Studies on Architecture Design Procedure
A Framework for Parametric Design Thinking

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ABSTRACT

Parametricism is a term for a new call epochal global style of architecture and covers all the design disciplines and also becomes an important benchmark in architecture design as well. The term recently, has developed a global movement that becomes mature in the body of technology and contemporary issues on architecture and urbanism. Parametric design, in recent years has become a motto as its being used mainly to design structures that respond to their environment, climatic issues and contextual features while, it can operate as a powerful tool in contribution to the realm of the design process in architecture design however, it is only appreciated as physical applied parametric modeling techniques.

This research tries to explore in existing design processes and design thinking in order to settle a framework for parametric design procedure by means of implementing computerized tools, methodologies and enablers in the skeleton of design and achieve an integrated approach in architecture design milieu. The developed framework could be alternative method where parametric design will be used as a tool in answering multilingual characteristics of design process and design thinking. The methodology of the research is clustered with theory of pattern language as exterior layer where the assistive tools create pattern layers in order to break complex problems into manageable ones. Moreover, a survey is conducted as inner layer of methodology in order to extract the ongoing procedure of design among designers and architects and measure their awareness about existing methodologies and tools. The final outcome will be a systematic framework for parametric design thinking, in order to improve contemporary discourse of architecture by means of bringing existing tools and enablers in the body of design procedure in architecture design and education. The study mainly brings together the knowledge management as tools, the design processes as frameworks and decision making as design activities. The developed model could be possibility implemented and examined by designers and architects as well as architecture educators and institutions. It is tried to develop a common ground that has the possibility and flexibility of adopting itself with contemporary technologies and tools in different sub-systems of design as methodologies to deal with complex problem solving procedures of contemporary architecture.

Keywords: Parametric Design, Design Process, Design Thinking, Pattern Language

ÖZ

Parametrik mimari, tüm tasarım disiplinlerini kapsayan ve son zamanlarda mimari tasarım açısından önemli bir yaklaşım haline gelmiştir. Venedik Bienali(2008), ile birlikte, terim, teknoloji, mimarlık ve şehircilik gibi çağdaş konuları içinde barındırabilen bir olgu olarak küresel bir açılım gerçekleşmiştir. Yaklaşım, farklı gelişim ölçeğinde birçok tasarım uygulamalarında kullanılan ve aynı zamanda tasarım sürecinde de önemli bir yere sahip olmuştur.

Son yıllarda parametrik tasarım , yapısal bir olgu olarak, farklı tasarım sorunları ve bağlamsal özelliklerinin ele alınması açısından ağırlıklı olarak kullanılan bir slogan haline gelmiştir . Parametrik yaklaşım, tasarım süreci açısından farklı dinamiklerin birarada değerlendirilip yorumlanabileceği güçlü bir araç olarak çalışabilecek potansiyele sahiptir. Oysa, işleyiş olarak, sadece fiziksel uygulanan parametrik modelleme teknikleri olarak takdir edilmektedir . Parametrik yaklaşımın, mimari ve kentsel tasarım alanlarınd uygulamaları iki ayrı şekilde kullanılmaktadır. Bir yandan, " sosyal ve / veya ekolojik parametrelerin çözümlendiği metrik tabanlı teknik bir yaklaşım " olarak kullanılırken, aynı parametrik tasarım araçları , "form oluşturmak " için kullanılmaktadır. Yaklaşım, iki şekilde de farklı sıkıntılar yaratmakta, estetik kaygı açısından form oluşturma çabası olarak ele alınırken, diğer tasarım kriterleri, oluşturulan karmaşık formlar yoluyla gölgelenmektedir.

Bu araştırma, parametric yaklaşımın tasarım sürecinin bir parçası olarak ele alındığı ve bu bağlamda ilgili niteliklerin sağlanması açısından tasarm parametrelerinin ortaya konulacağı bir model geliştirmeyi amaçlamaktadır. Çalışmada, parametrik tasarım, tasarım süreci ve tasarım düşünme dilinin gereğinin yerine getirilebilmesi açısından ele alınacak, çeşitli tasarım ölçeklerinde ve sorunlarında entegre bir çözüm geliştirebilem için alternatif bir yöntem geliştirilecektir. Bu yöntemin ana odağı olarak tasarım yaklaşımının belli bir bütünlük içerisinde ele alınıp, kurgulanabileceği; Christopher Alexander "desen dili" çalışmasında geliştirdiği yönteme dayalı olacaktır. Ayrıca, bu çalışmanın temel amacı, tasarım sürecinin kompleks yapısını systematize eden, kolaylaştırıcı ve uygulanabilir bir çağdaş söylem geliştirmek için parametrik tasarım düşünme modelini önermektir.

Anahtar Kelimeler: Parametrik Tasarım, Tasarım Süreci Tasarım Düşünme, Desen Dil

To My Family

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When I am working on a problem I never think about beauty. I only think about the system how to solve the problem. But when I have finished, if the solution is not beautiful, I know it is wrong.

R. Buckminster Fuller

Engineer, Designer, Architect (1895-1983)

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Chapter 1

INTRODUCTION

Architecture and design are the terms that tied to each other since the beginning of design institution and practice and the main skill of an architect is to deal with existing problems in different scale by means of understanding skeleton of design. From the beginning on, design has followed certain procedures and process and tried to shape itself in the form of prevailing achievements in different eras. Also design was in the role of a platform which meant to set, prioritize and interpret different restrictions, constraints, and bounds. Since the out birth of term "design" there were different theories and procedures which aimed to bring these restrictions together and propose a solution based on physical or theoretical issues. So it was necessary to have a kind of process to deal with the amount of restrictions in each design problem. Moreover, architectural design could be possibly fit into the authentic tool rather than the standardized ones. Authentic tools mainly do not emphasis on the actual knowledge as end itself. However, it focuses on the capability to use appropriate knowledge, skills, and procedure for solving design problems (Utaberta et al., 2013). This perspective on design process could possibly transform the semantic and outcome of design from "end product" into "process product". This ability should be enhanced with maximum potential in order to reach "good design". Also, the architecture design has to emphasis on the process rather than the end product. If we consider the outcome of design process a form, which is the abstract of all influential constraints, then the characteristic of design and its process should be defined accordingly to have capability to transform all physical and non-physical parameters -not necessarily numeric or quantitative ones- into the body of final proposal. As the existing context of design is getting mature, the quantities of effective parameters are also increasing. So it questions the capability and efficiency of existing design procedures and processes in the field of architecture.

By the advent of computational problem solving methods and their application in different majors of science and architecture, algorithmic modeling challenges designers to logically confront what they do not know about the complexity of a design problem. As parametric design becomes more prevalent, there is a propensity to create complexity (Chronis et al., 2012). On the other hand, the wide spread use of parametric modeling, as a tool to capture design intent by architects and designers has led to theorizing parameterization in architecture. Also, there is a need for architectural designers to alter their mode of thinking to engage in parametric design and be able to implement diverse tools, methodologies and enablers within design procedure.

1.1 Definition of Problem

Design processes in different periods have had variety of definitions and clarifications. It should be mentioned that design process was not influenced by stylistic approaches but it has gained a lot from technological and theoretical alterations. More recently, parametric design as a novel attitude toward architecture which is shaped in the body of technological movements, started to bring itself in practice. Actually as its getting mature, it faces some failures but it has more to do in the future. In other words, recently parametrics has become a slogan as its being used to design structures and buildings that respond to their environment and other site conditions and constraints. While parametrics can be a powerful tool, we rarely see it leave the realm of the design process and venture into the physical applied parametric modeling techniques (Malmstrom, 2011). As the living world becomes more and more complex by the time goes on, the question comes up that how to take the complexities of a design in different parameters and reduce it down to a physical prototype? This is where a shift in thinking and design process is necessary (Collins, 2013; Howe, 2011).

Through literature review, it illustrates that variety of researches have been done in form finding process in order to generate parametric shapes, but less emphasize can be seen on contextual, functional and user perception of this process (Hudson, 2008; Kourkoutas, 2007; Lee, 2012; Oxman, 2006, 2008; Rodgers, 2013; Turrin et al., 2011; Yue, 2009). Also the lack of any systematic design procedure based on theory of parametric design by implementing computational tools could be possibly a questionable context and the necessity of considering other parameters in whole design procedure is on top and undeniable.

Parametric design process in general, is a kind of interaction between the parameters which are going to shape the solution for the problem, and the effect of solution on the parameters (Schodek, 2005). This kind of collaboration shapes the mature architecture based on formal, contextual, environmental, and economical and cultural constraints. In this procedure the form-making approach seems to cover a lack of genuine and conscious and competency through complexity generated from data. In other words, it’s too often that the process of producing forms by inputting and manipulating information and data does not need that the designer or architect develop an inclusive design strategy; and the procedure itself can end to a kind of easy complexity that covers the absence of any systematic approach (Scheurer & Stehling, 2011).

1.2 Aim and Objectives

On the bases of literature review in parametric and algorithmic design, there was no obvious realm of proposed design process based on parametric thinking and computational problem solving tools and methods. The traditional design processes seems to be not practical enough in computational design thinking and the necessity of propositioning new method for design thinking is notable. In design thinking field, there are varieties of design processes with major and minor steps from the brain storming to fabrication. The main aim of this study is to criticize existing design process and discuss its transformation into design thinking, in order to create an applicable design procedure for parametric design and also investigate on the existing methods and approaches by means of bringing effective parameters and enablers into the skeleton of parametric design procedure as systematic framework.

1.3 Methodology

The study is constructed as a combination of qualitative and quantitative research with in-depth literature review in the context to generate the parametric design procedure framework with the consideration of pros and cons of existing models and restrictions. The proposed model is the outcome of gathering standing design process models, and criticizing them in order to extract an applicable model for parametric and digital architecture design. In order to respond to the existing gap, which is the absence of qualitative parameters and applicable methods and tools in the body of design process, this research tries to bring them in the design procedure by means of surveying on the existing trials and abstract them by pattern language theory as methodology, into parametric design procedure patterns and position them in the holistic parametric design thinking procedure.

In this research pattern language is implemented as a methodology which Christopher Alexander (1977) and his team used to deal with the problem by means of gathering the existing solutions with the same commonalities from the standing context and regenerate the patterns which can provide a logical answer to the query. The interior skeleton of pattern language in Alexander`s theory consisted of three key parts: first, an issue oriented discussion of the central conflicting aspect of an existing problem (design process and design thinking); second, an examination of the existing evidence and noticeable facts (survey on the existing tools); and finally after synthesizing the examples, type prescriptive recommendation (parametric thinking model). The recommended action took the form of an essential conceptual diagram to help guide contemporary adaptation. Then the illustrated patterns need a system in order to have hierarchical intersection and interrelation, this system is called "Parametric Design Thinking".

Nikos A. Salingaros (1999), a University of Texas mathematician And Pattern Language admirer, in his article "Architecture, Patterns, and Mathematics" summarized his understanding of The pattern concept and methodology from "The Timeless Way of Building" as:

1. A solution that covers the same or similar array of problems and exposed by diverse researchers and users at altered times, in this research will be survey on existing design process models.

2. A kind of universal solution or answer across individual contemporary applications, rather than being reliant on special conditions, which means more systematic approach.
3. An approach to divide complex problem into small and manageable factors. The pattern methodology is to separate parameters of complex procedure so as to be possible to solve each one of them independently. The questionnaire survey implemented to manage and conduct factors of the design procedure.
4. Exposed or extracted by scrutinizing the successful practices already in use, but which are not consciously treated as a pattern. A successful pattern must be general solution to the problem. The successful practices are extracted as enablers and tools that can enhance the system.
5. The solutions should be applicable into variety of contexts and scales so they need to be highly abstracted that makes it applicable on a more universal level, if not the outcome will be solutions that are too unambiguous, and consequently inadequate for any other conditions. A pattern needs to have an essential range of vagueness in order to be guaranteed as universal solution. So it’s the reason that design procedure in considered as a system or pattern not as a process in order to give enough degree of flexibility and adoptability to different contexts, scales and parameters.

Architecture, as a process to present the abstraction into the reality, deals with sophisticated complex parameters from the beginning of design process up to physique itself to the real world. In other words, architectural design is not a simple process of drawing lines, it needs more complex tools to decode this complexity and purify it to be presented in built environment. So, in this research the existing methods and practices toward the application of diverse parameters are going to be scrutinized from the literature as a part of complex system, and then they are being proposed as pattern layers to the different sub-systems of design process to make it practical in computational aspects. In order to achieve the practical process of design among architects and designers, a questionnaire survey is conducted in semi structured format and distributed online. The outcome of the survey is analyzed in SPSS with T-test method in order to convert qualitative stages of design into quantitative numbers and observe the defragmentation of the steps in order to be able to bridge them by means of different enabler. The detailed discussion on the survey is explored in chapter 4 entitled as survey design.

1.4 Limitations

In recent years, multiple researches have been done in parametric field and this amount is increasingly improving day by day. The parametric discourse could be surveyed in diverse perspectives and viewpoints but this thesis limits this study on the process of design and tries to question this process in contemporary era where the technology and computational tools have become undetectable part of architecture design. It is also necessary to say that the methodology of this research is limited to theory of pattern language as a common ground and assistance for design procedure.

Chapter 2

DESIGN PROCESS AND DESIGN THINKING

2.1 Introduction

In this chapter the discussion is going to be on the existing design processes and procedures according to different perceptions and categorizations, by means of measuring the degree of their applicability into parametric design. In order to question this, we had a deep review on the starting point of design process theory and deliberating upcoming ideas in hierarchal order. The discussion will start with design process theory and prevailing ideas and thoughts on it, then it will continue with design thinking which is more developed theory on design and designerly thinking.

Over recent years, scholars of design theory, researchers, and practitioners and also designers, have projected a broad display of explanations to describe the essence and principles of design activity (Achten, 2008; Clarkson & Eckert, 2005; Cross, 2011; Lawson, 2006; Moore, 1974; Snyder, 1979). Design process itself in theory, have developed over very long period of time when the human started to make some utensils for his/her daily activities, even can be claimed thousands of years ago. Design process was never separated from design education, and it doesn`t matter whether education in apprenticeship and master style or in institutionalized layout. There is a close relation between the practice of design, the body of knowledge and the methods in the process (Achten, 2008).

Nigel Cross (1984) outlines design methodology as "the study of principles, practice and procedure of design in a rather broad and general sense. Its central concern includes the study of how designers work and think; the establishments of appropriate structures for the design process; the development and application of new design methods, techniques, and procedures; and reflection on the nature and extent of design knowledge and its application to design problems".

Design discourse and design method are completely different procedures and in order to be able to describe this differentiation we need a theoretical framework based on literature review for design and either it's starting point. The documented design theory is available since Vitruvius (25 BC in the region of first Roman emperor, Augustus) which was introducing the principle base design method (Gelernter, 1995). Also Vitruvius generated his method in different gages like, town planning, construction and design education. He based his design principles on formal basis but the process itself was established on experimented approaches. This was started on the conceptions originated from digging caves and imitating the nest of birds to build out the shelters. Even these struggles were more integrated with construction parts but in general view they are whole part of design process where the master was natural creatures. They improved these first imitations and experiments by observing and adding needed elements according to their own perceptions from the living environment (Vitruvius, 1914). It's hard to call this starting point for design theory but it was like an igniter for design thinking and on the other hand a shift for design education to make it more structured.

More contemporarily, design process in traditional perspective acts as a process of manufacturing (Schodek, 2005) which means, the same process can be applicable to different projects and the outcome will be the same with minority of differences according to their sudden changes which was the outcome of mass production and Fordism society. In this kind of process the building is considered as a machine which Le Corbusier states that house is a machine for life and in this conception the process of designing for this machine is the same as manufacturing. It is the outcome of putting different pieces together to reach the design solution. But when we come to recent theories and ideas architectural design is considered as method of communication. It is an extensive journey from the initial idea of the designer or architect to the built environment, requiring tools to explain a design in ways that provide adequate and unmistakable guidelines to the constructors during life cycle of the project (Scheurer & Stehling, 2011). In order to have a holistic outlook on the past resume of architecture design and design process, we are going to review existing theories and ideas. As Clarkson (2005) indicates, "design process improvement requires an understanding of how design processes work and what influences their behavior."

2.2 Multiple Theories on Design Process

The building and architecture design process has been studied and practiced for hundreds of years but it was only for the first time formalized in the 1960s (Archer, 1968) that design was approached as process. In this field Markus (1967) and consequently Thomas Maver (1970) suggested the process of design as the decision sequence of "analysis", "synthesis", "appraisal", and "decision" at progressively detailed stages of the design process. They explained diagrams of the architectural design process detailed in decision order as shown in Figure 1. The process in the illustration is like a close loop which repeats in itself and it is too much introverted.

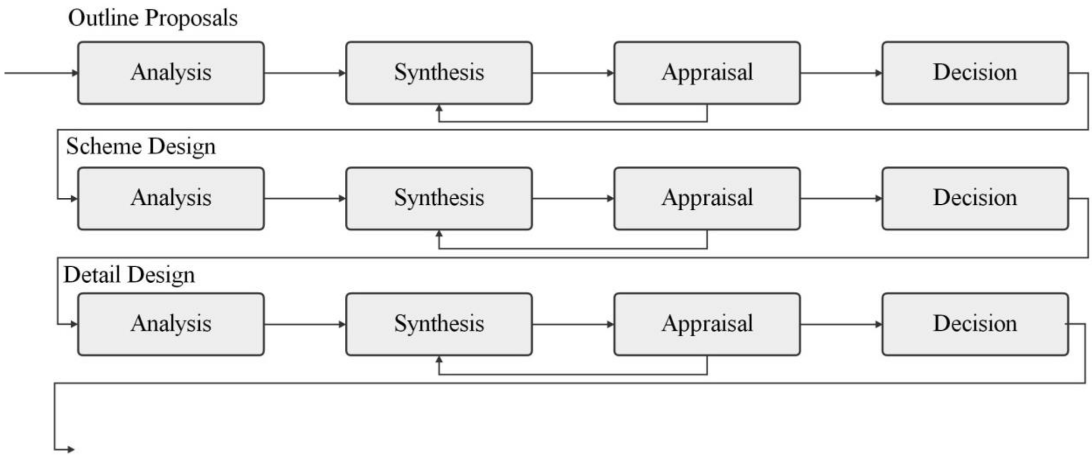

Figure 1: Markus & Maver diagram of design method (Lawson, 2006)

Another perspective on design process was sketched by John Wade (1977). He describes design as an activity to generate proposals that are going to change the existing things into something which is better. So he splits the design into 3 parts such as; initial state, method or process of transformation and imagined future statues. In Wade`s terms, design is identified by the process of converting existing elements and issue to the imagined future ones and these steps are exactly outcome of his definition and consideration about design itself (Figure 2). So he delineates the function of the designer as one who identifies problems and methods for achieving solutions and implementing those solutions. This strategy can be satisfied by programming alternative building design and implementing plans.[1]

[1] For more information refer to. “J. C. Snyder, Catanese, A. J., & MacGintry, T., "Design and the Design Process," in Introduction to Architecture, ed. Tim McGinty (McGraw-Hill, 1979)”

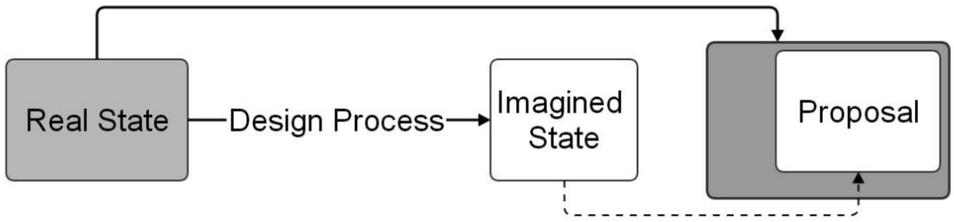

Figure 2: Design Process, Wade, J. W. (1977)

Another outlook on design process was engendered by Tim MacGintry, and he divides the process of transforming the initial state to future imaginary state in 5 steps: initiation, preparation, proposal making, evaluation and action (Snyder, 1979).

In the first step, the designer starts to recognize and define the problem with an official process, which means the understanding of the client and requirements. One of the main aspects of initiation stage is enabling the architect to cultivate imagination and aspiration. So he/she needs to spend the most time on understanding the problem beside participation of the client. Snyder (1979) states that “good client makes good building“.

The starting point for design process is a bit complicated, because it will affect the whole process and procedure. The first idea is that the designer is going to start with existing issues and transform them to the imaginary future through the specific process and the other mode which is completely in opposite direction is that the designer is going to imagine the project and through the process makes it exist in real world. In other words the first method is starting with the existing parameters in the context or real world and in the second approach the fundaments are inner intuitions of architect. In any case if these information during a certain process be transformed into an idea and this idea creates a formal proposal, then this process is only a form making procedure (Figure 3). In other words, the solutions that result from the synthesis stage of the design process are frequently lacking competency and might not reflect all the requirements, and internal conflicts. So they must be assessed reasonably in the evaluation phase (Jeong & Ban, 2011).

