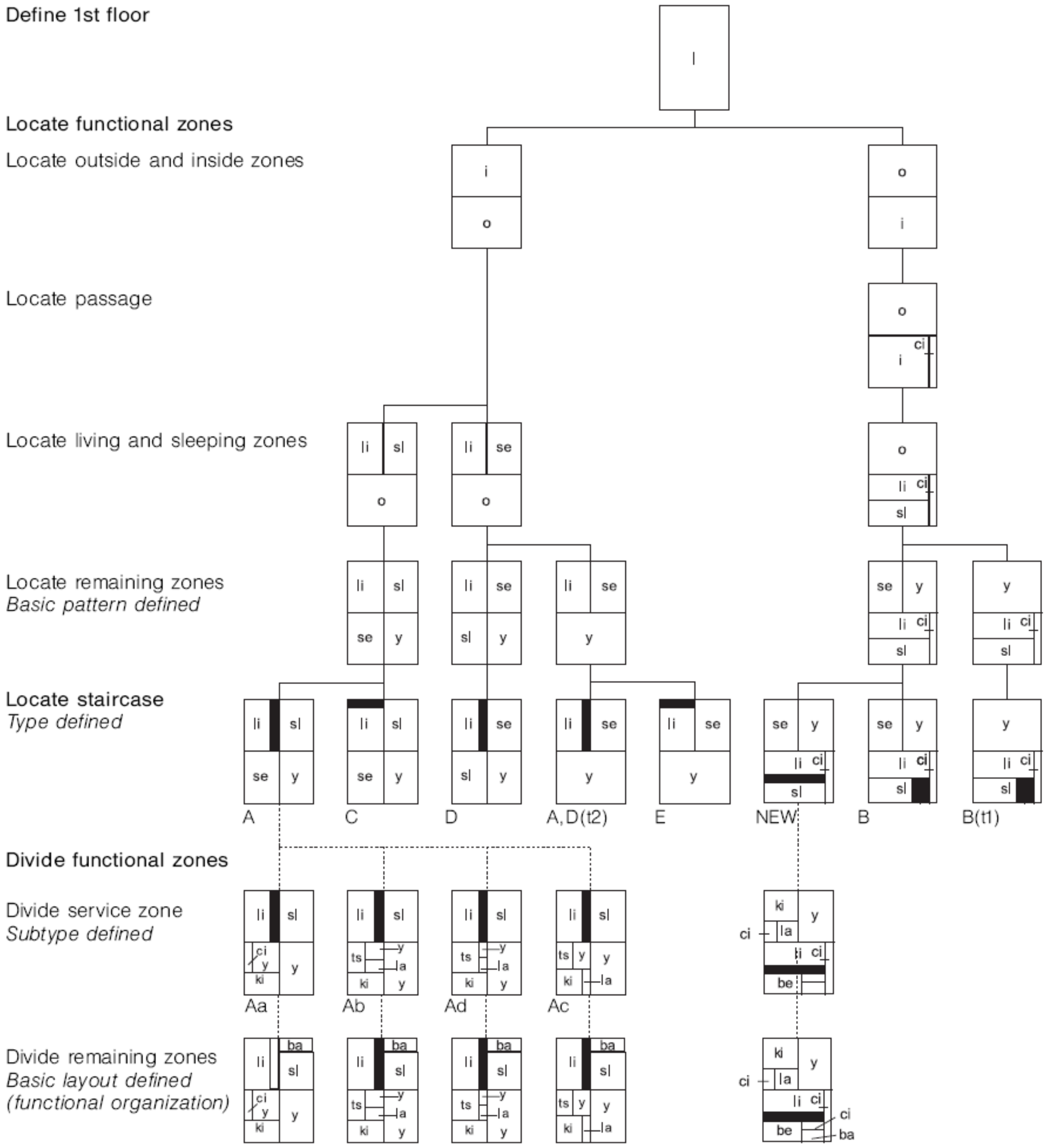

Fig.4.6 Tree diagram involving a partial generation of the house plans

Duarte, Jose P. "Towards the mass customization of housing: the grammar of Siza's Houses at Malagueira" In *Environment and Planning B,* v. 32. 2005, p. 356.

From the examples, it is possible to conceive a dynamic concept of hierarchy in recent generative design methods. The systems are composed of interrelated subsystems. The changing parameters loaded to the systems through the rules, gives the process a flexibility which can be adaptable to new conditions such as an unexpected demand of a user, or an unexpected formal expectation of designer. Each subsystem is related to another. Therefore a changing parameter in one effects the others.

4.1.2 Feedback loops in generative design

Simon states that feedback flow makes a design system adaptable to real world conditions. The changes at the environment directly effect the system, and the system acts responding to the new conditions.[156] Mathematics professor, Nikos Salingaros, expresses that this adaptability aspect makes a design process to gain a dynamic structure such as a living organism.[157] Salingaros claims that feedback flow supports the process to have an organized complexity and to obtain a coherency within the process and adds:

> Feedback is a two way influence occurring in two distinct contexts: 1) among system components of the same size and 2) among different levels of the system. Units or mechanisms act in parallel on any level, and their output is available to each other, and to the higher levels.[158]

Achim Menges emphasizes the feedback concept in his project Pneumatic Strawberry Bar. Achim Menges, an architect and one of the partners of the design office Ocean North, designs the Pneumatic Strawberry Bar for the Architectural Association's annual end of year party. In the design process of the

[156] Simon, Herbert Alexander. The Sciences of the Artificial. Cambridge: M.I.T. Press. 1969, p. 149

[157] Salingaros, Nikos. "Design methods, emergence, and collective intelligence." http://www.katarxis3.com/Salingaros-Collective_Intelligence.htm
Last access date 12 May 2008.

[158] Ibid.

Pneumatic Strawberry Bar, Menges firstly defines a three dimensional form which is obtained by "inflating" a very simple structure emanated from the combination of two "trapeziform surfaces". Menges uses this 3D object for running into the evolutionary process. Three surfaces of the object evolve simultaneously. Feedback loop, knowledge transfer, is supplied between the evolving surfaces, the environmental constraints and individual response. Menges claims that this feedback loop removes the sharp boundaries between the evolving structure and its environment. Another feedback loop, therefore interrelation, between the evolving structure and a "membrane engineering software", and an "additional physical test-modelling" is also established in order to support the form finding activity for the Strawberry Bar. [159]

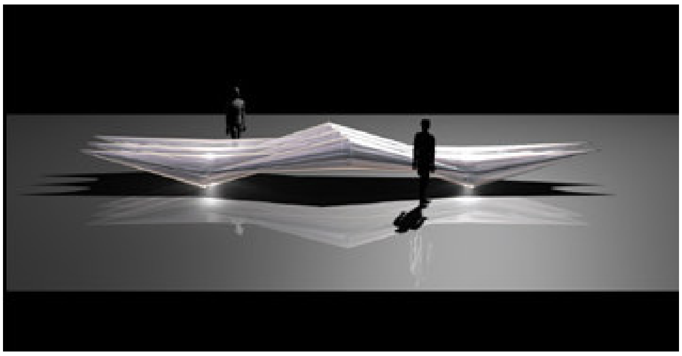

Fig.4.7 A perspective of the Pneumatic Strawberry Bar
Achim Menges, Online Portfolio, http://www.achimmenges.net/
Last access date 05 May 2008.

There is another new way of utilizing feedback loops in architectural design: combining designing and manufacturing steps in one. In order to develop this new circumstance in architecture, designers such as Haresh Lalvani continue

[159] Hemberg, Martin. "Exploring generative growth and evolutionary computation in architectural design."
http://projects.csail.mit.edu/emergentDesign/genr8/hemberg_chap.pdf
Last access date 05 May 2008.

searching new systems. Haresh Lalvani is an architect who makes "experiments with the relationship between a genetic code and the manufacturing process" and works for combining "architecture and higher mathematics to create a new architectural vocabulary of surfaces, especially in metal".[160]