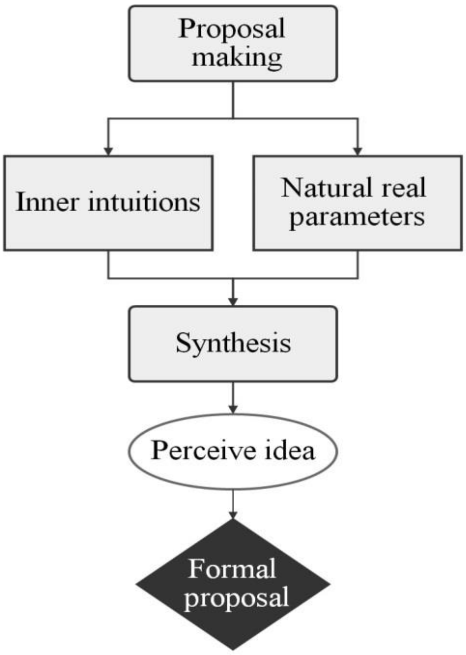

Figure 3: False procedure to create formal proposals (by author)

Second step of Snyder`s model, is defined for data gathering and preparing the collection of information including their analysis in direct relation with the problem. The act of building a system of information framework in called “programming”. The classification in programming can be affected with following steps of the process. For example the innovation of any new technology or material will affect in design process period or in site activities, so the programming of the project can be stretched up to the end of the project then, proposal making stage, that the architect or any kind of designer is asked to give ideas for the design problem and these tenders can be added and developed any time in the design process. Sometimes preconceived ideas which don’t have any relation to the existing parameters cannot answer the complexity of contemporary architecture. The obvious example is the effort of clients, architects and students when they propose the shape of the building and then try to force and fill the activities and functions into the perceived image.

The other stage and the actual procedure of making the proposal is called “synthesis” (Snyder, 1979). The action of synthesis takes place in variety of considerations such as context (social, economic, physical), the program, the site, the client, current technology, aesthetics, user perception, environmental issues and etc. The proposals are a kind of physical dimension of integration of very large number of issues and parameters and all this criteria are overlaying layer by layer to fulfill the problems and requirements of the project. In the last two steps, evaluation and action, the proposals and alternatives are assessed in different scales. This evaluation can be applied in different dimensions like: the establishment of goals and criteria for the design, the generation of potential design and solutions, and the measurement of proposed solutions and results with considering the program criteria. Finally in action stage the project is going to be finalized, the construction documents are prepared and confirmed. The steps of Snyder model for design process are illustrated in Figure 4. The map, such as it is, no longer suggests any firm route through the whole process. Bryan Lawson (2006) resembles:

> “This kind of process to one of those chaotic party games where the players dash from one room of the house to another simply in order to discover where they must go next. It is about as much help in navigating a designer through the process as a diagram showing how to walk would be to a one-year old child. Knowing that design consists of analysis, synthesis and evaluation linked in an iterative cycle will no more enable you to design”.

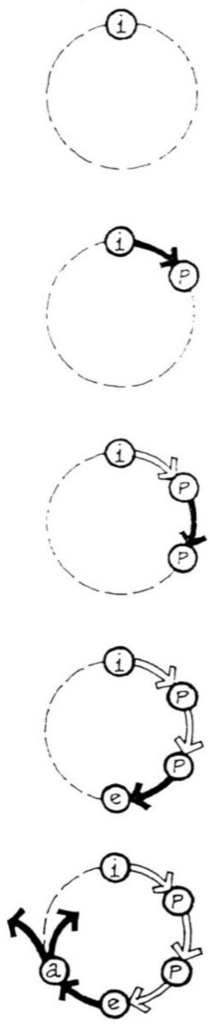

Figure 4: the five step design process initiation, preparation, proposal making, evaluation and action (Snyder, 1979)

He proposes more honest and practical illustration of relation between analysis, synthesis and evaluation is defined in Figure 5. It demonstrates that the relation between these three components is more than a linear process, which means they integrate in a systematic manner. Joan Zunde (2006) Also indicates that design is not an arbitrary activity, if it is to be practiced as a professional occupation, it is essential that a systematic approaches and methods should be applied.

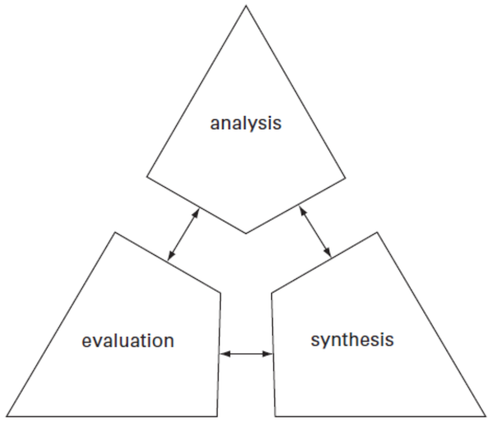

Figure 5: Practical graphical illustration of the design process (Lawson, 2006)

In order to make the steps of design close to more flexible system those different parameters can be adopted and integrated in diverse phases, the design process is proposed as “transparent multi layering system”. Further we are going to discuss about this system more (Figure 6).

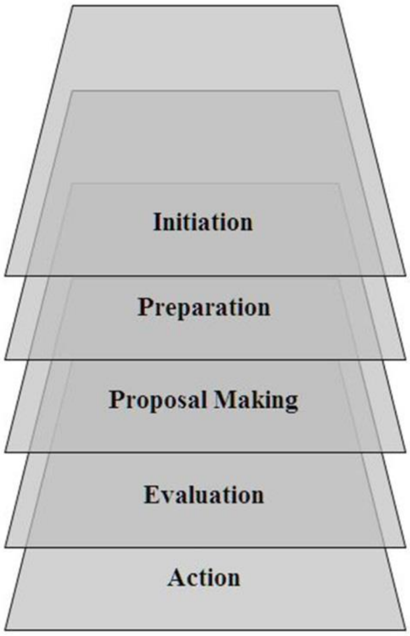

Figure 6: Transparent layering system (Applicable for all kinds of processes), Improved by author

We could continue the discussion on the exploration of the maps of design process but a considerable number have been developed. Maps of the design process similar to those previously argued for architecture have been proposed for the engineering design process (Asimow, 1962; Haik, 2010) and the industrial design process (Archer, 1968) and, even, town planning (Levin, 1966). These abstract maps from varying fields of design show a considerable degree of agreement that suggests perhaps the design process is the same in all fields. Well unfortunately most of the writers quoted here have not offered any evidence that designers or architects systematically follow their maps. These maps are likely to be both theoretical and prescriptive and at the same time inflexible. They seem like to have been emerged by thinking about design rather than experimental observations, but at the same time characteristically and structurally they are logical and systematic. Bryan Lawson (Lawson, 2006) indicates that

> "There is a danger with this approach, since writers on design methodology do not necessarily always make the best designers. It seems reasonable to suppose that our best designers are more likely to spend their time designing than writing about methodology. If this is true then it would be much more interesting to know how very good designers actually work than to know what a design methodologist thinks they should do! One compensating factor here is that most academic writers are also involved in teaching design, and thus have many years of experience of observing their students. However, that also begs the question as to whether students might design differently to the way experienced practitioners work".

In the next section the discussion is conducted with starting upon design process models in order to criticize and learn the applicable criteria through them then, in the following the discussion is being shifted on design thinking by means of exploring theoretical frameworks and discussions on both design as process thinking procedures.

2.3 Discussion on Design Process Theories

Table 1: Various Views of Design Process, analyzing and criticizing methods (Snyder, 1979) updated by author

	Design Process Theories	Design Process Defined Steps				
1	**Thornley Student Design Process (1) (1963)**	Accumulation Of Data	-	Separation Of main Concept or Method	Form Development	Presentation Of Solution
2	**Thornley Student Design Process (2) (1963)**	Program Formulation	Investigation Assessment Of Design Possibilities	Create	Refinement	Presentation
3	**Guenter and Corkill Systematic Approach of Architectural Design (1970)**	Basic Definition Preliminary Program	Investigation, Analysis Program Abstraction	Synthesis And Development Volumetric Design Proposal	Reevaluation And Modification	-
4	**H. Rittle`s Summery of Design Process (1970)**	Problem Identification	Collect & Analyze Information	Workout Solution	Solution Assessment	Implement and Communicate
5	**R. Whitaker`s Eight-step Design Process (1971)**	Recognition Definition	Preparation Analysis	Synthesis	Evaluation	Execution
6	**J. C. Jones`s Design Method (1972)**	Idea	Information Analysis	Synthesis	Evaluation	Optimization
7	**M. Asimow Engineering Design Process (1972)**	Feasibility	-	Preliminary Design	Detailed Design Planning	-
8	**RIBA Architecture Service (1972)**	Inception	Feasibility	Outline Proposals Schematic Design Detail Design	-	Production Tender Action Project Planning Completion Feedback
9	**G. T. Moore`s Design Process (1974)**	Identify Problem	Programming or Analysis Of User Requirements	Synthesis	Choosing From Alternatives	Post Occupancy Evaluation Implementation
10	**Five-step Design Process (Snyder, 1979)**	Initiation	Preparation	Proposal	Evaluation	Action
11	**Gavin Ambrose & Paul Harris (2009)**	Define and Research	Ideate	Prototype	Select and Implement	Learn
12	**AIA Basic and Supplementary Services (AIA)**	Predesign Services	-	Schematic Design	Design Development	Contract Documents Bidding Administration Of Contract Post Design Service

By searching in different design process methods in variety of time period which are collected in table 1, in different steps and stages most of them tried to separate and highlight limited phases. When we compare all different stage in the same column it's understandable that they are repeating the same language in different words which means that the root of all is a linear process. In order to criticize them systematically we can add that:

1. The methods are repeating same or equivalent steps with differing in words.
2. Most of the procedures for design are illustrated as linear process.
3. The models seem to be reasonable in preparing theoretical framework for design activity.
4. There boundaries of the stages are strict.
5. The procedures are not flexible enough.
6. There is no specification for scale of the project.
7. They are trying to dictate similarities in process in order to make it manageable.
8. These methods are behaving design as research problem solving with narrowing down in details step by step.
9. They seem to be out of control by increasing complexity and the scale of project (Oosterhuis, 2012).
10. The realm of management is undeniable on these processes rather than architectural footprint.
11. They seem to have been derived more by thinking about design than by experimentally observing it, and characteristically they are logical and systematic (Lawson, 2006).
12. In the traditional design process framework the tools are invisible and unreadable.

13. The solutions that arise from the synthesis stage of the design process, most of the time are incomplete, may not indicate all the necessities, and they must be evaluated rationally in the evaluation stage (Jeong & Ban, 2011).
14. Most of the available design tools do not include the overall design process. They rather consider only one of design stages. Moreover, most design tools for the early stages are manual ones while the Computer-Aided Design (CAD) tools could be a good enabler to enhance this process (Yezioro, 2009).

The design process, by definition, is a mental activity and we may see designers drawing while they think, but their drawings may not always reveal the whole of their thought process. In order to reach to the good design system we have to bring these two parts together and combine them, it is similar to Donald Schön`s (1983) theory about design process "reflection in action" but this reflection and action need a certain system it could not be unconscious and arbitrary activity.

More realistic image of design process and the relation between the problem and solution was illustrated by Lawson (2006). It shows the intervention between problem and solution with each seen as a reflection of the other (Figure 7). The activities of analysis, synthesis and evaluation are certainly involved in this negotiation but the map does not indicate any starting and finishing points or a certain process. In other words there is no direction of flow from one activity to another. Lawson (2006) indicates that, "this map should not be read too literally since any visually understandable diagram is probably far too much of a simplification of what is clearly a highly complex mental process."

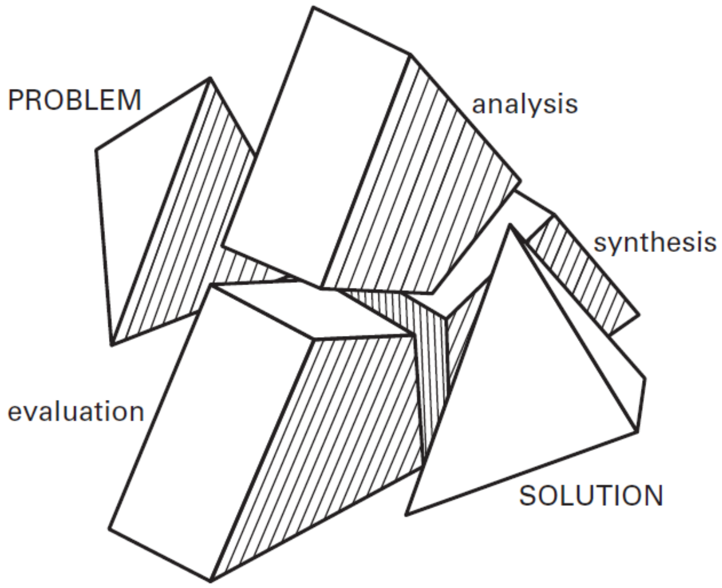

Figure 7: Design process as a cooperation between problem and solution by means of analysis, synthesis and evaluation (Lawson, 2006)

So far till here, we have focused and criticized the essence of design as a process and about the characteristic qualities of design problems and good solutions. Now it is time in this chapter to turn our attention to the thinking processes which are essential to be classified and understood the design question and design solutions by means of design thinking. Also, extracting the common qualities of design thinking which can enhance the design procedure. Because after all, designers are not philosophers and their thinking is directed towards some physical end product which must be transferred to others who may help to design it and to construct it.

2.4 Design Thinking

In the last few years, "Design Thinking" has extended to design procedure and it is now seen as an available new paradigm in order to deal with problem solving in sectors such as Business, IT, Medicine and Education (Dorst, 2011). And this movement creates opportunity to think more widely to bring this term into design research and architecture design. The term "Design Thinking" for the first time appeared in the title of book authored by Rowe (1987) but still there is no certain and agreed definition upon "design thinking". There will be a discussion on different definitions and theories of design thinking but before that there are certain discussions on design thinking itself.

First of all, the distinct discourses on design thinking is generally located in the design-based, academic literature (Johansson, 2009) but contemporarily several models for design thinking have developed based on broadly diverse ways of inspecting design conditions, problem solving approaches and using theories and models of design methodology, psychology, education, etc. At the present time, "Design Thinking" is recognized as pioneer paradigm for tackling with problems and guiding the complex and open-ended contests, in various professions, most remarkably IT (Brooks, 2010) and business (R. Martin, 2009).

Design thinking according to its context, has gained different meanings. For instance, in the managerial explanation, design thinking has been labeled as the finest way to be creative and innovate, however within design realm which is necessarily the creative problem solving approach, design thinking may be discreetly ignored (Johansson-Sköldberg, 2013).

The importance of survey on design thinking becomes more dominant when it is considered as contemporary discourse. The term “change” tied too close to our daily life and life style. In the era of change we need new alternatives and new ideas because the industrial systems of past times have finished their job, and undeniably those packages are part of the problem currently. But again we are in the midst of massive change and in these times of transformation we need new choices because our available solutions are simply becoming outdated. So why design need to be shifted toward thinking? Tim Brown intends that[2]

> “Because design thinking gives a new way of tackling with problems, instead of defaulting to our normal convergent approach, where we make the best choice out of the available alternatives, design thinking encourages us to take a divergent approach, to explore new alternatives, new solutions, new ideas that have not existed before”.

If we compare design thinking with design process it could be understood that they are totally in different direction because, design thinking tries to deal with the problems with creating choices but ordinary processes try to make choices by mean of creating different alternative for the problem (Figure 8). From the beginning, the process of design thinking was a mean to convey creativity. But as it was first conducted in order to appeal to the business culture of process, it has on case been reduced to a more linear process to remove the failure, conflict, emotions, mess and repetition that are part of the process.

[2] Tim Brown (2009) A call for "design thinking", Retrieved from TED.com

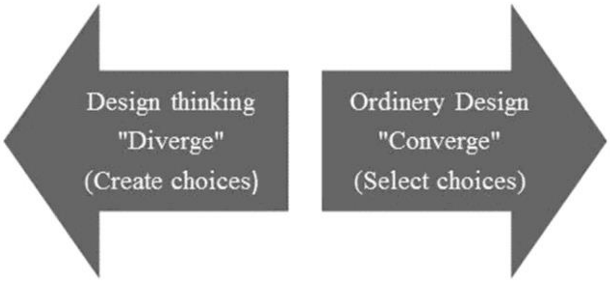

Figure 8: Design thinking vs. ordinary design process, Tim Brown (2009)

The statistical review on the existing researches on design thinking indicates that the numbers have progressively increased by year, beginning from Simon's (1969) initial work on the nature of design. In general the publications of design theorists are beginning in the 1980s, and staying more abundant round 1999, and touching a high point in 2009. Management researchers are the ones have firstly showed an interest in bridging business and design in the mid-1980s, and tracked by academics in other areas. The growth of the design thinking field is shown in Figure 9.

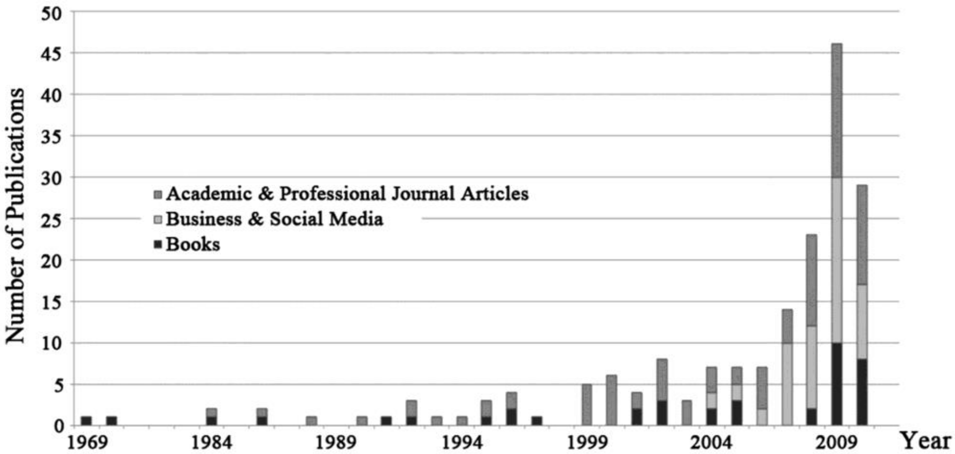

Figure 9: Time line of publications on design thinking (Collins, 2013)

Before opening the discussion on design thinking we have to make clarification between two mostly similar keyword which are; Design Thinking and Designerly Thinking: (Johansson-Sköldberg, 2013)

The first is called “Design Thinking” and it implies the discourse which design practice and its capabilities are used more than the design context together with art and architecture. Design thinking is supposed to be with and for people without an educational background in design. At that time it becomes a simplified form of “designerly thinking”.

The other discourse is named “Designerly Thinking” and discusses on the academic structure of the specialized designer’s training like practical skills and competency. Also deals with understanding and illustrating this non-verbal capability of the designers in theoretical reflections. Designerly thinking links theory and practice from a design perspective, and is consequently embedded in academic ground of design (Johansson-Sköldberg, 2013).

2.5 Theoretical Perspectives on Design Thinking

In order to have more categorized perception of the design thinking and its maturity process theoretical aspects could be divided into five categories, recognized as to have clear backgrounds and distinguished academic and theoretic backgrounds following, with the foundational works:

1. Design thinking, the artifacts materializer (Simon, 1969)
2. Design thinking, the reflexive practice (Schön, 1983)
3. Design thinking, the problem solving action (Buchanan, 1992; Rittel & Webber, 1973)
4. Designerly Thinking, Practice-Based activity and mode of cognitive approach (Cross, 2006; Lawson, 2006)
5. Design thinking, meaning formation (Krippendorff, 2006)

2.5.1 Design Thinking, the Artifacts Materializer

The idea of artificial for the first time founded by Herbert Simon (1916–2001) and his research was extended from computer sciences into cognitive problem solving procedures. Simon assumed that design should include all of the conscious events or activities in order to create artifacts and therefore he distinguished design from social and natural sciences, but not from engineering discourse. He believed that the design has to be about creation, while other sciences are dealing with currently existing facts. His idea about "the science of the artificial" was a kind of investigative approach toward design profession that opened footprints of research to design. His view point on the design was in a way that he believed the design is a system to transform existing conditions into preferred ones (Simon, 1969). There are some critical writings about Simon`s ideas, because he has distinguished the activities that create or generate something new and activating which are dealing with present reality, but at the same time he didn`t put clear reference on artistic creation and engineering. The difference between engineer and designer way of thinking which is sometimes problematizing in practice is not considered by Simon`s manifestations (Johansson-Sköldberg, 2013).

2.5.2 Design Thinking, the Reflexive Practice

The theoretical framework of "the reflective practitioner" is introduced by Donald Schön (1930–1997) by focusing on logics of invention. He has considered the role of technical knowledge in contrast with artistry mediums. In contrast to Simon`s ideas Schön illustrated the picture of design as a practice based activity with the emphasize on the relation of creation and reflection. The practice-based methodology toward design was not something to be detachable from the work of architects and also has some managerial notions, too (Bousbaci, 2008; Dorst, 1997). Schön believes that a designer is one who "converts indeterminate situations to determinate ones"(Schön, 1983). In order to have comparison of Simon and Schön`s ideas, Simon created an objective framework for the field of design and design thinking, while on the other hand Schön emphasizes it with explanations of designers in practice.