Lalvani continues his investigations with a metal-fabrication company Milgo/Bufkin. He works on developing algorithms in order to develop metal surfaces that are not deformed when they are curved and that also have low costs (Fig. 4.8, 4.9). Lalvani's algorithm, Milgo experiment, enables to bend the sheet metal in a more economic and accurate way with the use of digital instruments such as laser cutting, water-jet cutting, press braking and digital punching. [161] Lalvani claims that Milgo experiment "integrates shaping (morphology) and making (fabrication) into a seamless whole" with a feedback flow which is supplied by a software enables knowledge transfers between the two. He gets the inspiration for the algorithms of the experiment from nature and focuses on genomic architecture. The roots of his studies on genomic architecture depend on the Morphological Genome. [162] The process of the Morphological Genome follows a series of algorithmic steps as Lalvani explains,

> At the first level is the genomic concept, a meta-algorithm, which defines a family of interrelated, intertransforming shapes tied to a fabrication process. At the second level is a computational algorithm of developable surfaces, surfaces

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[160] Milgo/Bufkin, AlgoRhythm Technologies Home Page
http://www.milgo-bufkin.com/algorhythms/Haresh_Lalvani.html
Last access date 06 May 2008.

[161] Lobell, John. "The Milgo Experiment: An Interview with Haresh Lalvani" in AD vol.76, no.4. pp.46-52

[162] Ibid.

that can be formed from flat sheets by bending without deforming.[163]

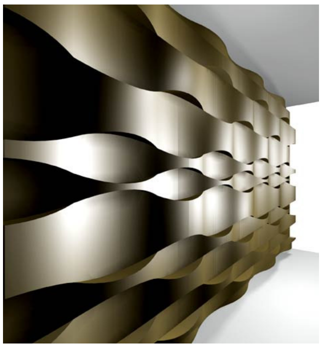

Fig.4.8 Nested Undulation Wall System

Milgo/Bufkin, AlgoRhythm Technologies Home Page
http://www.milgo-bufkin.com/algorhythms/Haresh_Lalvani.html
Last access date 06 May 2008.

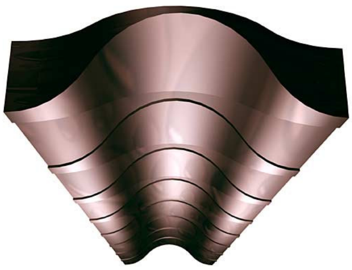

Fig.4.9 Vaulted Wave Ceiling System

Milgo/Bufkin, AlgoRhythm Technologies Home Page
http://www.milgo-bufkin.com/algorhythms/Haresh_Lalvani.html
Last access date 06 May 2008.

Feedback loops deliver coherence within the design process. The knowledge transfers between the subsystems establish interrelations in the system.

[163] Lobell, John. "The Milgo Experiment: An Interview with Haresh Lalvani" in AD vol.76, no.4. pp.46-52

Therefore, the parts of the system do not produce their solutions independently. The solutions emerge in a coherent way. Furthermore, the studies on inventing such systems that combine designing and constructing steps in one single system by knowledge transfers continue, as it is seen in the examples. Therefore, the relations between the designing and constructing systems are also systemized. This systemization prevents the loss of knowledge between the two procedures. In the proposals Design Methods Movement feedback loops were also supplied in order to establish relations between the subsystems of larger systems. On the other hand, knowledge transfers, namely feedback loops, happened between the steps of the process in a linear order. The linearity of the systems avoided the design processes from being adaptable to the real world design problems.

4.2 Selection in generative design

In natural evolution, reproduction happens through natural selection. Reproduction increases the variety in a population. New members of the populations have many features of their parents by inheritance. Besides, because of the variety, encountering new features in a population is possible. Among the variations, the members who fit their environment in a proper way will survive and contribute to reproduction. Therefore, each generation is supposed to be better qualified than the preceding. The artificial design systems mimic this process for creating design solutions. The selection in a process is done according to the fitness values of the variants. The process is progressed for obtaining better solutions at each time, and finally selecting the best one. [164] The following projects are chosen in order to exemplify the selection processes and selecting criteria of current generative design methods.

[164] Janssen, Patrick, John Frazer, Tang Ming – Xi. "Evolutionary Design Systems and Generative Design Process." In Applied Intelligence. V. 16. 2002. pp. 119-128.

The Hylomorphic Project is one of the participant projects by designers of Open Source Architecture (OSA) and the structural engineer Prof. Kristina Shea of the exhibition called “The Gen[H]ome Project: Genetics and Domesticity” which was opened in the MAK Center for Art and Architecture in Los Angeles on March 2006. The aim of the exhibition is to observe the innovative approaches to integrating genetics and architectural design. These approaches are exemplified by genetic modifications of the Schindler House’s structure, interiors and grounds.[165]

The creators of the Hylomorphic Project claim that computation in architectural design process should be more than a tool which is only used for representing the final product. They propose a computational form finding method, in which genetic algorithms are used, in order to design a canopy for the main courtyard of the Schindler’s House.[166]

Kristina Shea’s generative design tool which contains genetic algorithms, “EifForm”, is used for form generation and form selection. Shea claims that EifForm is an:

> optimization software that is based on a cost efficiency model analyzed through an iterative process. Once a base condition is established, the software runs multiple iterations and then analyzes them to determine a best scenario. The initial design of the canopy, based on the structural

[165] Open Source Architecture “The Hylomorphic Project” in The GenHome Project, MAK Center, Los Angeles, 2006
http://music.calarts.edu/~cchaplin/movies/hylo.pdf
Last Access date 09 May 2008.

[166] Ibid.

parameters of the existing house, will be computed in EifForm and an optimized solution will be determined. [167]

Fig.4.10 shows a partial selection of the generations produced by EifForm and Fig.4.11 and Fig.4.12 show the final selection.

As it is seen in the example, in the problem space of a generative design system, the rules are set in order to transform, generate and select solutions. Therefore, the products in the solution space may be integrated into the system again and again as an input. This continues until the designer thinks the solutions start getting closer to the the best one. Soddu states that In a generative design model, the designer has the chance of grouping, eliminating and selecting the solutions in the variations. Thus, the designer has the chance of selecting the best solutions between the others instead of focusing on one solution during the process and directing the process in a linear way to get that solution.[168]

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[167] Open Source Architecture "The Hylomorphic Project" in The GenHome Project, MAK Center, Los Angeles, 2006
http://music.calarts.edu/~cchaplin/movies/hylo.pdf
Last Access date 09 May 2008.

168 Soddu, Celestino. "Generative Design. A swimmer in a natural sea frame" In GA2006 Papers, pp. 2-4.
www.generativeart.com/
Last access date in 18 February 2008