2.5.3 Design Thinking, the Problem Solving Action

Buchanan (1992) has another perspective on design thinking as a matter of dealing with wicked problems with an essential vagueness and without any single answer as solution. Buchanan introduced the concept of contextualization and placement as a tool for purposely generating and shaping design conditions also this perspective on design opens a platform for collaborative design by means of bringing user into the design process. As Wylant (2010) admits:

> "Design thinking is the discipline of cycling through many contextual exercises of placements to understand how sense can be made of something and given this, the designer is then in a position to choose which contexts should dominate and the manner in which they should".

Buchanan's process based perspective helped to achieve better understanding of design thinking in a progressively complex technological environment. He proposes four diverse areas of design thinking as rooms of interventions that problems and solutions could be possibility reconsidered: (Buchanan, 1992)

- Symbolic and visual communications (or graphic design)
- Material objects (or industrial design)
- Activities and organizational services (or service design)
- Complex systems or environments for living, working, playing and learning (or interaction design)

This classification is going to be one of the basic platforms of proposed parametric design thinking procedure model in chapter 4.

2.5.4 Designerly Thinking, Practice-Based Activity and Way of Cognitive Approach

Cross and Lawson are both scholars in design thinking discourses from reflective and practical point of views but at the same time they have some dissimilarities in their ideas. Cross mainly is focused on what the designers are doing all through the design procedure, however, Lawson emphases on the psychology of creativity during design process. They both have a kind of practice-based ideas rather than philosophical standpoints. Also they have logical processes and understanding to make generalization form observation and creating patterns through practical experiences and substantially could be redefined practically in design. But finally both of them suggest a “model” of the design process: and in both perspectives the realm of process based attitude is extractable.

2.5.5 Design Thinking, Meaning Formation

A different perspective on design thinking is introduced by Krippendorff (2006) with semantic background. He explains the designer and work of designer as matter of meaning creation rather than artifacts in Simon`s view. For Simon the core of design process is creating artifacts and the meaning is the quality of it, however for Krippendorff the core is creating meaning and the artifact goes as a medium for communication and representation. the semantic approach of Krippendorff has transformed “science for design”, as “a systematic collection of accounts of successful design practices, design methods, and their lessons, however abstract, codified or theorized, whose continuous rearticulation and evaluation within the design community amounts to a self-reflective reproduction of the design profession” (Krippendorff, 2006). The semantic based method of Krippendorff differentiates it from the practices of Lawson and Cross at the same time. Verganti (2009) has stretched Krippendorff's ideas into innovative processes, deliberating that "innovation in meaning is as imperative as technological innovations that are frequently related to the concept of innovation which can be further study topic in design thinking discourse".

Table 2: comparison of different design thinking theories

Founder	Background	Core Concept	Reflection on Design Activity	Year	Framework
Simon	Economics & Political Science	The Science Of The Artificial	Research in Design	1969	Theoretical
Schön	Philosophy & Music	Reflection In Action	Practice-based design	1983	Practical
Buchanan	Art History	Wicked Problems	Contextualization in design	1992	Contextual
Lawson & Cross	Design & Architecture	Designerly Ways Of Knowing	Process-based Design	2006	Cognitive
Krippendorff	Philosophy & Semantics	Creating Meaning	Semantic-Based	2006	Semantic

Through all these diverse perspectives in design thinking, it's comprehensible that each point of view is indirectly gives a clue about the nature of design in itself. In other words the previous step on design thinking theories is the definition of design where in this discussion has got different coats such as theoretical, practical, contextual, cognitive and semantic (Table 2).

In more contemporary field of design thinking, Nigel Cross (2011), a prominent design researcher and the author of "Design Thinking: Understanding How Designers Think and Work", has updated his sentiments and come up with some valuable descriptors. Some of the feedbacks are discussed below in order to create a comprehensive system for design thinking.

The first one is dealing with the emergence of design thinking. The directions taken during the investigation of the design problem are influenced by what is learned along the procedure, and by the limited overview of what might happen ahead. Features appear as unclear ideas for resolving a design problem; in other words, both problem and solution develop together. Design thinking is opportunistic which means the route of exploration cannot be projected in advance.

Secondly, design thinking is reflective as Donald Schön admitted. A designer's thinking processes seem as centralized around the correlation of internal mental procedures and their external appearance which is an action and reflection procedure similar to cause and effect model. The designer uses a medium, which might be a sketch or a three-dimensional model that enables half shaped ideas to be articulated and to be reflected upon and developed, revised, reviewed, rejected, considered or retreated. We are going to discuss about enablers extensively in chapter 4.

Next, design thinking should be considered as co-evolutionary method. It`s hard to understand a design problem without engaging ourselves in its investigation and progress. In other words, our ideas help us to understand the problem accurately gives clue to our ideas pursue to address. Conversely, we need to understand something of a design problem before we can bring our creative and systematic design thinking to bear. The design problem and the design solution grow and become mature accordingly.

As a final point, there is no need to have a global language for design but we need to strengthen our global design conversation. We could learn so much from users and designers in other parts of the world if we develop a multi-cultural system of thinking. There is a necessity to give more importance to the user which means to create solutions from a user-need outlook rather than through the conventional method of questioning a potential market. Having that attitude will help us use design thinking as a more-balanced system to creative results (Collins, 2013).

2.6 The Reason That We Have To Apply Design Thinking In Design Procedure

One of the main issues of contemporary design research is to understand the modes of designers work and embracing some designerly practices, because designers have been dealing with infinite, complex problems and questions for many years, also the main focus in design is problem solving process and the designing discourses have established intricate professional practices to grasp this goal. As reference to previous discussion about design thinking and designerly thinking, we can admit that these key concepts have to follow each other in reflective manner because the study of designerly thinking will help to improve the body of design thinking. So by application of designerly thinking in the frame of practice, the system for design thinking to deal with complex problems will be accessible. The experiment of dealing with these open-ended and complex problems leads to a specific concentration in the methods that designers create frameworks (Dorst, 2011). These frames time by time knows as restricted and cliché kind of processes and the repetitive implementation of these frames in projects with different potentials end up with dilemmas. In this occasion it’s important to magnify that design is very dissimilar to other fields and it should provide a potential platform to interoperate other fields into discourse of design and create a close interaction by means of a flexible system or a framework.

In order to highlight the importance of design thinking in problem solving Kees Dorst (2011) compares two different problem solving methods in logical and predictable ways. And he highlights the patterns that we are using in problem solving with diverse settings but similar rules. He shows a simple equation that we use to identify, predicts, and prove or to derive as a conclusion from something known or assumed we act as below:

$$\boldsymbol{WHAT}\ (the\ elements) + \boldsymbol{HOW}\ (operation\ principles) \rightarrow \boldsymbol{RESULT}\ (observation)$$

In this kind of framework we know the elements also we have the rules and principles that how they will affect each other we will be able to predict the result. For instance in computer applications, if we create a box and we know the component which transforms it, then by applying the forces we will be able to predict and observe the outcome. (This is called deduction)

$$\boldsymbol{WHAT}\ (the\ elements) + \boldsymbol{HOW}\ (operation\ principles) \rightarrow\ ???$$

Now consider a situation that we have two images one is the form before transformation (the element) and the other is the form after transformation (the result) but we don`t know the HOW, the components and rules that create this transformation. In this case recommending of working principles that can explain the outcome and perceived behavior as a hypothesis will be a creative approach. (This is called induction)

$$\boldsymbol{WHAT}\ (the\ elements) +\ ???\ \rightarrow \boldsymbol{RESULT}\ (observation)$$

This perspective to problem solving was the core context of discovery in science and was the clue that hypothesis were formed and after being experimented to falsify or accept them. This form of analytical and logical reasoning helps us to forecast and clarify phenomena in the world (Dorst, 2011). By means of explained equations, now we are going to discuss that why design cannot be a distinct process and needs more systematic way of thinking and application.

2.7 Why Design Cannot Be a Process

The method mentioned above toward dealing with problems, could be practical only in discovery of justification for happening but what if we need to generate value for others like design or other products? So this orientation changes the equation in a way that we have to end up with certain values rather than statement or fact.

$$\boldsymbol{WHAT}\ (the\ elements) + \boldsymbol{HOW}\ (operation\ principles) \rightarrow \boldsymbol{VALUE}\ (aspiration)$$

In this equation we face two possibilities, in conventional problem solving, we recognize both the value and the working principle that guide us and this will enhance to attain the value we are looking for. The only missing part is WHAT which stands for an object, a system or a need. This method is known as conventional one because most of the designers do it to produce a design that functions with experimented and known principles and rules in the frame of defined scenario for value creation. This is called a close problem solving method (Dorst, 2006).

$$???\quad + \boldsymbol{HOW}\ (operation\ principles) \rightarrow \boldsymbol{VALUE}\ (aspiration)$$

The other form of problem solving is more complex because we only identify the value which we are going to create or attain. These values can be simplified as user satisfaction factors. This method is open form of problem solving and can be end up with wide variety of solutions because; the rules are also differentiating according to priorities of each project.

$$??? \ (the\ elements) + \ ??? \ (operation\ principles) \rightarrow \boldsymbol{VALUE} \ (aspiration)$$

This method gives more opportunity to the designers to be innovative and opens wider horizon in front of them. Here the duty of designer is to figure out what to create while there are no framed principles that end up with aspiration. In this method both working principles and objects should be created parallel, which means we need more complex system to tie all these objects and rules together. Designing is not simple and cannot deal with simple approaches; its nature is complex and needs complex systems. As Kees Dorst (2011) states, "Performing the complex creative feat of the parallel creation of a thing (object, service, system) and its way of working is the core challenge of design reasoning."

2.8 Discussion on Design and Research

Following the previous discussion and explained models and equation for design, and the necessity of systematic approach toward design, which had to have capacity of creating interrelation between principles and elements, we can have some dialogues on the shared qualities of design and research.

The beginning of design procedure, in design process or even in design thinking, has to follow certain information collection and research. Also architecture design is not similar with product design or industrial design, and the misleading part is that most of the time the design process which architects use, is specified for small scales that all the components and subsystems are in control. For example in product design there are lots of inspirational magnets that are motivating the designers and they try to choose only one of them because the scale of the project dictates it to them, but it's totally different in architecture design. Also there is no space to research more in inspiration and apply different ideas in one straight way.

The other issue comes up when we misunderstand design with research and try to deal with design problems like a research problem which means we search in our inspiration library and choose the best research then try to magnify it, go in detail narrow down the research and what we slip here is "architecture" itself because, architecture should have answer for pack of problems rather than choosing only one and scrutinizing it.

As we discussed the research is undetectable part or design procedure. In traditional design processes in the commencing steps the maximum research is done as data collection but as the process goes on the research loses its effectiveness (Figure 10).

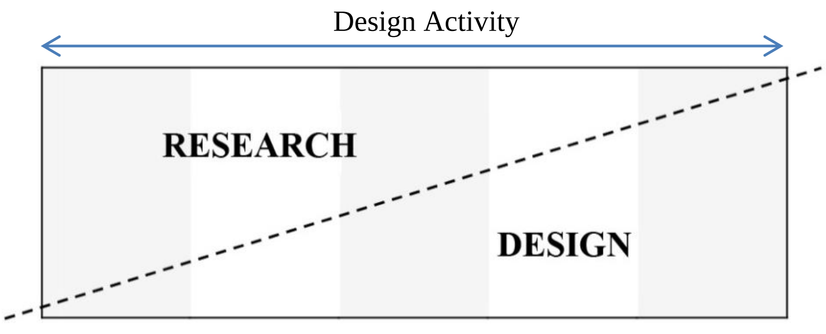

Figure 10: balance between research and design in the process, (by author)

In order to have systematic approach the research should be enabled with certain components in complete timeframe of the procedure. This kind of thinking would be one solution for negative outcomes of design process as discussed in chapter 2. For example, if we extend research into the whole design process, then the data collection stage will act as a process in itself, in other words, there will be no gap between data collection and synthesis stages and both of them will act accordingly with upcoming problems in every phase of the design procedure (Figure 11).

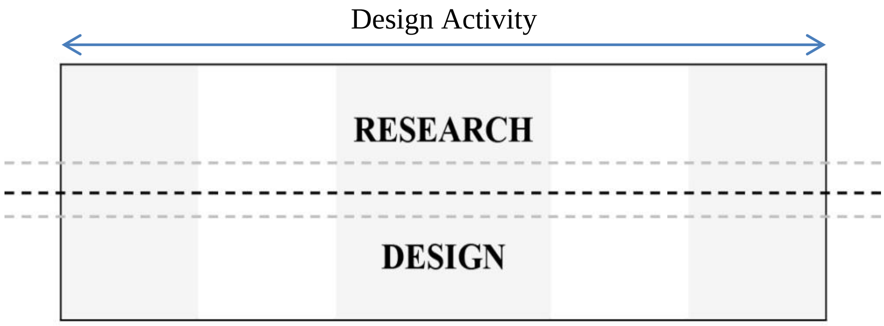

Figure 11: proposed division for design and research in the process, (by author)

Most of the designers would not like to consider themselves as researchers, because they maybe admit that we are working in practical part however, the base point of main steps in design procedure have to commence with research. Nijhuis and Boersema (1999) have created a chart which shows commonalities and shared characteristics of design and research (Figure 12).

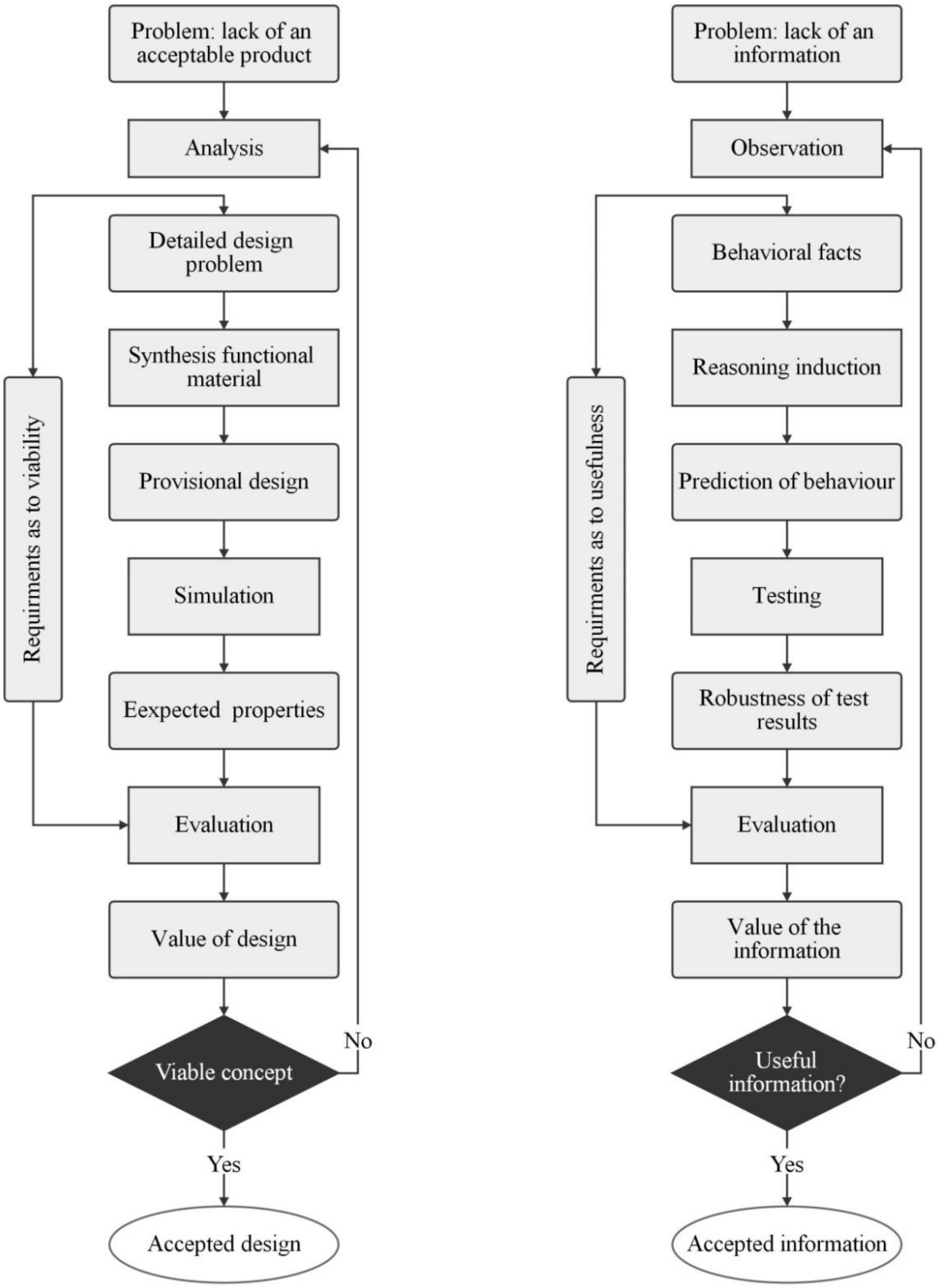

Figure 12: comparison of research process with design process
(Nijhuis & Boersema, 1999)

The commonalities between these two charts are noticeable in that, both are going through the process of identifying a problem which exists on the context. Dealing with research problem as a process is not even the correct attitude but here is not the milieu to discuss about it because it also needs its own systematic way of thinking not a repeated process. Also the charts seem to be in similar process in design and research but they occur in totally different context and setting. In systematic way of thinking for design, research is a good platform and the process of thinking about the research can occur in 3 categories among the designers who are engaged in practice: searching for understanding, searching for ideas and searching for solutions (Press & Cooper, 2003). These 3 subcategories also can be interpreted in design procedure by means of having more accurate understanding of the existing ideas and solutions in order to produce more creative responses.

Moreover, in the case of design, the initiative force is commonly referred to as a "problem" (for example, need for a new building or product) that encourages the development of a designed artifact or product as a solution that will be attained in the future. In research, the drive is usually outlined in terms of a "question" to be answered at least in part by investigative current or past evidence but at the same time all these procedures are "systematic design models" (Groat & Wang, 2013).

Furthermore, Nigel Cross (1977) In his brief chronicle of this remarkable epoch in design and design process, hints how tentatively offered proposals for conceptualizing design became an accepted model for design process that is in practice for last two decades or more. What suited widely known as the "systematic design process" is quiet influential in practice, though much less so now in academia. Never mind that the authors of this model unambiguously indicated that the model was not intended to replace intuition with logic, but rather incorporate a synthesis of the two (Morgan, 1980).

By the advent of "design thinking" there was a shift in architecture profession where the architects found themselves in a situation more than a simple problem solver and they were facing issues such as management programing, and other problems which are not directly related to building design and construction. For instance, they begin to care more about human behavior and discussed more on psychological, sociological and anthropological effects on their design and their design on them. This point can be called the evolution of design because in this stage the designer or architect needs to change the direction of design from process design toward system design, where all of these components which are dealing with art, science, practice, human behavior and management will shape the architecture in multidimensional approach. So the architect is going to design a process rather than following the existing ones. This only can be achieved by considering research as a supportive tool for design. In other words; research will enable the procedure of design by means of putting all existing parameters together and abstract the solution which can push the problem steps forward. Also we have to admit that, the only system which can collect, store, analyses, synthesis and mange this much of complexity and parameters is “human brain”. Because of that we propose this model as a design thinking method that in the first step all the parameters are collected and classified then they will be processed according to the existing guidelines, criteria and enablers.

To sum up and have final discussion on design and research we are going to open a discussion on shared qualities and commonalities of them in order to put out some recommendations for parametric design thinking framework.

2.9 The Comparable and Shared Qualities and commonalities of Design and Research

After having the discussion on important, necessary, and valuable distinctions between design and research, the aim is to determine the qualities which can be shared in term of logic, meaning, scope, process and practice. By using the term comparable, we highlight features of the two actions that assist similar roles but are not exactly equivalent. And in using the term shared, we highlight faces of design and research that perhaps are more fundamentally equivalent but frequently different in importance or prominence. Table 4 summarizes this comparison, in aspects of difference and aspects of similarities.

Table 3: Matrix of the primary differences and shared qualities of design and research (Groat & Wang, 2013)

Design		Research
	Aspects of Difference	
Proposal for Artifact from small scale to large scale interventions	**Contribution**	Knowledge and/or Application that is Generalizable
Generative	**Leading Processes**	Analytical & Systematic
Future	**Sequential Focus**	Past and/or Present
Problem	**Drive**	Question
	Aspects of Similarity	
Systematic Design Process	**Models of Reconstructed Logic**	"Scientific" Method
Abductive Inductive Deductive	**Multiple Logics**	Abductive (Research Design/Hypothesis Formation) Inductive Deductive
Generator/Conjecture Model Problem/Solution	**Logics in Use**	Multiple Sequences of Logics, Dependent on Research Questions and Purposes
Macro/Micro and Mid-level in applied/clinical setting	**Scope**	Big/Medium/Small Theory
Situated Practice	**Social Context**	Situated Research

About the aspects of difference we discussed that the contribution, the process and the drive magnet for each of design and research are acting with diverse responsibilities. As Richard Buchanan (1992) has suggested, “Each of the sciences that have come into contact with design has tended to regard design as an ‘applied’ version of its own knowledge, methods, and principles.”

On the other hand about the similarities, of the process mainly in abductive and deductive logics they both are acting similarly. About the logic of use in design and research Cross (2011) notes that “more experienced designers tend to employ “generative reasoning”; rather than simply finding solutions, designers tend instead to create a ‘generative concept’ which is misunderstanding of difference between research and design.” Likewise, Graeme Sullivan (2010) a scholar of research in art, observes that the artists and scholars contrast research and art in the following epigrammatic way: research necessitates the search for stuff while the arts generate it. Among these commonalities and differences, the idea that can enhance existing problem of design process and design thinking is that, we have to bring these ideas together under a systematic approach in a way that each of them can fill the gap of each other in similar or different context. Even though both design and research are activities that are typically commenced for a “contextually situated purpose”, the specific motivation for each is slightly different. In the case of design, the drive is frequently referred to as a “problem” nonetheless in research, the impetus is typically is “question” to be answered. As final issue, we have to ensure that new designers are curious about science and technology and enthusiastic to open up to R&D departments. Design thinking calls for multiple skills and disciplines in a co-creative and collaborative process, and a design thinking approach can make this possible.

Another main issue which arises from comparison of design and research is that, in research the scholar always looks for a methodology in order to put data into it and get output which is going to have meaningful answer for the problem of the research. In design procedure if we want to build up similar system and structure, there is necessity for different methodologies with the possibility of inputting and outputting diverse kinds of parameters in order to have systematic design procedure. The main lack of existing design processes is undefined methodologies toward the existing problems (Abdullah & Kamara, 2013). So in following chapters we are going to discuss on already existing tools and enablers in order to shape framework for different parts of design process and create meaningful perception of the procedure which is going to end up with solution for the design problem. The commencing step is to be familiar with parametric design and its roots and origins.

Chapter 3

PARAMETRIC DESIGN

3.1 Introduction

In this step if we want to consider parametric design as a simple process which is being criticized in chapter2, then it is considerable that this process; consciously or unconsciously is created by the system itself. It means that in parametric design most of the main decisions are made by the aid of computational tools and the operator is the follower. In order to make this procedure more manageable and controllable as mentioned in previous chapter, the necessity of applying design thinking into parametric design could be surveyed. So in this chapter the main propose is to unwrap the theories and principles of parametric design in order to interpret more in its procedures and try to make this process more understandable, explicable and comprehensible by means of bringing qualitative and quantitative parameters into a systematic design procedure. Following this approach, Tim Love [3] (2009) divides the adoption of parametric design to architectural and urban design into two strands. At the one end of the spectrum, parametric design tools are used for "form-making", while at the other, the same technology facilitates "a metric-based emphasis on social and/or ecological relevance" that both are going to be considered in the research.

[3] LOVE, TIM. 2009 "Between Mission Statement and Parametric Model", Retrieved from http://www.designobserver.com/places/entry.html?entry=10757

The necessity of research in new tools and bringing technology into design procedure could be possibly investigated because there is not long time, that architecture is pioneer in implementation of digital technology and innovation. Certainly, architects and designers have not any effect on invention of digital technology and tools but they have just accepted, implemented and embarrassed it. They are using animation software from the movie making industry or CAD-CAM[4] technology from air-crafting manufacturers. By means of these tools and enablers, in the 1990s architects and designers tried to give more tangible representation to the digital media. An extraordinary architectural experience, by the aid of new aesthetics of free form finding procedures have become a foundation of technological achievements and platform of education for all of the designers because most of them eager to be part of this development. Mario Carpo (2013) states that:

> "Free form represented and symbolized a new techno-cultural environment where all the tenets of industrial Modernism had been jettisoned, and a new universe of differentiation, variation, and choice – which Postmodernism had advocated, but could not deliver – became possible, tangible and affordable and, some claim, even pleasurable. In the process, architects and designers contributed to some significant technological advances, and digital design theory in the 1990s set the trends for digital thinking at large".

The necessity of transformation in modes of thinking could be the main agenda toward designers and architects. In order to shift into digital and computational thinking, the first step is to build up computational knowledge and basic awareness on parametric issues, so in this chapter we are going to have different point of views on definition and implementation of parametric design from design procedure lens in order to create platform for holistic design system.

[4] CAD: "Computer Aided Design", CAM: "Computer Aided Manufacturing"

3.2 The Roots of Parametric Design

"Parametricism" is a term for a new what call epochal global style of architecture and all the design disciplines including urbanism, architecture, interior design, graphic design, product design, and even fashion design. The term first launched in 2008 in Venice biennial but after these all years now it's a global movement.[5] Furthermore, through the past fifteen years digital media computational tools in architecture were implemented in different methods and affected the entire field of architecture construction and design. Digital media were practical only as a representational tool for presenting ideas, at the beginning. With developing digital tools and technology architecture has faced new tools for diverse activities within architecture design process in digital media (Schnabel, 2007). Furthermore, parametric design has its roots in the digital media improvement, animation techniques, and computational tools of the mid-1990s. The style has been introduced and emerged in recent years by advancement of innovative parametric design systems. Nowadays, the single and dominant style for avant-garde practice of contemporary architecture is Parametricism (Schumacher, 2008).

A parametric illustration of a design is known usually by means of a dimensional multiplication and variation or quantitative ones. But any other qualities like color, scale, orientation about the form or even more qualitative restrictions could be varied parametrically. In order to design parametrically means; to design a parametric system that sets up a design space which could be explored through the diversification and variations of the parameters.[6] In other words, parametric design is a process of choosing appropriate set of parameters with the most sufficient

[5] Patrik Schumacher, Parametric Architectural Order, Lecture at Georgia Tech, February 2012
[6] Kilian, Axel. MIT, From an interview conducted in March 2004 by Victor Gane

correlation to fulfill the design problem requirements and setting up the model definition that then can be used to explore the solution space. In principle, parametric design procedures can control, coordinate and address variety of programmatic references and concerns if rules for the design are obvious and the constraints and assumptions are sufficiently set prior from the beginning of the design process (Madkour et al., 2009).

There are diverse definitions of parametric design from scholars and practicing architects. Frank Gehry (2004) believes that parametric design is a system that affords inputs and outputs and that generates design spaces and mechanisms to arrive at a solution. But Axel Kilian (2006) discusses parametric design as a process of choosing appropriate set of parameters with the most sufficient correlation to fulfill the design problem requirements. To design parametrically means to design a parametric system that sets up a design space which can be discovered through the deviation of the parameters. Parametric design system makes possible the communication and transformation between a built environment`s geometric frame and physical or other parameters (Chronis et al., 2012). The advantage of parametric design is to plan and synthesize the overall requirements and relationships of many design elements into one form. This process allows the designer to investigate variety of possible solutions quickly. Another key aspect in the usage of parametric design enablers in the design practice is the assortment of rules and the transformation of design problems and associated references into parameters, features and dependencies.

A good definition of parametric model contains four elements; first, parametric models are typically defined by a combination of dimensional, innate and rule-based constraints, Second parametric objects have connective rules which means a change in one parameter will have effect on whole system, third characteristic is that parametric models will not allow themselves to break the rules or they will signal the designer about the rules and requirements, finally, parametric systems are able to broadcast or export set of attributes (Burry, 2003)

Hernaldez (2006) has wider perspective on parametric design as a process and he admits, “parametric design is the process of designing in environment where design variations are effortless, thus replacing singularity with multiplicity in the design process”. And in systematic perspective parametric modeling system allows designers and architects to model classes of design and parts of the editing process. Using them, designers will be able to design both their project and how it can change in its context. In other word the project and the process are in parallel system which could possibly lead to the solution (Woodbury et al., 2011).

As discussed in pervious chapters, in the literature there is a great effort on parametric form finding. Whereas, parametric modeling and form finding only allows variations, which enhance the generation of related forms within the same family of forms, this does not allow geometrical transformations into produce an infinite number of design solutions. It is also limited in its flexibility to allow the generation of sophisticated forms and surfaces (Abdullah & Kamara, 2013; Carpo, 2013; Chronis et al., 2012; Kourkoutas, 2007; Madkour et al., 2009; Oosterhuis, 2012).

The development of ‘Design System’ rather than ‘Design Process’ has been proposed to overwhelm some of the restrictions and limitations of parametric design.

Furthermore, the need for scripting design thinking to more fully achieve the benefits of design systems is usually beyond the designers/architects who are involved in the design procedure. The nature and complexity of the architecture design stage, as well as the demand to generate variety of design solutions directed to the idea of integrating “Parametric Design” with “Design Thinking” and other significant generative methodologies and enablers to introduce a new approach in the name of “Parametric Design Thinking”. This assimilation can be seen as taking viable aspects of parametric design and design thinking to overcome the limitations of parametric design. This system takes different parameters; Geometric Parameters, Topological Parameters, Representational Parameters, Material Parameters, Environmental Parameters, Mathematical parameters, Human Parameters and etc. (Jabi, 2013) as inputs, and computes them through an encapsulated systematic process to interactively generate and explore solutions for the design problem.

3.2.1 Parametric design and complexity in design

Complexity is a multilevel, multidimensional phenomenon investigated by many academic researchers from many points of views representing different domains of knowledge within diverse systems. In both engineering and science, there is an increasingly popularity in the studying of "systems". Its popularity is because of a pressing necessity for analyzing and synthesizing complexity in order to apply this development into the body of knowledge and at the same time improve technique for dealing with complexity (Simon, 1962).

We all become increasingly intelligent designers of increasingly complex processes. But we also carry our past, our traditions, our histories, which limit our free choice of future solutions, with us. In this notion complexity comes to be viewed as integrated with progress: increasing complexity expects growing specialization. In this standpoint, complexity exists by design. “Only complex organizations can tackle complex problems” (Miguel Pina & Rego, 2010).

Complexity based on simple rules characterizes the dramatic paradigm shift from mass production to customization. The new kind of building is complex yet systemic in its design method. The new kind of building dramatically enhances the potential of today’s architectural expression while keeping strict control on its data, including diverse parameters and truly nonstandard architecture is simply complex (Oosterhuis, 2012). The existence of nonstandard architecture is inevitable according to variety of tastes and styles in contemporary lifestyle. The issue is that, the fact attracts young architects is that; this architecture is simply different and original and at the same time leaded by innovation and technology. But we need to investigate or question that why it is superior, what makes it so essential, what reflects it more creative, and that’s commonly would be the ability to emerge and generate complex systems and engagements where variety of parameters, different kinds of special qualities and variety of functions can integrate and fit into complex forms, that are called an “odd geometry”. This style certifies architecture in order to familiarize these complex circumstances, and particularly complex inner relations to have an identifiable unity. It also allows the designer/architect to identify what belongs together rather than in traditional architecture design, where if you put too much of diverse things together, it will become a bit odd. But here, in one context, you have the capability of creating a more complex demand which is also more legible.

3.2.2 Parametricism, Commencement and Application

In traditional design procedure the beginning foot step was conceptualization with sketches and rapid hand movement but computerized tools made it different and somehow rational. Patrik Schumacher the pioneer of Parametricism style admits that:

> "In general description, Parametricism means that all the elements of architecture are become parametrically variable, not rigid fissures anymore and plastic fluid malleable can be recognize and react to their form. Forms start to set relationship with each other that is power beauty the meaning making the element and figure parametrically variable and moving from a word of platonic solid cube cylinder which are used to compose everything in classical architecture as well as modernism. It's always district object that added to each other and never influence each other they never notice and sense to each other". [7]

He also criticizes modernism as a system that generates urban garbage because they glamorize a lot of diversity with lack of identity and creating just series of piling with no legible local order. He finds the solution in objects being sensitive interactive with dynamic field they generate strongly organic orders by means of introducing ontological shift in design. (Figure 13)

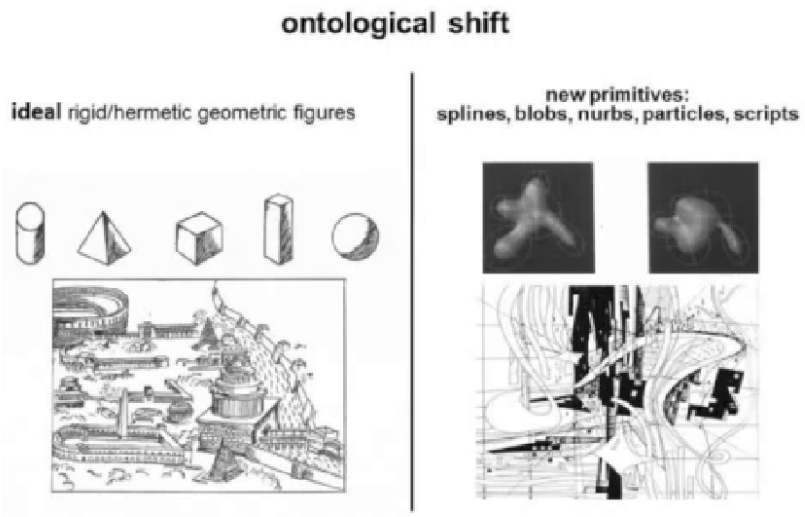

Figure 13: ontological shift from modernism into Parametricism

[7] Patrik Schumacher, Parametric Order, 21st Century Architectural Order, Lecture at Graduate school of design, Harvard University, 2012

During this transformation, rigid figure cubes and cylinder that have not ability of fluid alteration are rejected. Lines set to motion let them configure self-organize into complex variable orders and they create exterior complexity and interior complexity simultaneously. This procedure create plays itself free continuously variation of form situation rather than just assembling of preconceived elements. And the main issue is that, it would be hard to invent and imagine this style without computational tools.

In broader scale, in urbanism whole groups of element not only repeating but generating in its urban texture and existing context which brings that context into larger order very strong different internally (Schumacher, 2009). In other words, there is one coherent differentiation rather than many repetitive zones. For example in Istanbul master plan which was proposed as parametric design, the design is something radically new but at the same time fits the existing context. They use street system by banding and clustering line through viscosity of water, they pick up all the little street from the context but the new territories cannot be let remain untouched, so they start to define new territories according to logic and they propose some new kinds of fabric and work with two type of block type and tower type and allowed to these two types be similar to each other by means of creating plaza. Also in details, in blocks the façade relief on the outside in very deep and in the inside court yard. You can find a kind of façade respond which becomes shallower and transition of public space into private space. There in a kind of semiology where you are on the system and which way you are moving, it means you are moving into private territory. This generates complex variety there is correlation of element with network and very rich into unique identity and never boring, always different and navigable. With each step in urban context something new comes to the view (Figure 14).

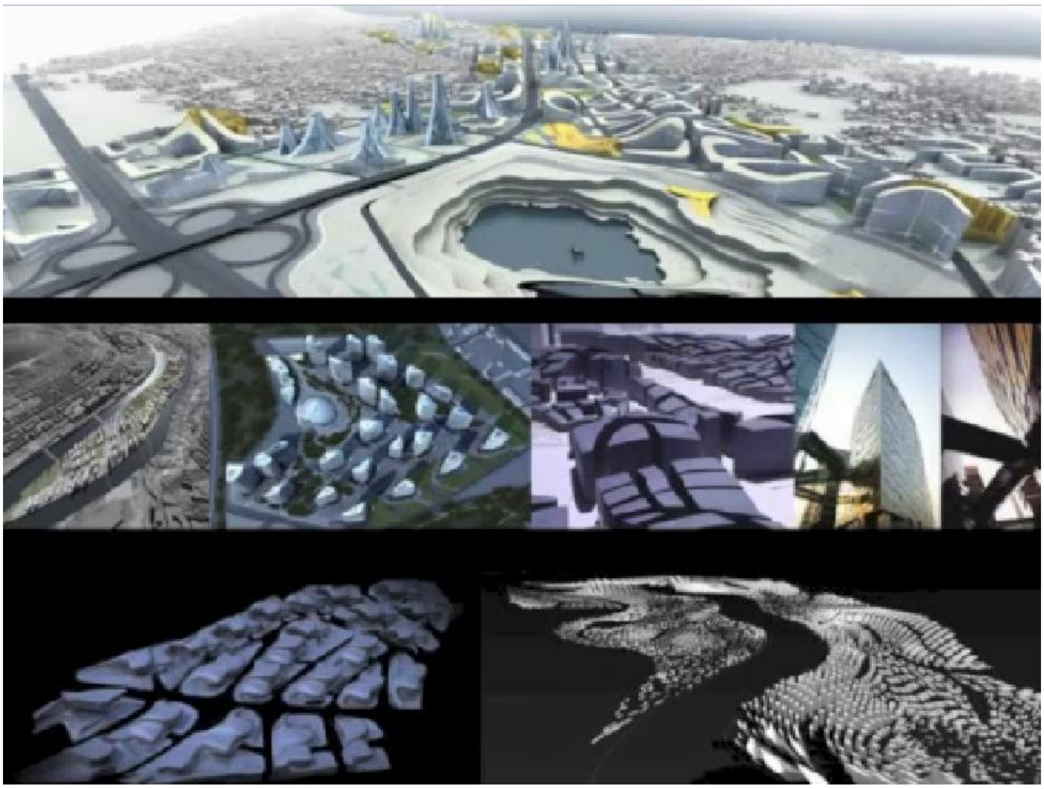

Figure 14: parametric design in urban scale

3.3 Principles of Parametric Design

Each style in design and architecture has its own manifestations about the limitations and principles and parametric design is not the exception. In this style the base is nature, in nature you can find complex varied order, the law is interaction between different subsystems coming together and creating form lawfully. The main struggle is to create second nature by the same order generate parameters outside of natural ranges. This richness of forms creates endless forms of nature (this endless richness can be created by complex rules that are computational). There is movement from physical to digital and return back into physical and there is no end to what you could choose. Some principles of Parametricism can be mentioned as (Schumacher, 2011):

3.3.1 Freedom

All the forms are soft, have degrees of freedom parametrically variable, and forms that can take different shapes. There is much variation to explore, and there is not only one idea or range of modulation. The background is intelligence which comes with computation; this variation is out birth of computation of parameters. In wide degree of variety and freedom, to play and search a universal possibility while having not already fixed rational criteria. In this method you can impose further constraint, fabrication constrain, formal or grammatical constrain and then read these constraint into research and pre constraint form.

3.3.2 Differentiation

It's important to distinguish Parametricism as style which comes as particular desire of differentiation. Application of tool that uses parametric system adopts different geometric conditions to deliver kind of neutralization of alterations to look different as usual. This differentiation means it doesn't have in advance reason why difference, it just says our default condition is differentiation rather than giving offering a client or city hundred equal same blocks. It give hundred different blocks in different scales and there is a kind of ordering which is discovery of potentials so differentiation is with reason but reasons come later. For instance, in high-rise building, the skeleton should be differentiate from ground floor to top because forces are much heavier on the ground the load the movement and must be differentiation in the axis. As the tower start another react as bending using the stress analyses and using information to make subtle differentiation of the skeleton to generate an algorithm that can translate stress diagram of envelope into net structural network of diagram and develop skeleton. The idea of openings, floor plate, rips, setbacks, interaction of core with our envelope and this all create subsystem and generates natural beauty with differentiation and correlating that grows onto the topography.

There is a kind of well order that makes environment more beautiful navigable (Figure 15).

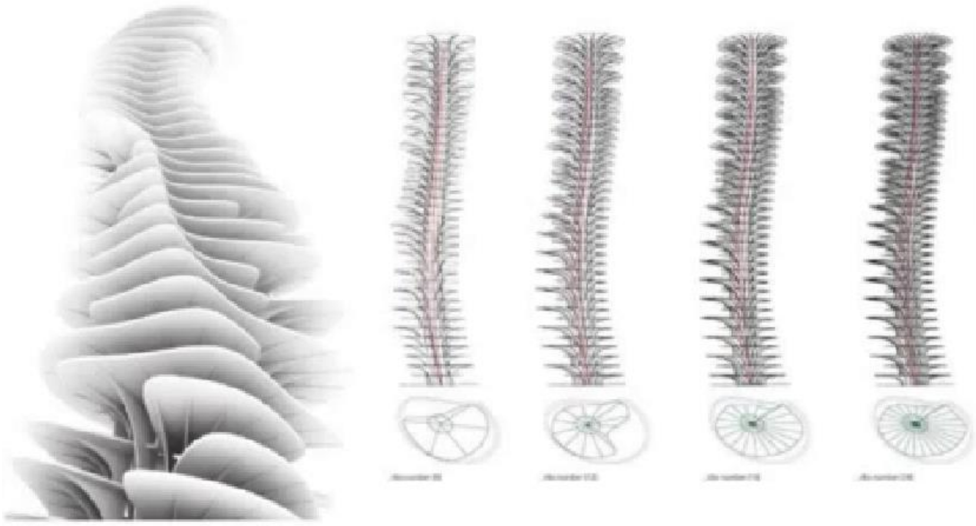

Figure 15: parametric form finding of skyscraper (Park et al., 2005)

3.3.3 Correlation

Once we have “subsystems” in differentiation we have to imagine that every architecture design has more than one subsystem that is going in different layers into urban texture and building relation envelopes. Each of these subsystems has to correlate with the system. For example system of void being reacted to the system of stair so there is a kind of action and reaction between subsystems. Each element of architecture design can be a subsystem and if these subsystems are going to touch each other then, there must be interaction and correlation in between.