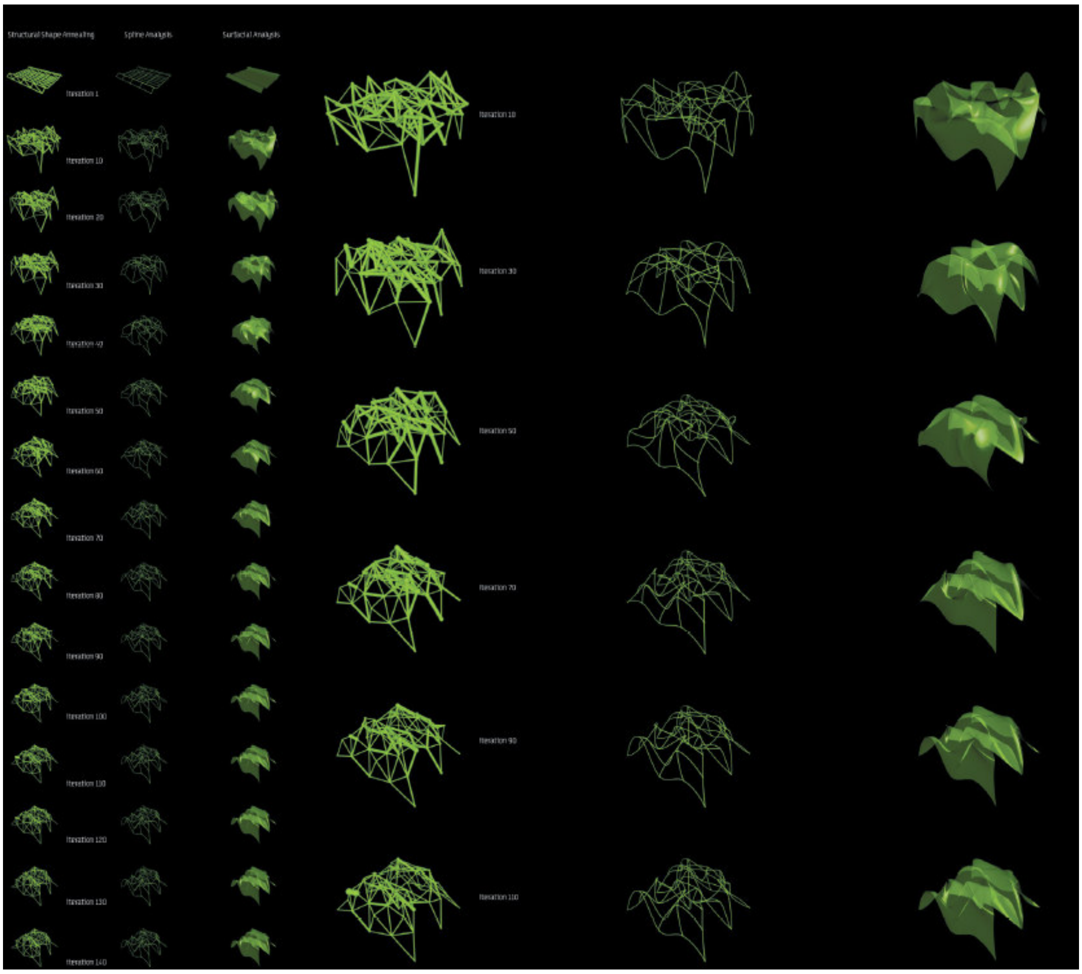

Fig.4.10 View of EifForm iterations

Open Source Architecture "The Hylomorphic Project" in The GenHome Project, MAK Center, Los Angeles, 2006
http://music.calarts.edu/~cchaplin/movies/hylo.pdf
Last Access date 09 May 2008.

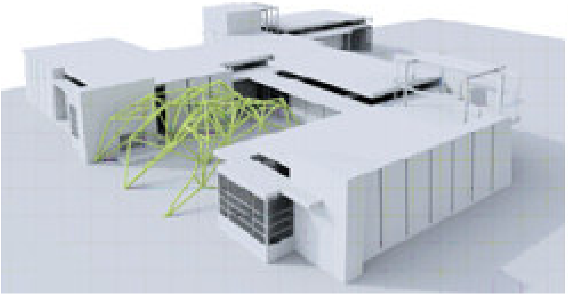 

Fig.4.11 (On the left) Aerial Perspective of the final product of the Hylomorphic Project

Open Source Architecture "The Hylomorphic Project" in The GenHome Project, MAK Center, Los Angeles, 2006
http://music.calarts.edu/~cchaplin/movies/hylo.pdf
Last Access date 09 May 2008.

Fig.4.12 (On the right) The canopy structure

Cambridge Engineering Design Centre,
http://www-edc.eng.cam.ac.uk/~Hylomorph_018.jpg
Last Access date 09 May 2008.

CHAPTER 5

CONCLUSION: REVIVING METHODS IN DESIGN

This thesis explored the impacts of Design Methods Movement in the changing architectural design thinking in terms of regarding design as a systematic study. Considering design as a problem solving activity and developing systematic problem solving methods in order to reach the goal of a design task started a new era in architecture. Designers within the movement focused on the design process instead of the product. This paradigm shift in design is one of the focal points of design research. Although the Design Methods Movement has failed in developing realistic design solutions, it has fulfilled a very indispensable role in design history by rationalizing decision making processes in design. It has quantified design process and initiated computational applications in architecture. Today computational approaches still keep the organizational principles of the Design Methods Movement, even though they have very different process structures. The thesis evaluated contemporary computational design methods as the approaches practicing concepts which are inherited from the design proposals in the 1960s. By exploring the existence of the features of computational problem solving from the 1960s in recent generative design approaches, the thesis drew attention to the interrelation between two perspectives.