3.3.4 Multiple Sub Systems

The motivation is to shift from a solo system differentiation to scripted connectivity of multiple sub-systems like envelope, internal subdivisions, structure, circulation void and etc.; the diversification in any of systems is associated with differentiation in other ones. This kind of approach to design is creates a new field of design thinking in order to bring this much of complexity and subsystem together. If we consider design as process and end product, in this approach there is no chance to have interaction, correlation and relation with these subsystems. In other words systematic approach toward design and architecture needs its own systematic way of thinking which should be abstract of contemporary enablers and innovations.

3.3.5 Contextual Embedding

Picking up lines geometries and masking the building and designing very much similar to the next door building seems not to be contextual embedding. In macro and mega scale there is necessity to create internal simulation with context. Parametric design is criticized most of the time that, it's too strange or lacks identity or not culturally sensitive but the followers of this style admit that people love strangeness, love to be stimulated like going to different countries to see things different. In parametric design as you don't rely on known rules and certainties it's risky to propose completely different space and atmosphere to the dwellers (Schumacher, 2008).

Table 4: Principles of Parametricism (Schumacher, 2011)

(tools of criticism and project development/enhancement)	
Negative Principles	No rigid form
	No simple repetition
	No unrelated elements, collage of isolated
Positive Principles	All forms soft (intelligent: information = deformation)
	All systems differentiated
	All systems correlated

Patrik Schumacher in his book entitles "Autopoeisis of Architecture: A New Framework for Architecture" has opened diverse discussion on parametric design and the contemporary meaning of existing keywords in design and architecture. He also had presented a theoretical framework for criticizing and understanding parametricism projects (Table 4). It is obvious that this framework cannot be limited in theory and need to be plasticized. The principles of parametric design are achievable by means of computational and parametric thinking. “Parametric design thinking” is a common heuristic, exploratory and empirical systems used by designers in practice. Heuristics is used here referring to thinking relying on the use of intuition, human feeling, experience and rules. To think parametrically is a mode of relating tangible and intangible sub-systems into a design proposal by means of digital tool specificity and to establish relationships between properties within a system (Karle & Kelly, 2011). In order to achieve this system, there is a necessity to survey on the existing parametric and computational design processes.

3.4 Parametric Design as Procedure

As discussed in previous paragraphs and according to Schumacher`s manifestations of parametricism style, it is understandable that the main and most significant output of this style is visual and formal representation. Meanwhile, one of the preliminary objectives of this research is to push this movement forward and propose a system of design procedure in order to somehow balance the formal image with other constraints in architecture design. In order to reach that point, there is a need to discuss a little about computational design and parametric design processes. As mentioned before, parametric design as a system requires series of tools and enablers in order to deal with existing complexity of architecture design. These enablers are computerized tools that are using computational processes to find the finest solution for the architecture design problem. So, computational design is very close to parametric design but they are acting as supportive and collaborative organizations with each other.

In literature there are some proposed processes for computational and parametric design but there have some missing points. The one is “Flow chart of proposed parametric design methodology” proposed by Chronis, Liapi and Sibetheros (2012) and is in series of process format (Figure 16). This methodology is based on algorithmic parameters like site algorithms, climatic algorithms and proximity algorithms. The missing point as discussed before in these kind of processes is that the tools and enablers are not defined and also this system is dependent only on site parameters and there is no realm of systematic procedure for architecture design. This model can be possibly improved by means of differentiating layers of design steps and implementing more comprehensive parameters of design not only climatic ones. Also the design system cannot be closed loop in itself, it must be like a pattern applicable for different design problems and needs to be flexible enough to be updated according to different constraints and conditions of the project and designer.

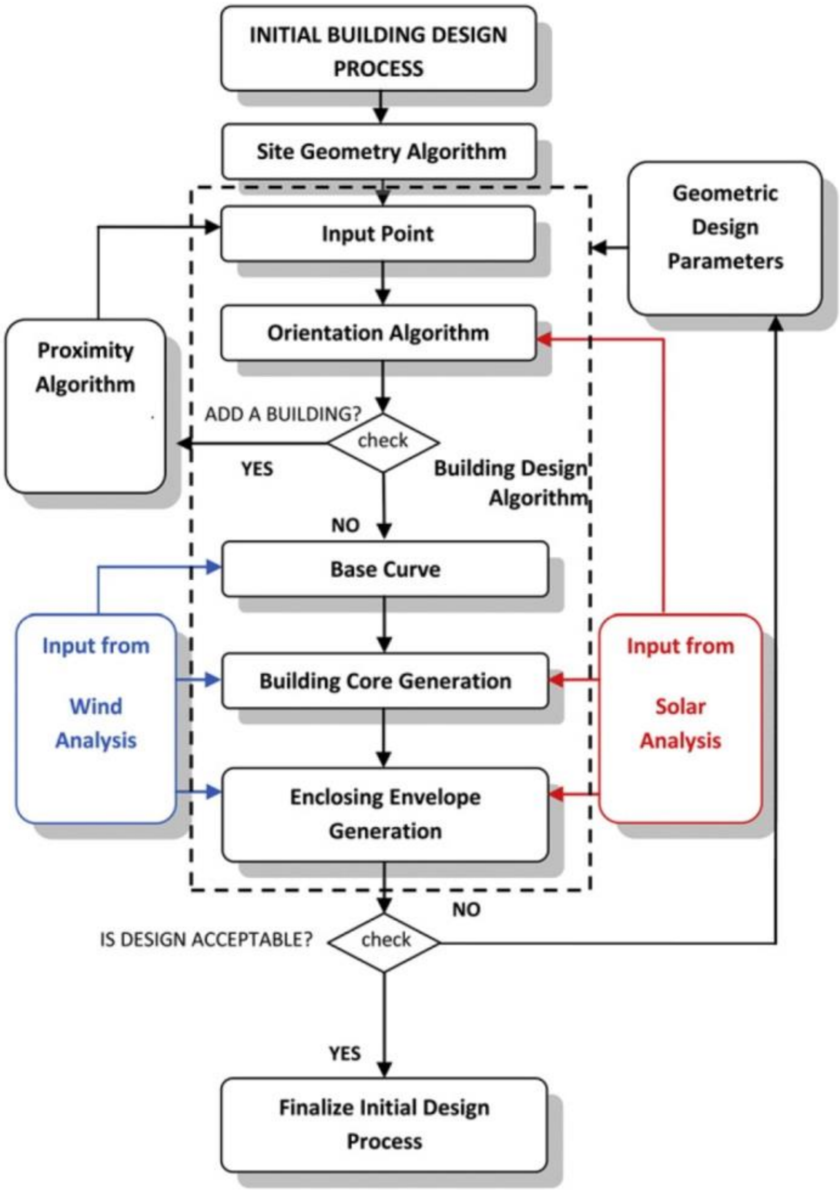

Figure 16: Flow chart of proposed parametric design methodology (Chronis et al., 2012)

Another parametric design process methodology is founded by Abdullah & Kamara (2013) and it is mostly applicable in conceptual design stages (Figure 17). The positive point of this system is the ability of inputting parametric design and computational methodologies in the procedure. And also the procedure is not a closed loop because could be supported by different inputs and methodologies in order to utilize and control the design strategy.

This model brings the opportunity for “Top-down” and “Bottom-up” a procedure which is necessary in computational design, because it directly enhance the flexibility and adoptability of the procedure by means of collaborative transaction between the operator and tools. The only missing point of this procedure as pervious one is formal representation of the process and not considering qualitative parameters in design procedure.

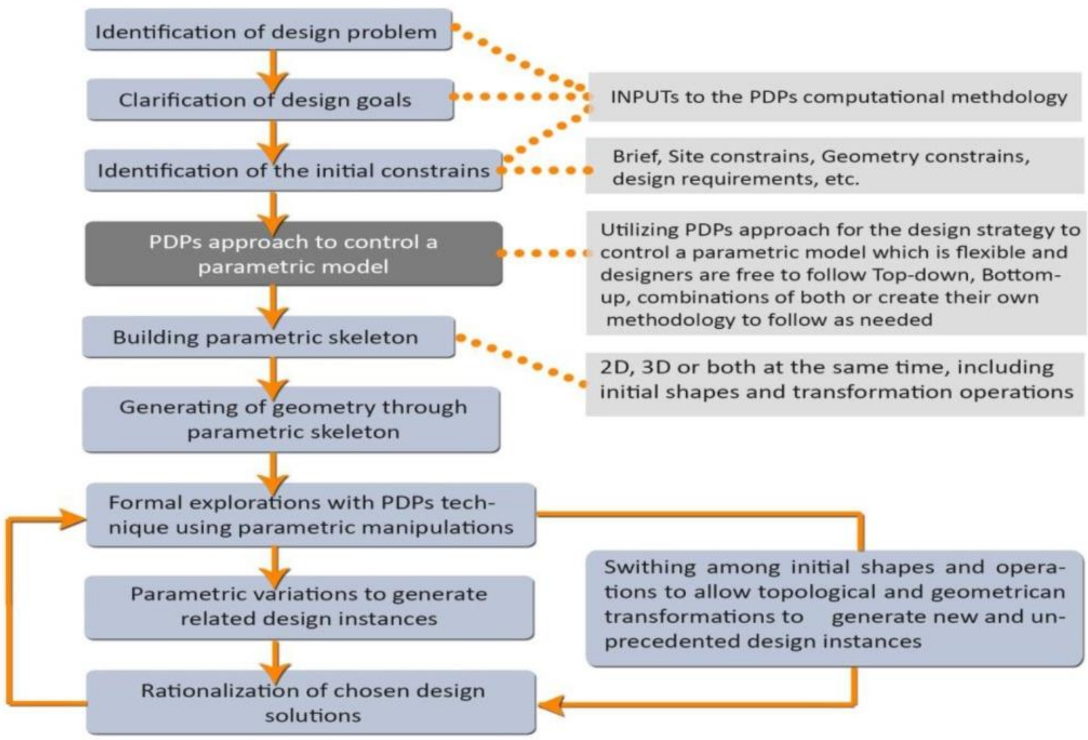

Figure 17: Parametric Design Process (PDP) system as a computational methodology to generative forms (Abdullah & Kamara, 2013)

Ramesh Krishnamurti (2011) in his article entitled “Bridging parametric shape and parametric design” suggests macro scale of the design procedure where the designer, Maker, Scientist and Engineer are collaborating and connecting with each other and controlling certain parameters (Figure 18). Also this system follows compositional explorations of geometry; formal and functional studies via parametric design, designing patterns and physics-based simulation; and fabrication or assembly are positive issues in proposed system.

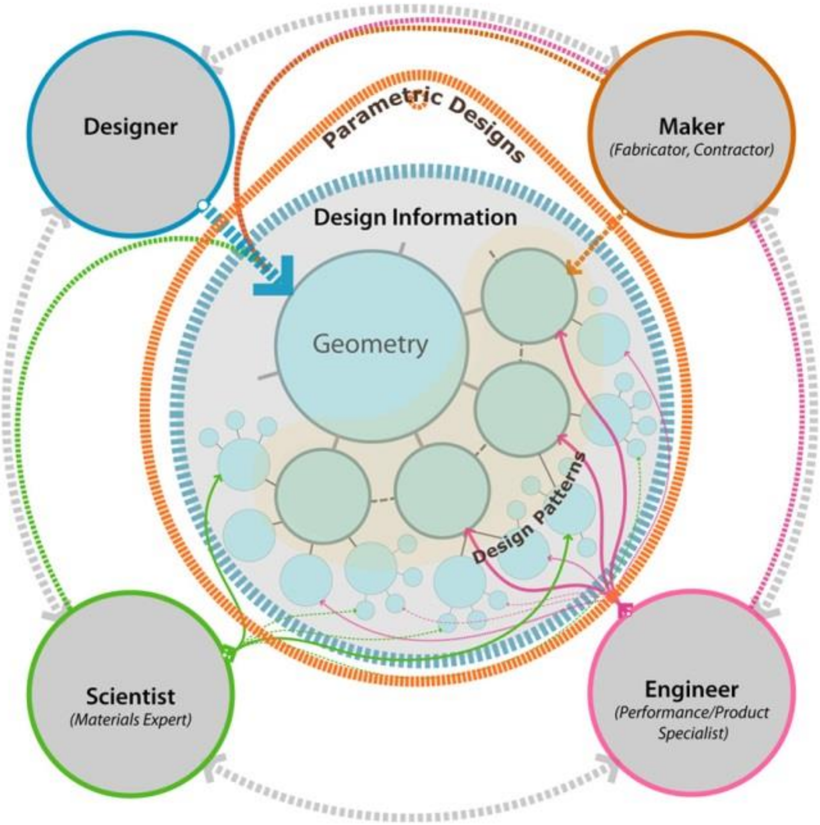

Figure 18: Agents and entities in design process (Krishnamurti, 2011)

The realm of patterns in architecture design is not something new and innovative but using language of patterns in design process in order to create meaningful relation between parameters is seems to need more investigation and in last chapter the implementation of pattern language methodology will be discussed in detail.

Last but not least, another proposed model by Victor Gane (2004) is more complex and systematic strategy for parametric design. This model can be divided into three main methods; implementation of a “top-down”, “bottom-up” geometry control or a combination of both. The “top-down” control method has an extremely structured appeal as it requires a rigid structural hierarchy of all components. These are normally built with direct dependence on the other elements and should one be erased or modified, the entire parametric design will break or update, depending on established relationships. On the other hand, the “bottom-up” method uses not as much of rigorous approach when it comes to hierarchical organization of the model’s components. These are separately created as independent entities and brought together to form an association. Furthermore, the bottom-up control method allows to independently modifying components outside of the assembly (Figure 19).

Once the designer is clear of the implications that the method he chooses on the design, and then the next step would be identification and implementation of initial constraints and existing tools. The constraints can be a set of dimensional parameters that will define the future artifact, or boundaries, which the design cannot go beyond. The boundaries can either be geometric and dictated by the need to respect (Gane, 2004). In this model development of design strategy is considered accordingly to types of thought variation and different parameters are in close relation with the system, but still the overall consideration is about formal representations.

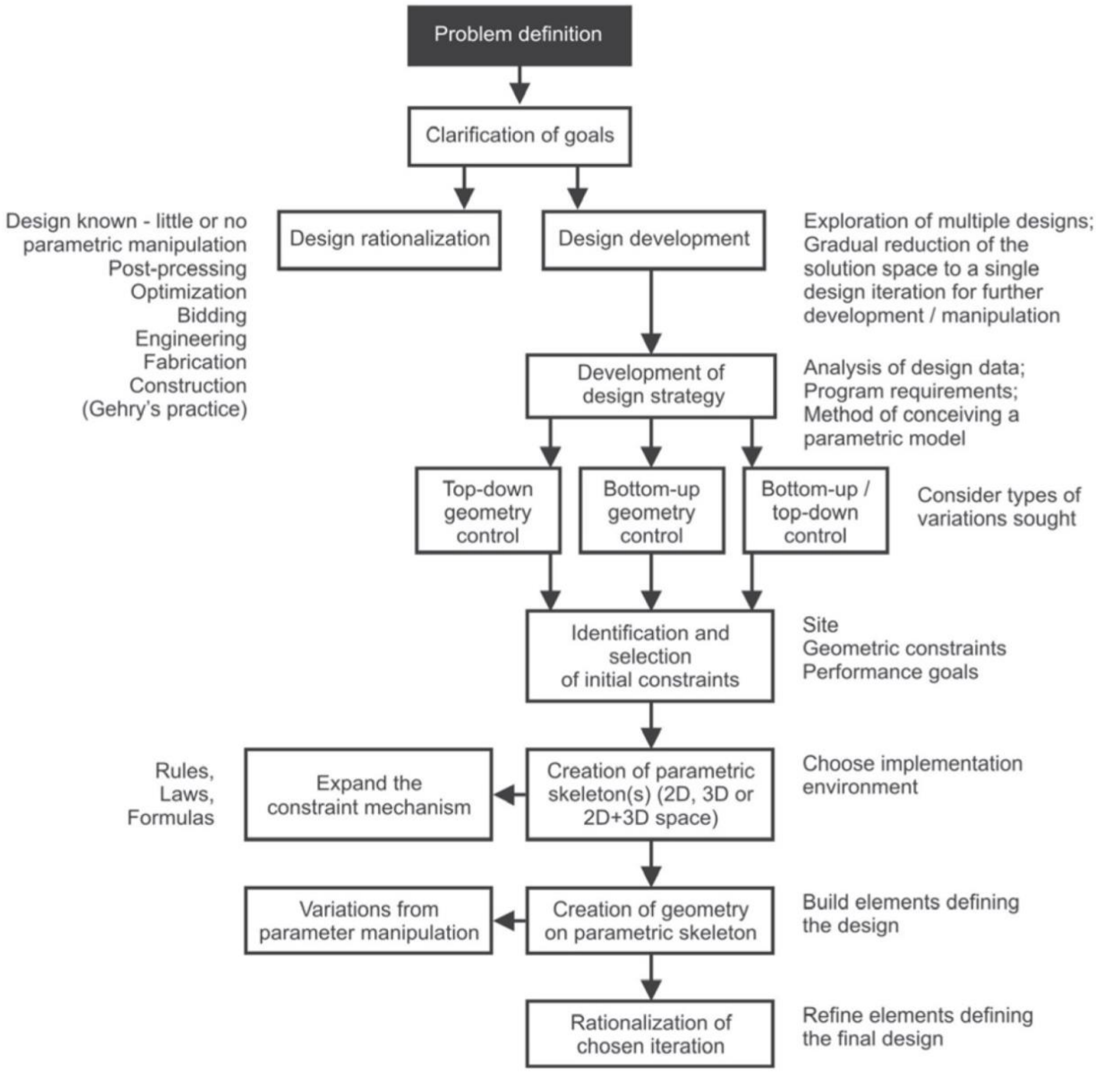

Figure 19: Strategy for Parametric System Diagram (Gane, 2004)

In the next chapter "Parametric Design Thinking Framework" is been proposed by consideration about the missing points and failures of existing methods. The main aim of proposal is to bridge theory and practice by means of bringing existing tools in the skeleton of design procedure and create systematic way of thinking and design for computational and parametric architecture which could be possibly applicable for contemporary architecture design.

Chapter 4

PARAMETRIC DESIGN THINKING FRAMEWORK

4.1 Introduction

Architecture discourse is dealing with different factors generated from environmental issues up to construction regulations. Many of these roles and regulations are extremely complex and the process which is going to manage these complexities needs to be compound and multi-disciplinary. This complexity is in the same ratio with the scale of the project. As the project becomes superior in scale the more sophisticated compounds needed to be analyzed and considered. In huge scales the problem of managing and consulting the parameters and building a logical connection between them, always remains the noteworthy element of the building design process (Lawson, 1998). Dealing with this much of complexity and considering them all in different stages of design process, lights the necessity of a powerful, reliable, malleable and swift tool. Moreover, the tools have to be enabled with: Symbolic and visual communications, Material objects, Activities and organizational services and complex systems or environments for living, working, playing and learning or interaction design.

Michael J. Ostwald (2012) in his article entitled “Systems and Enablers: Modeling the Impact of Contemporary Computational Methods and Technologies on the Design Process” start a totally new and diverse discussion on design procedures with the perspective of computational tools. He presents a new model for architectural design process and discusses how it has changed over time. Rather than being a conventional "design as process" model, the new model is trying to concentrate on the relationship between the meta-conditions of design. These conditions are categorized as: representation, proportion, information, operation. Moreover, the tools, devices and technologies that enable these conditions are considered in this system. Consequently, this is a framework recording the relationship between conceptual systems and practical enablers which tries to minimize theory and practice gap, and therefore could be described as a system-enabler model of the design process.

As discussed in second chapter, conventional models are focused on the stages that occur in a design process; typically including conceptualization, sketch design, developed design, documentation and reflection. These stages while offering a reasonable reproduction of a design process; they pay little attention on the primary conditions placed on a design, or the methods, techniques and technologies that support the process. The new model is loosely founded on the traditional design process, (Asimow, 1972; Cross, 2000; Miller, 1997; Moore, 1974), but with several key differences and improvements:

- First, it is a comparative model; its purpose is to chart variations and flexibility in design practice and process.
- Second, its focus is on the shifting relationship between the meta-issues in architecture and the tools used to support them
- Third, it interprets the design procedure as holistic system which follows the tools as enablers

- Forth, this system is the outcome of overlap of theory and practice which is applicable and improvable in not only identified in architecture but also in engineering, interior and industrial design

The system-enabler model takes a different viewpoint on the design process in order to clarify how it has changed in the past, and how the development of new technologies, tools and devices will support change in the future and can be flexible enough with rapid changes. The intention of this system is not only to create designs within the computational tools, but also to interact with the real world through the computer, and bring the existing potential of design research under a comprehensive system. Moreover, this system will be able to visualize the part of the architect's work process that these technological enablers have the most influence over. While this system is framed around the architectural design process, it is also relevant to fields of engineering design, industrial design and interior design all of which will be changed, in subtle or dramatic ways, by the introduction of new methods and technologies.

4.2 A Meta-Model of the Design Process

Since ancient times to the present day, the architectural profession has relied on a blend of three major design systems "representational", "proportional" and "indexical" to describe any planned, but as-yet unbuilt, structure (Ostwald, 2012). In addition to these three, over time specific "operational" systems were developed to contribute the design to be realized or constructed. When viewed together, these four systems could be considered to establish a conceptual framework of the architects' conventional role; the production of designs that result in completed structures. These frameworks are needed as a platform for each project in order to define certain hierarchy among the sub systems not necessarily in step format or following any kind of strict process. This system tries to simplify the meaning and language of design procedure in order to get the most influential, essential and obligatory meaning. This abstraction will become mature in contemporary context.

4.2.1 Representational

The first of the four steps, the representational, includes the most visual appearances of the architects' work; models and drawings of buildings. These representational tools can be outlined from Ancient Egypt and the practice of engraving or carving lines into flat panels of wood, as a record of a designer's spatial and formal objectives. Both models and drawings of present buildings were shaped in earlier times and the use of representational systems to pre-figure architecture and support the construction process, occurred much later (Kostof, 2000; Morrison & Ostwald, 2007). Nowadays, the improvement in representational tools has stretched its effectiveness and implementation into whole procedure of design.

4.2.2 Proportional

The proportional system was required to connect the representational media of drawings and models to the physical world. In its earliest periods, proportional systems were generalized from elements of the human body. To avoid variations, each civilization established local standards that functioned, to a greater or lesser extent, within their geographic and contextual borders (Wilson Jones, 2006). For example, the Roman civilization transported copies of these regulations to each colony to be used as a unified system for translating representational practices, drawings, into constructed buildings. Nevertheless, the system of measurement adopted by each following generation, architecture has remained dependent on a strong conceptual link between the representational and the proportional to allow the designs of the architect to be assembled. Even in contemporary era the necessity of having proper tools to link this gap is undisputable.

4.2.3 Indexical

The next system that has traditionally supported the switch from unbuilt proposal to constructed reality is entitled the indexical. The word “indexical” has two related meanings in this framework. In conventional use, the word “index” defines a process that separates particular components of a larger set and gives them a new order. For instance, the index in a book archives the location of words in a larger text, and alphabetizes this list for ease of access. In semiotics however, the word indexical has somewhat different meaning, it refers to any way of methodically organizing and connecting one set of information to another. Nevertheless, whether the first or second description is adopted, the indexical in design could be considered as relating to a type of “rigorously ordered information”. This information could be parameters or constraints of the project in its context. In architecture, for example, the form of a projected design may be described as a combination of scale models and drawings (proportionally constant representational systems), but this is not sufficient information to construct a building. The architect must also transfer information to be constructed from or the probable values to which the building must perform. Therefore, the representational system is complemented with an indexical system that outlines specific types of construction parameters and performance standards for a building.

4.2.4 Operational

Till the early 19th century these three systems continued to be sufficient for the majority of designs to be built. Conversely, following the industrial revolution, the construction industry became progressively complex, with tighter time-frames, superior expectations. By the 20th century the procedure of guiding a building from its design platform through to accomplishment had become larger and more complex than the rest of the process it supports. In the later years of the 20th century the role has become so specialized that a new profession, process managers, has ascended to share responsibility for the design process. Furthermore, with design regularly being commenced by large teams, in part to promote the high level of indexical information required for every project, operational systems, as an addition of the design process, have come under increasing pressure.

It is noticeable that these four systems, representational, proportional, indexical and operational cannot be utilized in segregated format. In order to support or build a network among these systems a range of tools, techniques or protocols are necessary. These tools has improved and modified in different eras by means of technological, theoretical and practical transformers. These tools in meta-model design process are titled as “Enablers”.

4.3 System Enablers

Architecture design as a language needs specific tools in order to be able to communicate. These tools have appeared in variety of coats in different eras. For example, in Ancient Greece, the architect might present a client with an engraved drawing on a soft-timber panel, a wax model, and notes on a wax tablet, a set of drawers and a state certification. The drawing and the model, part of the representational system, have been enabled through the use of original right-angled triangular guides, knives, scrapers and a stylus. Furthermore, the sample drawers are an ideal example of an indexical system that both holds and orders information. Finally, the warrant is an authority to build; an operational enabler. In this example the design process is attentive on the representational and the proportional, as the most important systems and leaving the indexical and the operational as relatively minor components of the process (Figure 20).

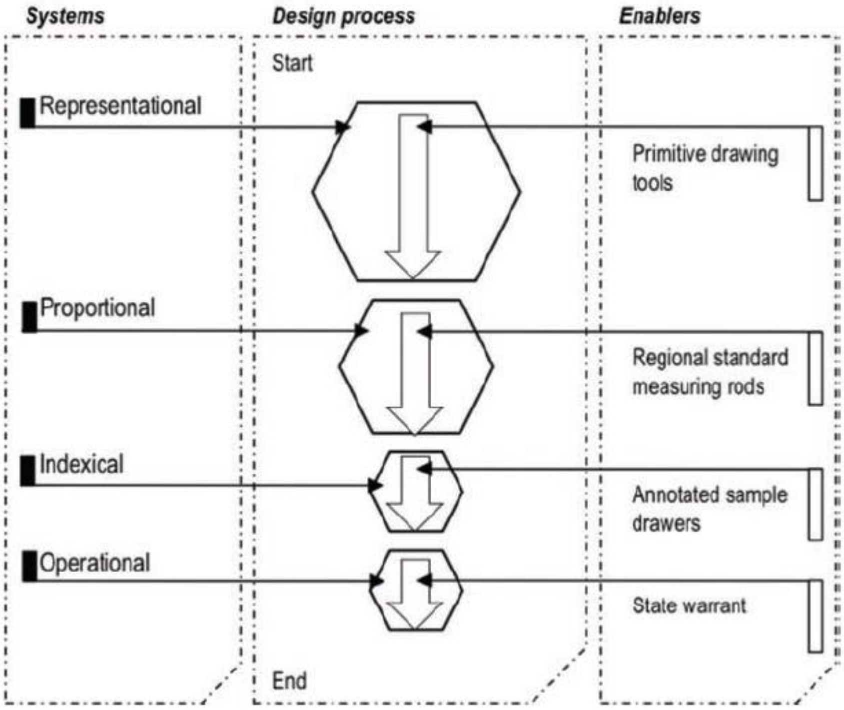

Figure 20: System-enabler model: The design process in Ancient Greece (Ostwald, 2012)

Another example from Renaissance architects indicates that, they have produced and annotated their drawings with both dimensions and graphic scales and with acronyms and abbreviations that shows certain materials or performance principles. This procedure has certain overlaps between representational and proportional stages by means of creating more linkage and balance in ordet to represent the ideas more constently (Figure 21).

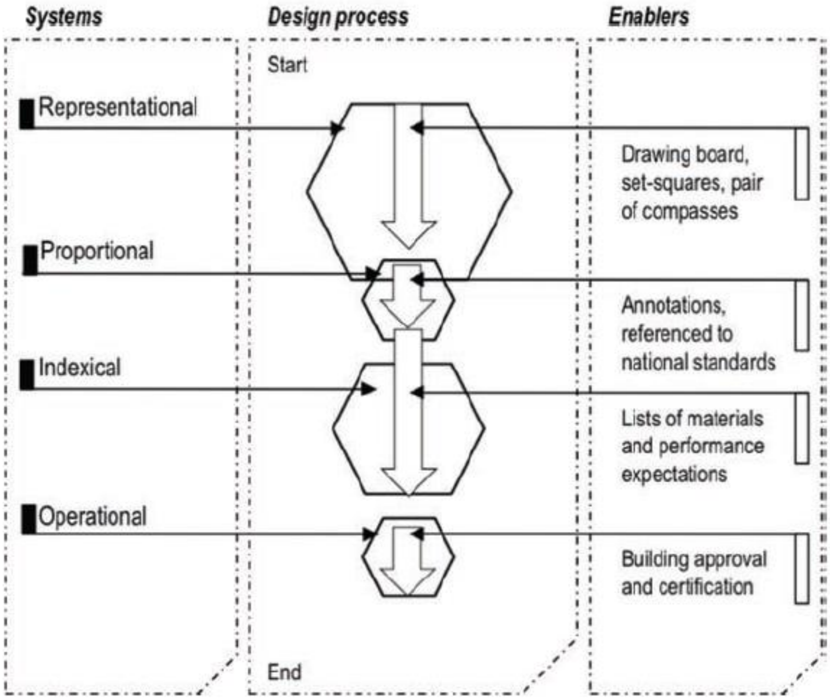

Figure 21: System-enabler model: The design process in the Renaissance (Ostwald, 2012)

In 20th century by the advent of industrial revolution the possibility of mass production, put its finger print on design process. The designers start to think about materialization process of their projects by means of creating multiple layers of information. By the middle years of 20th century the indexical system has become mature en0ough and closely followed by operational system (Figure 22). In this evolution process the proportional and representational steps has slightly became less important because they were embedded in the body of architecture design. But it doesn`t mean that there is no need for representational or proportional enablers.

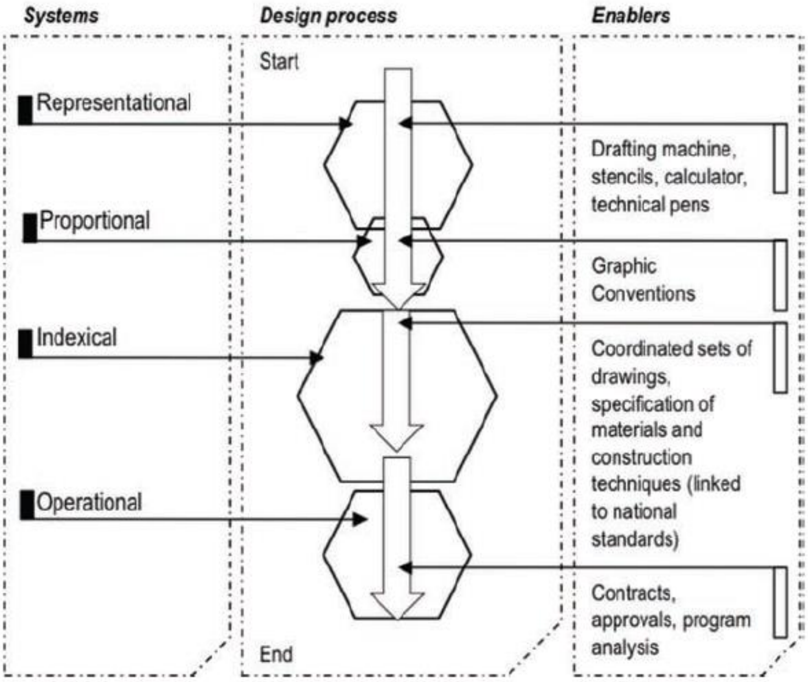

Figure 22: System-enabler model: The design process in the mid to late 20th century (Ostwald, 2012)

To sum up the discussion about the evolution of design procedure in different periods and the consequence of different systems and enablers on it, they are being compared in table 5 and each stage in contemporary context has the possibility of development in technological, theoretical and practical framework.

Table 5: hierarchical comparison of systems and enablers

		System Enablers		
		System-enabler model: The design process in Ancient Greece	System-enabler model: The design process in the Renaissance	System-enabler model: The design process in the mid to late 20th century
Systems	representational	Primitive drawing tools	Draw board, set-squares, pair of compasses	Drafting machine, stencils, calculator, technical pens
	Proportional	Regional standard measuring rods	Annotations, reference to national standards	Graphic convention
	Indexical	Annotated sample drawers	List of materials and performance expectations	Coordinated sets of drawing, specification of material and construction techniques (linked to national standards)
	operational	state warrant	Building approval and certification	Contracts, approval, program, analysis

It wasn`t until the end of 20th century that the major changes in the body of system-enablers detected but with rise of computer aided design tools (CAD) the boundaries between different stages of design process started to break down. The implementation of computational tools can be categorized in 3 main cases (Madrazo & Weder, 2001): The analytical studies, the purpose is to recognize a comprehensible body of architecture practice and to extract a generic type or a system of rules from them; Visual and representational reproduction of distinguished works of the past; multimedia representations of the work of a precise architect or contemporary architectural style. These improvements have mainly taken place in the body of building information modeling (BIM), generative design and parametric design.

One of the primary goals of CAD movement was to create link between representational and proportional systems. Also it created a well-defined system of information wired with different sub-systems from the beginning of design procedure up to the end. This improvement has continued with parametric design. Parametric system as mentioned before, mostly is dealing with dimensional parameters thus the qualities of objects are not only able to be described using dimensional variables (Eastman et al., 2011) but if we locate these parameters within a hierarchical system that relates set of parameters together it would possible fill the existing gap.

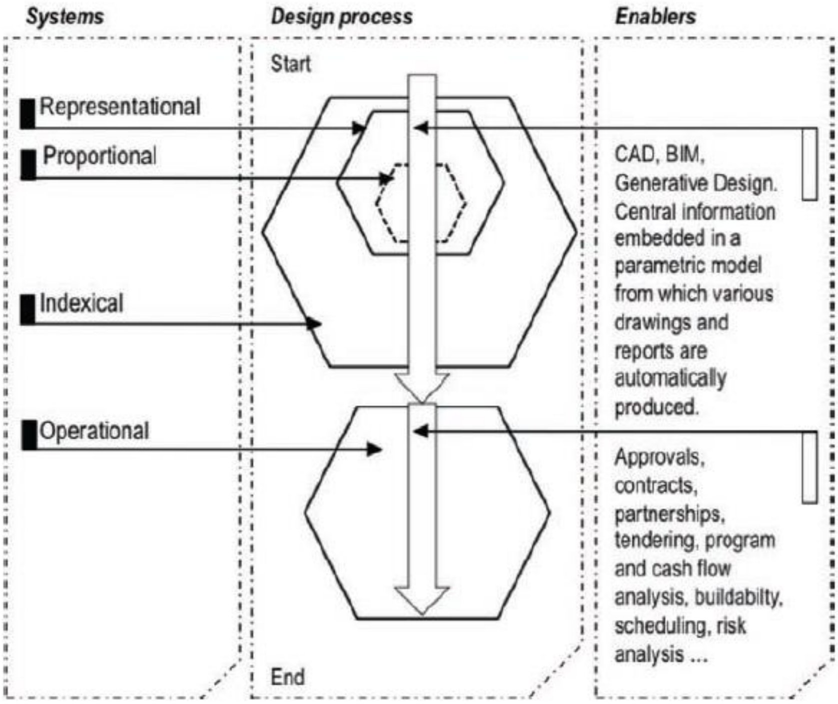

Figure 23: System-Enabler model: The design process at the start of the 21st Century (Ostwald, 2012)

Recent mode of design process which is embedded by CAD, BIM, generative design and information modeling is a system or "transparent layering system"[8] that is systematically networked (Figure 23). In this the systems are collectively sought to place the representational and proportional systems within an indexical framework and information for the first time has become central feature of design process.

[8] Chapter 2, Multiple theories on design process

Moreover, BIM, parametric design and generative methods have enabled consistent way of thinking during design procedure. The two major areas of necessary improvement for the building profession can be identified as “tool-related” targeting developments of tool usability and “process-related” targeting practical integration of simulation, evaluation and conceptualization tools in the design process. In the next section the enablers are going to be discussed as assistive technologies widely. The successful parametric design system can be defined as a one that creates the most connectivity between capabilities of computational tools (Lawson, 1998) and existing parameters and constraints (Jabi, 2013) (Figure24).

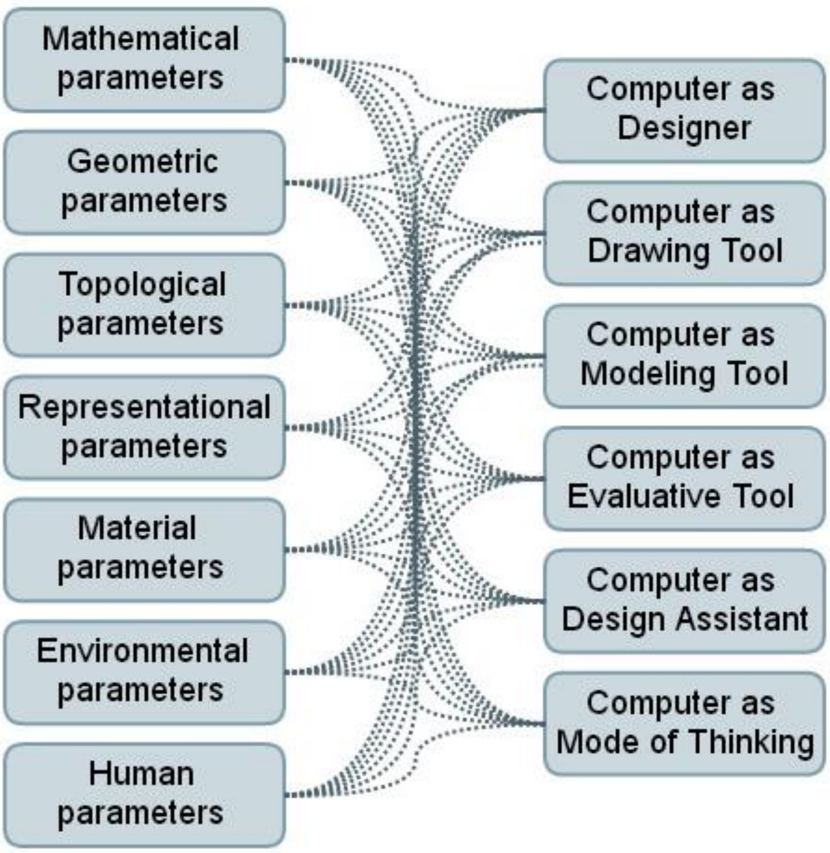

Figure 24: Systematic network of parameters and enablers, Proposed by author

4.4 Assistive Technology for Architecture Design

Assistive technology is one of the supporting strategies for architects, planners and engineers and it's applicable in design process in order to have consistency of framework, toolsets, and specific software applications. These tools are able to the building design procedure with respect to the requirements of the project and user with significant knowledge based and scientific results. The input data could be variety of parameters or a set of comparison of values or individual attributes such as detailing or structural constraints. However, the possibility to examine and control these parameters through the design procedure including qualitative spatial integrations and quantitative components has been recently investigated only by few scholars.

Assistive technology based on both geometric and qualitative representation and conceptual reasoning by the aid of complex set of data visualization can help to facilitate architecture design procedure for architects and designers. (Bhatt et al., 2013) There are number of important application that could be implemented in design procedure in the context of building design. These application are summarized in Table 6 providing information regarding; a brief description, terms of application and the sub-system that the enablers could possibly boost.