The thesis inquired the presumption that generative design systems are contemporary interpretations of the Design Methods Movement approaches. Generative design methods reinterpret the problem solving activity through hierarchic compositions of knowledge arranged by adding a flexibility feature which makes the system to gain a dynamic structure. In generative design, in order to operate on the knowledge, a system, similar to the problem solving models of the 1960s, is developed. Within the limits of the rules and formulations of the system, decisions are made and design process is progressed. The significant issue about the generative techniques in design is that the system is not cut off from the real world during the process and each decision is made in an interaction between the system and the real world conditions in a simulated environment. In other words the process is applied in a tight feedback flow which is established between the inner and outer environments and also problem and solution spaces of the system.

In Design Methods Movement, regarding design as a problem solving method avoided design from being a pure artistic event limited by designer's creative capacity. In order to develop rational problem solving methods, designers gave account to problem solving proposals of other disciplines such as economics, linguistics, engineering and genetics. Therefore design literature has fed on expressions of these disciplines since 1960s. Today, architects mostly focus on the collaboration of disciplines in order to develop new design systems or to improve current systems. Thus, in most of the scholar studies it is possible to see that architecture is examined through other disciplines' perspectives as well. This study also made use of some scholarly thoughts come from scientists but not architects.

Design Methods Movement has been a target of scholarly critiques. These critiques mostly proposed to leave the deterministic approaches of the movement and to transform design understanding into a more elastic body. This thesis also has some concluding remarks on this issue. Firstly, Design Methods Movement has considered problem solving as a static process. The rigid structure of design methods avoids design process to be adaptable to any new situation that may exist during the design process. However, design has a very dynamic structure which may react to the changing situations of inner and outer spaces of the problem solving process and this gives design a very creative potential. Therefore, thesis remarks that proposals of Design Methods Movement is updated for obtaining a more elastic and dynamic structure through current practices. This enables design process to be adaptable to the continuously changing parameters of the inner and outer environments. The thesis assumed generative design methods as the systems that are keeping the idea of computing of the knowledge within a system that contains rules and new formulations. The rules and formulations of generative design methods avoid designers from limiting the product with designer's imagination. Additionally these rules and formulations succeed to release from the linearity of the early proposals and to gain a more elastic structure in order to be adaptable to the complexity of the real world design problems. Moving away from the linearity, containing the possibility of emergence of changes at the direction of the process at any moment, hinders the designer to focus on only one solution. This changing structure of the process, brings unpredictability of the product, in other words brings novelty and creativity to the process.

Secondly, scholars of Design Methods Movement have rationalized design process into a pure information processing activity. When "architectural design" is in question, the process may be more than a pure act of "data" collecting and transforming it into information. During an architectural design process, the produced output is integrated into the process again and again as input. Therefore it is reinterpreted again and again. The process transforms input from raw information into knowledge. However, there are reservations about reducing the architectural design process to a quantitative operation. With this kind of a pure quantitative approach, designers may miss the point that architecture is for human beings. Design has a creative aspect which comes from cognitive problem solving process of designer's mind involves unknown working principles and immediately changing decisions. This thesis is based on the understanding of knowledge as an inclusive concept that comprises experience and interpretation as well as data and information. Designers may guide the process by interpreting the output according to their previous experiences and also previous user experiences for similar problems and these interpretations may be taken into the process again as input. Designer and process have a relationship which depends on the interpretation of the designer. On the other hand, externalizing the intuitive creativity from the design process, and ignoring the expert knowledge of the designer, may cause the product to be insufficient for the functional, aesthetical or other concerned expectations of the user when it is experienced. New design approaches aim to keep intuitive aspect of the designer within the process simultaneously with systemization by rules and algorithms.

This thesis has been concerned with the idea that the design process requires to compute knowledge in a systematic way. Opinions of designers on how to compute knowledge in a design process change and evolve according to the technological and philosophical trends. Therefore, fixing design understanding of different eras of architecture into one point of view is a tough task. However, the thesis has claimed that different eras of architectural design may be interconnected in some fundamental principles and systemizing design is one of them. Common factors that make design systematic exist in different design approaches of different design eras. Specifically, the Design Methods Movement has been influential in the history of contemporary computational design and could be further studied for integrating recent methods with its characteristics for developing new systematic approaches.

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