Table 6: List of tools & enablers for design procedure

	Tool	Description	Components & Implication	Application	Sub system
1	**INTEGRA**	The Integra system is being implemented as an Integrated environment, with multiple applications Rolled into a single coherent system (Bouchlaghem, Shang, Whyte, & Ganah, 2005)	It includes eight functional components: user agent, client briefing tool, cost modeling tool, constraints, Checking tool, risk assessment tool, sketching and drawing tool, 3d visualization tool, and Synchronous and asynchronous communication tool	Collaborative	Early stage of design
2	**VISCON**	This enables all the participants in design and construction of a project to access the project drawings, illustrations and documents from anywhere inside the office or on site (Bouchlaghem et al., 2005)	2d drawing 3d models virtual reality modeling Language animation sketching system	Clarify and Communicate build ability information	Whole process
3	**SUSTARC**	used to create the solar envelope that shows the maximum available volume in which it is possible to build (Capeluto, Yezioro, & Shaviv, 2003)	Build while keeping the solar rights of the existing neighborhood	parametric analysis	Evaluation
4	**FLUENT**	To evaluate the existing situation, the proposed solution and the mitigation design, in which the wind rights to the residential neighborhood, were preserved, while ensuring tolerable winds along the pedestrian sidewalks. (Capeluto et al., 2003)	-	Decision making Create the solutions in urban context	Evaluation
5	**AUTOLISP**	A graphic interface which can build a hierarchically structured library of types (Madrazo, 1999)	There are two kinds of type: (1) simple extruded shapes, called profiles (2) compound objects, which result from the combination of individual instances	Modeling 3D compositions	Conceptual
6	**GENETIC ALGORITHMS**	Used to search for design solutions, evaluate them and continue the search guided by the results of evaluation. The designer is then provided with the results of that looping process (Caldas & Norford, 2002)	Environmental Performance of the building lighting and thermal behavior	Optimization	Late stages of design

7	**PREVENT**	it is intended to serve as the performance expert who stands behind the shoulder of the architect (Wiezel & Becker, 1996)	Provides an appropriate interface for defining both the brief and the activities of the user as well as for generating the building layouts. Site and technology characteristics have to be drawn from data banks. The description of the user's activities and of the different spaces in the building should be obtained from the owner or the designer	Comfort zone	Performance Evaluation
8	**a.SCatch**	Intuitive system for searching floor plans by using a sketch-based interface. Complete system for automatic floor plan analysis and able to extract structural and semantic content of floor plan from given image. Enables the user to easily access knowledge from past projects. (Ahmed et al., 2014)	Automatic extraction of the semantic structure of older projects extraction of the semantic structure from the sketch of the architect retrieval of similar floor plans from the repository, Visualization of the results and the interaction with the user interface	floor plan analysis system extracts the semantics from existing floor plans	early design phase
9	**Energy_10**	A user friendly tool intended to be used at the early design stages, where many design decisions has not been taken yet. The user needs to roughly define box volume, the size of the openings, material properties, the mechanical system to be used and basic schedules. (NREL, 2005)	Results can give the designer an idea of the energy performance of the proposed building, yearly, monthly and/or hourly.	Energy Analysis	early design stages
10	**eQuest**	Energy analysis tool, where the designer can choose either to use the internal wizard or to import the building model from external applications. The level of definition required from the designer is high in order to get a more precise simulation (Yezioro, Dong, & Leite, 2008)	The definitions include materials and lighting properties, precise schedules, and a good definition of the mechanical system	Energy Analysis	late design stages
11	**EnergyPlus**	Comprehensive simulation engine for better temperature and comfort prediction. The level of expertise required to use the tool is rather high and any definition can result in a significant impact in the obtained results (Yezioro et al., 2008)	high definition of the mechanical system is required	temperature and comfort prediction & evaluation	last design stages

12	**Hybrid Ideation Space (HIS)**	Developed to respond analog tools with digital capabilities respecting the designer's needs for uninterrupted reflective conversation with the representation that should, in turn, enrich ideation. HIS maintains the intuitiveness and ambiguity needed to generate ideas (Dorta, Pérez, & Lesage, 2008)	It allows users to sketch and make models all around them in real time and in scale using a digital tablet and an immersive projection device. The HIS adds to traditional sketch and models the advantages of a virtual environment, which provides a sense of immersion and presence.	formulating new concepts	ideation process
13	**PLA(id)**	Tool for organizing and sharing product information on the World Wide Web and about on-line product information used by architects, engineers and other design professionals. (Ofluoglu, Coyne, & Lee, 2002)	allows users to organize web links graphically and in folders product and material portfolios Integration into CAD Design support and product selection	design strategies and development tools	design decision making Detailing
14	**ConDes**	Allows architects to sketch the coarse organization and functionality of a building. This tool enables the valuable conceptual design information. all decisions about the organizational structure of the building, not gets lost. (Kraft & Nagl, 2007)	enables conceptual designs to be checked against this formal conceptual knowledge	Bridging conceptual design and CAD environment	conceptual design
15	**DONKEY**	Creates a geometric model, appropriate for structural analysis, by using a fully automated tool (algorithmic architecture) or a standard drawing procedure (human input based CAD layout). (Svoboda, Novák, Kurilla, & Zeman)	Collaboration: The interface can be understood as a generic tool which combines geometric modelers and a software for analysis Learn: allows the user to understand what he does rather than to provide him with plain answers Form-finding: The response of the model to loads or geometry changes is visualized in real time.	improve the interaction between designers and structural engineers	conceptual design
16	**DDDoolz**	Innovative system dedicated to mass study and spatial design. Using 3D painting as a metaphor, the design system has been developed for creating 'rough' three-dimensional solid models with only a limited set of operations. (de Vries & Achten, 2002)	Granularity Modeling effort Representation Design or presentation medium	Combines the directness of physical scale modeling with an intuitive computer user interface.	early stage of architectural design

17	**GOAL**	Accesses a number of databases which hold information on climate, unit costs of materials, user requirements, building regulations etc. and numerically appraises each proposed design in terms of construction cost, annual energy costs, combined costs in-use, thermal energy consumption, lighting energy consumption and planning efficiency; additionally the software generates any number of perspective views of the geometry (J. Petric, 1993)	Provide the benchmark against which each new design can be compared; the more designs which are appraised, the more knowledgeable and useful the database becomes	design decision support system	Integrated appraisal
18	**SEMPER**	A preference-based formalization of design intentions and criteria is used to cope with ambiguities through dynamic control of the degrees of freedom of design-related parameters during the interactive design process. (T. Maver, 2000)	''multidirectional'' approach to simulation based performance evaluation	performance evaluation	interactive design process
19	**CITYZOOM**	Decision support system for urban planning, with a specific built-in city model, where data is represented in an object-oriented model representing the urban structure to simulate the impact of alternative urban regulations for a large number of plots (Donath & Lobos, 2009; Grazziotin P., 2004)	-	simulate the impact of alternative urban regulations	Early Stages of the Design Process
20	**Space program**	The space program is a transcription or translation of the needs of the client into an architectural programmatic language, or words and figures that can be interpreted by the architect in terms of rooms, sizes, and relationships. The spaces and their sizes (areas) must be named, listed, and grouped by zones. (Donath & Lobos, 2009; Lobos, 2006)]	A digital database represented by a dynamic shared table is used to store, edit, and quickly exchange the required building data	conversion of the needs of the user into an architectural programmatic linguistic	Early Stages of the Design Process

21	**CB daylight systems design**	The program consists of pop-up menus that allow the user to interactively select room properties, daylight conditions and daylight system variables with scales and buttons via the mouse. It also has a 2D-CAD interface that allows the user to view the room plan, place the viewpoint and the monitor interactively on this plan and to draw custom-tailored reflectors of arbitrary shape and size. (Martin & E., 1996)	the program works is as follows (user input is accepted in any sequence): The user defines the context like space geometry and space materials. She then adds the window description and defines its width, height and depth as well as the window sill height. Automatic checking is performed for all geometry parameters to make sure that the window fits into the wall	Daylight Evaluation	design solution assessment
22	**GENWIN**	For a desired day lighting performance in a room, it can generate all satisfactory window configurations (Khemlani, 1995)	To assist in the window design of a prototypical room with very specific lighting criteria to be satisfied.	Design appropriate opening	design solutions
23	**Research Engine**	The RE is a set of automated computational processes that simulate a spatial–structural design process. It generates a structure, performs a structural analysis and provides an indication of its structural behavior. (Davila Delgado & Hofmeyer, 2013)	(1) Spatial Design to Structural Solution (2) Structural Solution to Optimized Structure (3) Optimized structure to Spatial Design (4) New Spatial Design to Optimized Spatial Design	prescribes interactions between spatial and structural design considerations	design processes early stages
24	**Design Performance Viewer (DPV)**	The tool enables fast estimation of energy and energy performance of the specific design, facilitating necessary parameter input by using non-expert decision criteria (Schlueter & Thesseling, 2009)	It enables balancing between building form, materials and technical systems and makes a holistic view of the building possible	energy performance of buildings	early design stages
25	**Window Information System (WIS)**	Simple building simulation tool for integrated daylight and thermal analysis. The tool is capable of importing the thermal and visual properties for different glazing and shading positions from the Window Information System (WIS) program. (Hviid, Nielsen, & Svendsen, 2008)	Evaluate the impact of incoming daylight on the energy consumption for lighting.	integrated simulation the hourly daylight levels	early design process

The deficiency for having a pattern as a design procedure is to find and construct a platform which is also flexible enough to work as system. So the commencing phase of the work is done to review and analyze the current available software for architecture with a focus on their applicability within design procedure. Moreover, there is an opportunity to highlight missing digital tools required for enhancing and encouraging different stages of architecture design procedure with the integration of design systems and innovative technologies. The above mentioned list is the abstract of more than 200 related researches concerning with design enablers. The tools are included in the category of: CAAD[9] tools, simulation tools, visualization tools, performance evaluation tools, design decision supportive tools and late design stages enablers. In Table 7 the design stages along with sub-systems are illustrated according to possible enablers and software in order enhance the design procedure.

Table 7: Enablers embedded into architecture design system

Sub-systems	Design stages	Enablers
Representational	Data collection	a.SCatch Research Engine
	Analyze	Energy_10 CITYZOOM Window Information System (WIS)
	Ideation	GENETIC ALGORITHMS Hybrid Ideation Space (HIS) DDDoolz
Proportional	Synthesize information	DONKEY GOAL CB daylight systems design
	Conceptualization	FLUENT AUTOLISP ConDes Design Performance Viewer (DPV)
Indexical	Drafting	PLA(id) GENWIN
	Evaluation	SUSTARC PREVENT eQuest SEMPER
Operational	Detailing	EnergyPlus
	Presentation	VISCON

Second phase of the research in aimed to learn from the designers and architects about their awareness about the existing of such tools and the method they use in architecture design, as well as identifying the obstacles that they may face during

[9] CAAD: Computer Aided Architecture Design

CAAD. An international survey was conducted by expert architects and architecture teams.

4.5 Survey Design

The main methodology of this research was structured on the pattern language methodology and in order to create a “pattern” for design procedure there is necessity for certain clues that can be the background for this system so, the survey is implemented to have fundament. The main aim of the study is to discover the ongoing procedure of design in practice and the implementation of CAAD tools within this procedure among designers and architects. The literature review elaborate the collection of in-depth, qualitative data, and the survey provided the chance to test those findings and apply them from the lens of computer aided architecture design (Hien et al., 2000; Robertson & Radcliffe, 2009). The steps of design which are implemented in this survey are the abstract of the study in second chapter of this thesis (Data collection, Analyze, Ideation, Learn & Education, Conceptualization, Synthesize information, Evaluation, Detailing, Drafting, and Presentation).

The survey targets specifically at designers and architects who regularly use computer aided design packages in their work. A pre-trial of the survey was accompanied with a minor number of respondents (5 numbers) in order to recognize any problems with the examination mechanism before it was released to broader spectators. Several minor changes were done before the final survey was released, but no major problems were found. The questionnaire was organized in a way to deliver information concerning:

- Computational tools commonly utilized in building design and evaluation
- Scholastic background of the software operators and their experience duration
- The main software that they use in design process
- The phase of design process which the software was utilized
- The pattern of design process by means of the steps they follow
- Their awareness about the existing tools that can enhance design process
- Reasons for not using CAAD tools
- Reasons for using CAAD tools and the problems that come upon
- Perception of systematic design support method based on practice
- Proposals towards the improvement of CAAD software utilization in design process in different phases
- The barriers they maybe face in implementation of available tools
- The missing and required CAAD tools in different stages of design process

The questionnaire survey was conducted in structured format with close-end and open-end questions in online format and tried to use a variety of methods to reach practitioners: by means if publishing links for surveys through professional newsletters and magazines, in national associations of architects and online databases of professionals architects (Appendix B). There was totally 62 responds and out of them 50 questionnaire selected as reliable ones. There were participants from different countries such as; Cyprus, Iran, Germany, New Zealand and Britain. Generally the occupation of the contributors was freelance architects or member of architecture team with the educational background of postgraduate studies and the experience of 4 to 6 years in architecture profession. About the using of CAAD tools, approximately 40% of the participants have been using CAAD packages in their design and profession for more than 7 years. Also most of the applicants are using CAAD tools constantly or occasionally in their design work. The summery of the background of the responds and type of their work is shown in Figure25.

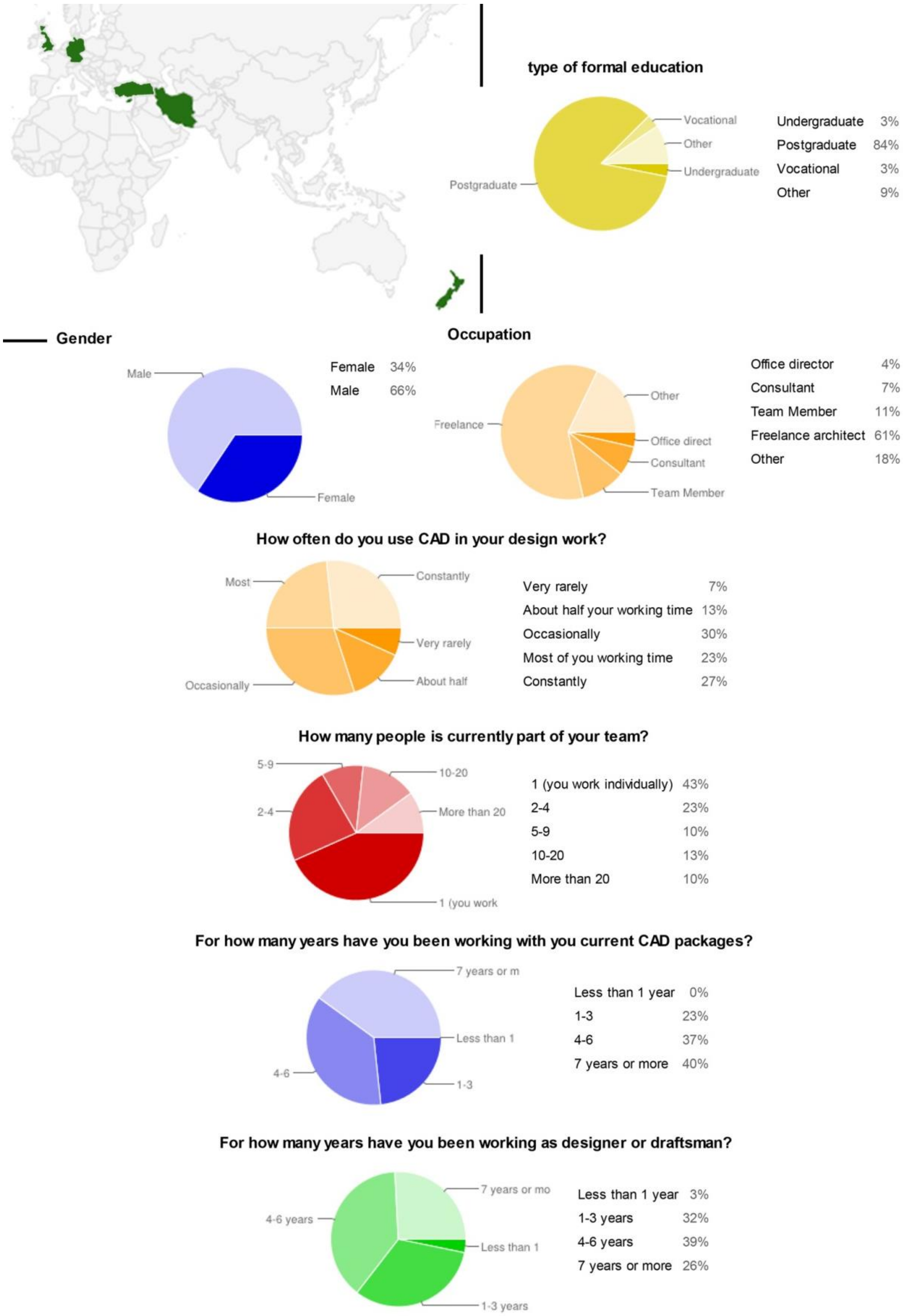

Figure 25: General information of the contributors to the survey

As the design process and the stages of design are qualitative data in order to convert them into quantitative ones, they are measured by Likert scaling system (Likert, 1932) and the raw data was analyzed in SPSS with one sample T-test method (Student, 1908) in order to calculate the weight of each attribute and extract the order of design activity. As it's discussed in second chapter, the design process had faced major fluctuations and there are diverse models for theoretical and practical framework. In this research, design procedure steps are been studied mainly through the lens of practice and tried to have a systematic order for design stages. In below tables, the statistics and T-test calculations are available (Table 8, 9).

Table 8: One-Sample Statistics for the order of design process in practice

Procedure Steps	N	Mean	Std. Deviation	Std. Error Mean
Detailing	50	7,12	2,789	.394
Ideation	50	4.16	1.931	.273
Learn & Education	50	4.92	2.996	.424
Evaluation	50	5.48	1.898	.268
Analyze	50	4.12	2.700	.382
Data collection	50	3.04	2.806	.397
Drafting	50	6.20	2.100	.297
Presentation	50	7.88	2.379	.336
Synthesize information	50	4.92	2.212	.313
Conceptualization	50	4.92	2.617	.370

Table 9: One-Sample T-test for the order of design process in practice

Procedure Steps	t	Mean Difference	95% Confidence Interval of the Difference	
			Lower	Upper
Detailing	18.048	7,120	6,33	7,91
Ideation	15.233	4.160	3.61	4.71
Learn & Education	11.614	4.920	4.07	5.77
Evaluation	20.418	5.480	4.94	6.02
Analyze	10.789	4.120	3.35	4.89
Data collection	7.660	3.040	2.24	3.84
Drafting	20.881	6.200	5.60	6.80
Presentation	23.423	7.880	7.20	8.56
Synthesize information	15.730	4.920	4.29	5.55
Conceptualization	13.292	4.920	4.18	5.66

The outcome of analytical method demonstrates that in design procedure in order to keep continuity of the stages there should be logical bridge between “Analyze” and “Ideation”, “Synthesize” and “Evaluation”, “Drafting” and “Presentation” phases. In general the process starts with data collection and after analyzing data the tool or enabler that assists this data to transform into idea is missing. It is the same for synthesizing and drafting (Table 10).

Table 10: The hierarchy of design stages

	T-test Value
Data collection	0.1
Analyze	2.9
Ideation	4.2
Learn & Education	4.5
Conceptualization	5.2
Synthesize information	6.1
Evaluation	9.2
Detailing	10.4
Drafting	10.8
Presentation	14.5

Another outcome of the survey is the placement of learning phase in the beginning stages of design procedure, and from ideation to conceptualization, the education background acts as connector. In order to have better understanding of learning phase with its upper and lower stages, the correlation of these three phases are illustrated in figure 26, and displays that in the beginning steps the process has education role and as the procedure goes on this role decreases and in the last stage again it booms.

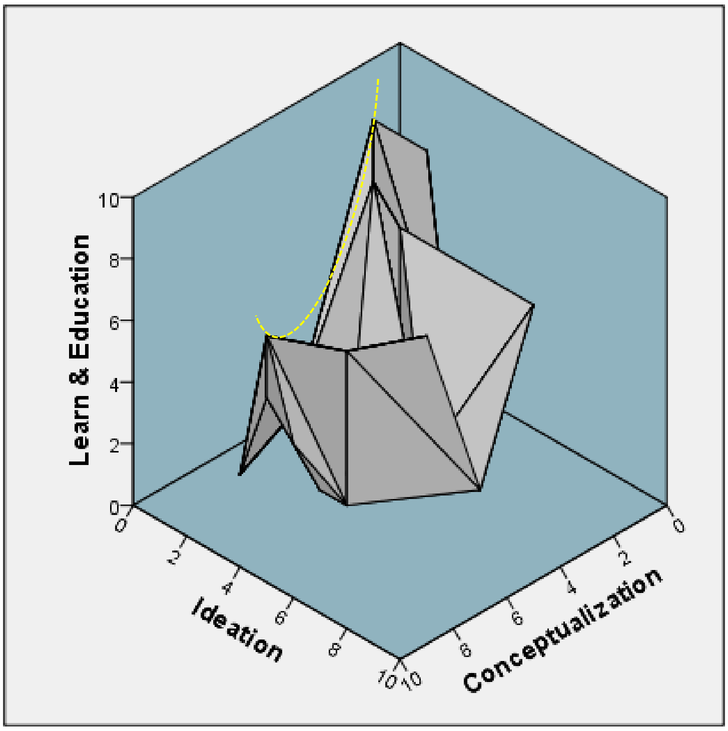

Figure 26: correlation of learning phase with ideation and conceptualization

Also the network of this phenomenon admits this declaration that there is a compressed density of connection in both beginning and ending of the procedure (Figure 27). The reason that we highlight learning stage in design procedure is that, design process in itself is sub-system of education and needs its own tools and enablers. As in the next step we are going to discuss about tools in the body of design procedure, so the education phase also needs to be considered in its own process and the relation of it with upper and lower stages of design could possibly effects the tools that we are going to assign for them.

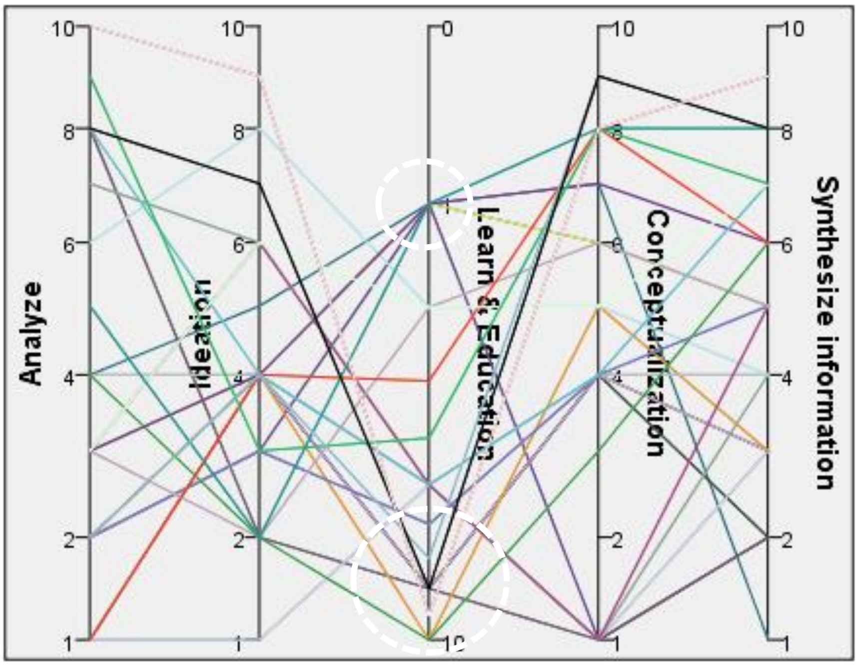

Figure 27: The GGraph networked interrelation of learning procedure in design process

As mentioned before, another main objective of this survey was to measure awareness of designers about existing computational tools that can enhance design procedure.[10] Figure 28 illustrates the rate of this awareness about the tools that are extracted from literature and practice in previous chapter. The similarity among all enablers is that more than 75% of the designers have not heard about these tools and the ones who have heard about them they do not use them in design procedure.

There are certain reasons that the designers do not use existing tools, for instance the main highlighted barrier is lack of training facilities in institutional system or in practical one (Figure 29). So why we focused on leaning stage in design process could be understood better now because in the commencing stages of design educational background can extremely boost the ability of designer if he/she has required awareness and knowledge about the tools within design procedure.

[10] The detailed results of this study is available in Appendix A

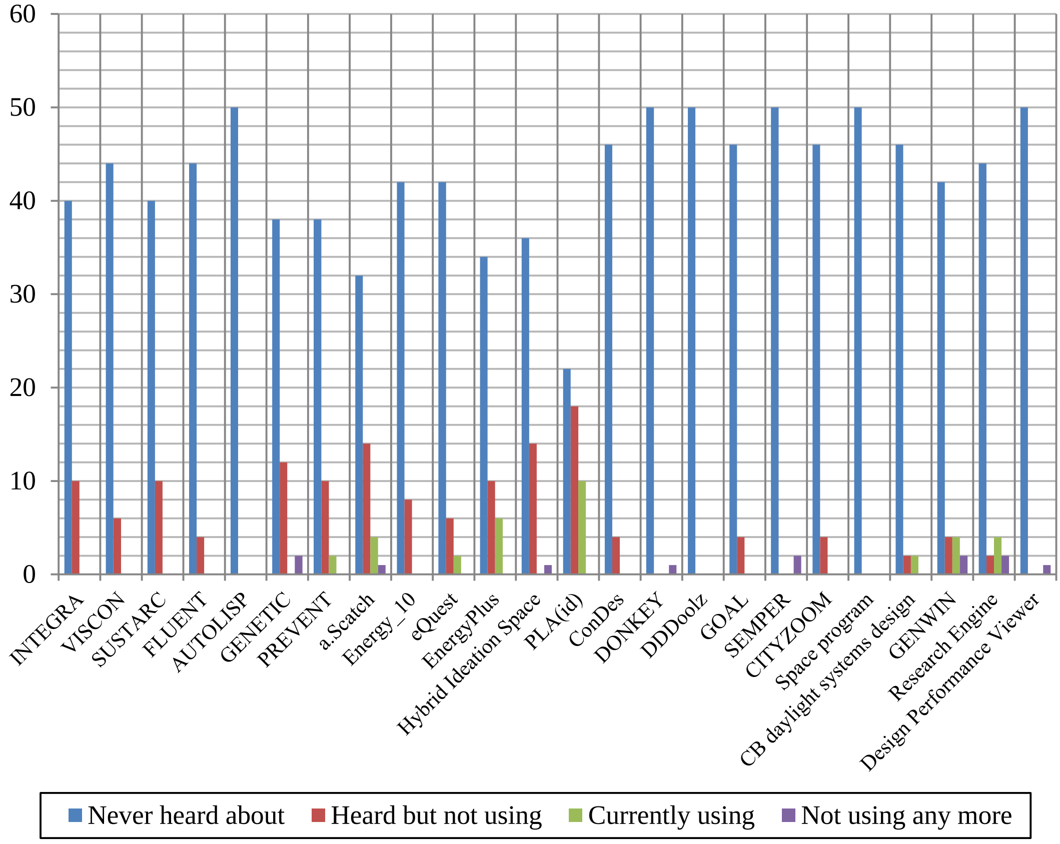

Figure 28: Awareness rate of contributors toward computational enablers

Other reasons for not implementing CAAD tools are; not being necessary for all of the projects, lack of skill and training in usage, not being user friendly interfaces and expensive or not cost effectiveness of the tools.

On the other hand the contributors in this study are asked to reply the reasons that they are using CAAD tools in their design and the most emphasized item was that they implied “CAAD tools speed up design process” which means they eager to use these kind of tools in order to have better performance in the procedure and also they admit that the tools enhance evaluation of complex design strategies (Figure 30).

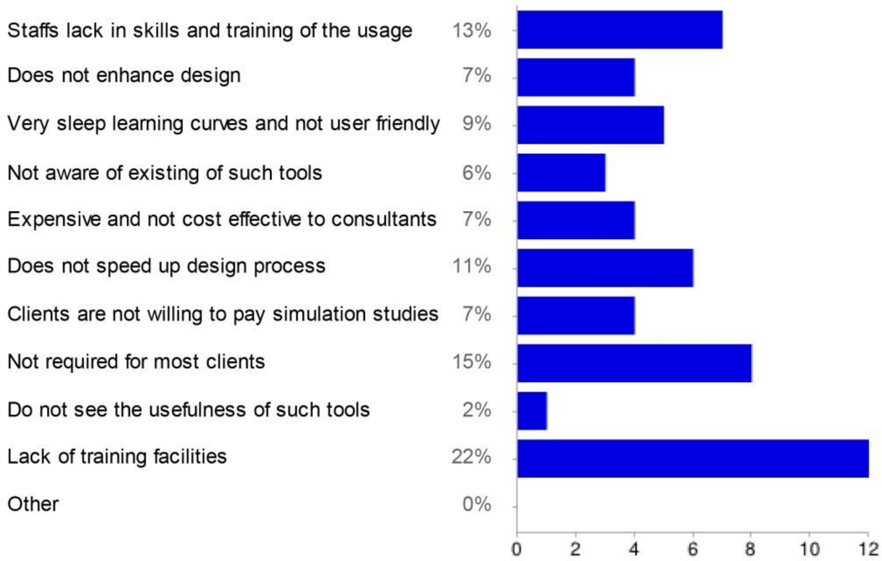

Figure 29: The reasons for NOT using CAAD tools in design procedure

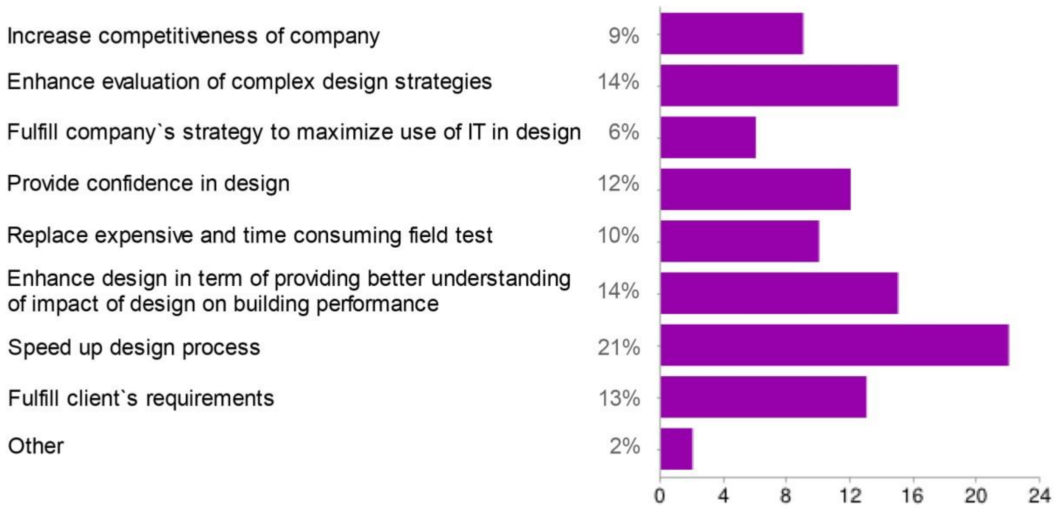

Figure 30: The reasons for using CAAD tools in design procedure

4.6 Pattern Language

Architectural design patterns of Christopher Alexander as published in “A Pattern Language” (Alexander et al., 1977) more than 35 years ago but their true implication and significance has respected only by few scholars. Nikos Salingaros (2000) is one of these practitioners that implies:

> “Patterns are a powerful tool for controlling complex processes, but because of misunderstandings, they have not played a wide role in architectural design and instead, patterns have found unexpected success in computer science (Gabriel, 1996; Gamma, Helm, Johnson, & Vlissides, 1993; James, 1995)**.** Unfortunately, the pattern language was never claimed to be a design method and it is always a struggle to integrate patterns into an actual design project. Architects, however, desperately need a self-contained design method or system”.

The built environment consists of two main actors; the physical geometry and the people. People have fundamental emotional and physical requirements that should be satisfied by means of built environment and regrettably most of them are neglected nowadays. The positive point of Alexander`s work was considering the human and the pattern of human life as a focal point in architecture design. On the other hand the geometry of built environment has always considered as the specialty of design language. But in contemporary era, the exploration and explanation of geometry has been transformed and the advent of free form shapes has entirely varied this condition. As discussed before, the procedure of architecture form finding is quickly becoming complex by means of digital technology and innovative tools and at the same time lacking of coherent and comprehensive system of design creates another problem and makes the situation even worse.

Today architecture discourse is highly dependent on research facilities and tools. Some research is being done about the architectural geometry aiming at the development of more practical tools but primarily there is a need for a methodology for bringing these tools together (Pottmann, 2010). In order to create successful interactive systems in design, and to improve its interaction with user, the designers and architects there is a need for variety of experts from different professions as a multi-disciplinary team but at the same time this group lacks common terminology to share and exchange ideas, values and opinions (Borchers, 2001). In this research we are trying to integrate commonalities and tools in diverse disciplines and propose an approach that uses pattern language methodology to intersect and capture the body of knowledge from different disciplines and connect them in a manageable, understandable, practical and improvable system of architecture design.

When we are talking generally about design, there are some common and shared problems and lacking languages. In architecture design it is really difficult to transform knowledge or data sets into following stages of design but having certain tools will enhance this absence. It is where pattern language can improve the problem break the complex system into manageable sub-systems and interpret each of them with appropriate tools (Kim, 1990). Pattern language can help the designer to challenge with complexity of systems in different scales ranging from buildings to cities. Each pattern which is called sub-system, contains certain rules in itself and the patterns are information based pieces that are the outcome of specific enabler and mainly targeting the human being needs in the built environment (Borchers, 2001).

4.7 The Language of Patterns Association

In this research we tried to work on the origin of design process on one hand and construct an actual system of design procedure based on pattern language on the other hand. In pattern language, each pattern stands for a problem in design procedure and the solution of this problem is a universal one that could be applied in different contexts and hundred times over and over. The nature of connection between patterns is also followed by process in other words, the tools which we discussed and categorized, are going to deal with certain problems and will enhance them in the body of the procedure itself. In short, none of the patterns are isolated entities. Nikos Salingaros (2000) provides a better understanding of what is meant by patterns connectivity:

- Each pattern contains solution for set of problems in itself.
- Set of patterns are corresponding to each other and one needs the other pattern for completeness.
- Diverse patterns solve different problems that may possibly overlap and exist on the same level and they can solve problem in equally or alternative ways.
- Distinct patterns share a similar structure, thus implying a higher-level connection.

With considering these rules in the skeleton of pattern language, and thinking once more about the principles of parametric design; we can admit that, nature of pattern language in its “sub-patterns” acts like parametric design system. Because in parametric design each parameter deals with certain set of problems and these parameters are not isolated from each other, which means that any kind of diversification, alteration or transformation will have impact on the system. Now let's return back to the idea of pattern language and consider each pattern as set of parameters which are set in order to improve certain problems in design procedure, so the system or the language that links these patterns together, could be a system which defines certain enablers that get inputs (parameters) and gives solutions for the design problem. In short, the parametric design system can be interpreted as the language of patterns. Clarkson & Eckert (2005) describe "Patterns of Designing" as the aspects of design process that can shape the whole system of design (Figure 31).

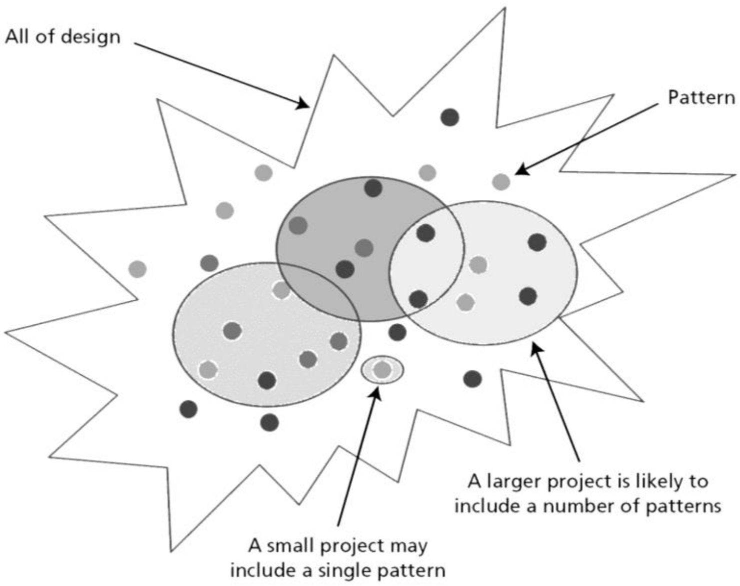

Figure 31: Diagram of design with patterns (Clarkson & Eckert, 2005)

Each design sub-system could be described with referencing to the pattern that occurs in consequence with the existing problem. Patterns of designing can input different kinds of parameters according to the enabler capacity. Design patterns terminology refers to an abstractly generated solution in order to curing the problem, together with the explanation of problem type, the enablers and the consequence of applying this pattern. This is the concept that introduced into architecture discourse by Christopher Alexander and extensively adopted in software engineering . It is now time to apply this mode of thinking and methodology of systematic approach into architecture design procedure and implementing contemporary technology, existing tools and bridging theory and practice in a way that answers the problem of present-day architecture design.

Chapter 5

CONCLUSION

5.1 Introduction

The Roman and Ancient Greeks have maintained the role of architects as the one whom strengthens the existing structure of fortifications (Vitruvius, 1914), and supporting the design and construction of building by means of visualization and communication. Whereas this role has not been changed considerably since Renaissance, the methods of the architecture design and the procedure have altered in countless directions. Particularly, the computational tools and technologies which at the first evolved to support the design procedure recently started to alter the mode of working and thinking of the architects. Thus, this chapter is going to illustrate a framework of architectural design procedure based on the evolution of existing process, applicable tools and enablers, theory of design thinking and based on methodology of pattern language.

This proposal is a systematic approach toward design procedure and the stages of design. The main concept of the model is based on four sub-systems; representational, proportional, indexical, and operational that are supported by range of computerized enabler and connected to each other as a system. The purpose of emerging this model is to highlight the necessity of reconsidering design process in architecture and updating it through technological and innovative tools. Computer based methods are recently used as an impressing tools in various fields of architecture design such as creating odd geometries. These tools are needed to be applied in a way that produce and design better buildings, Schlueter & Thesseling (2009) believes that:

> "New tools make it possible to design and actually build forms that would not be possible without the use of computers. These powerful methods have to be applied to actually design better building, not only better looking ones. Incorporating building performance analysis into the design process could utilize the full potential of computational methods in architecture. To capture the complex dependencies, to view the building as a system makes new approaches in architecture possible. These approaches have to be further explored".

One of the applicable investigations toward shifting and improving architecture design is rethinking about the process of it. The advent of CAD tools and increasingly implementation of them will unquestionably have impact on the process itself in this increasingly knowledge based era (Séquin & Kalay, 1998). The concept of using CAD tools is most of the time considered as the procedure which the designer or the architects would be the end-user with no contribution to the procedure itself. In other words, when the operator works with the application, expects to have the final outcome by series of inputs and not thinking about the procedure in computational or parametric way. As the complexity of a system increases the reliability of traditional methods become increasingly challenging and there is necessity to have more holistic, qualitative and/or quantitative, in-depth approached to represent innovative, knowledge-based, meaningful and intelligent solutions.

5.2 Parametric Design Thinking Framework (PDT)

The main challenge of this research since the beginning was to have a systematic approach and perspective on design procedure rather than an introverted close-ended process, and it is briefly discussed that traditional design procedures seem not to be efficient enough for contemporary architecture design and even design education. Also it is discussed the possibilities and advantages of transforming design into design thinking model.

This research tried to implement maximum potentiality of architecture theory within practice in order to propose a system which has the capacity of dealing with complex problem not only in theoretical framework but at the same time in practical discourses by means of implementing available tools, methodologies and enablers. The main structure of the PDT model is based on theory of pattern language and each problem in design procedure could possibility managed within series of patterns. These patterns are enabled to deal with complex problems by means of implementing certain tools that we discussed. Each pattern is capable of dealing with set of problems by using assistive technologies that transform the problem in understandable manner into solutions. These assistive technologies and tools and enablers in themselves are following bottom-up and top-down process. In other words, the top-down geometrical, parametrical and/or non-parametrical forces are imposed from the designer into the program or software and at the same time there are bottom-up forces/or guidelines that the tools are imposing to the designer or operator. Generally the procedure is that the top-down force inserts specific data and information into the parametric bottom-up system(Oosterhuis, 2012). These parametrical constraints generate a pattern layer that act as connector between the tools and design activity stages. Pattern layers in themselves are closed loop because this circulation continues until the optimized solution is being created.

Mainly PDT model is knowledge-based system in order to have maximum connectivity, flexibility, applicability, transformability and updatability according to diverse dimensions of contemporary changing era and available tools. The intersection and relation of these three items are illustrated in Figure 32.

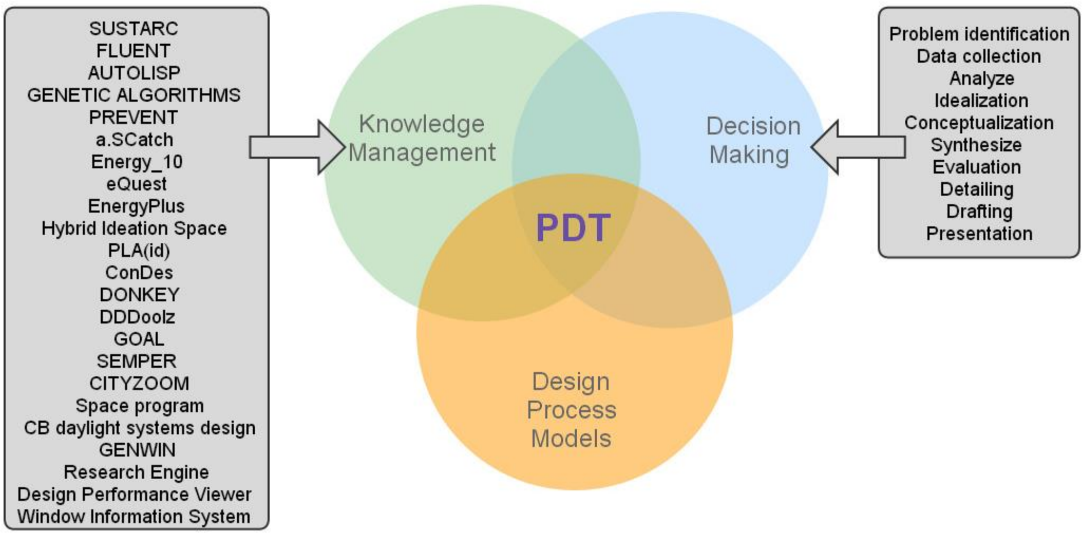

Figure 32: Knowledge-based Model for design procedure, Proposed by author

This model is mainly organized from 3 main magnets; decision making, knowledge management and design process models. Decision making activity is the abstract of our survey on design functions among architects and it creates a systematic layer which prioritizes the thinking order of designer. On the other hand we discussed about research, meaning creation, contextualization and practicalization in the body of design thinking by, means of using different methodologies in design. In order to achieve it, knowledge management layer which is supported by practical tools is implemented. The bottom part of PDT model is facing with design process models that are proposed for parametric and computational design that it is discussed as parametric design procedures.

PDT framework functions as systems in themselves that clusters of design activity layers and in outer layers there are sub-systems of design (representational, proportional, indexical, and operational) which are layered on top of each other. Also from the existing models for parametric design different agents or team such as: scientist, engineer, Fabricator, Contractor and designer are conceived and tried to apply to the holistic procedure, because this system enables them to collaborate and share commonalities at the same time. Through the existing enabler "INTEGRA" multiple applications in an integrated environment could be implemented (Bouchlaghem et al., 2005).

It is tied to propose PDT model by considering the previously projected solutions. As discussed in design thinking sections, the evolution of design thinking has started by Simon`s ideas about artificial intelligence and bringing research into the core of design and after that with Schön's philosophies shifted this route into practice-based frameworks and being contextualized from problem solving notions. In some theories of Lawson this procedure got a process-based structure and finally Krippendorff added some drops of semantics in the package. Design thinking, in its fluctuating way, had become mature by means of theory and practice but these elements are like pieces that need a structure or system to put them together and at the same time make them more practical, professional and knowledge-based.

In the proposed model as well as enhancing design thinking in a systematic manner it is tried to build up a common ground for different kind of parameters quantitative and/or qualitative together by means of highlighting the necessity of implementing methodologies and tools in design procedure. This system works in multi layering method and there is no linear or any kind of strict process. This flexibility gives chance to the system to embed infinite number of parameters in design procedure. Another issue is about pattern layer that is located between the design activity and the enabler or methodologies. So as the design activity goes in hierarchical manner the enabler in different layers creates solutions in the shape of patterns and this procedure goes on (Figure 33).

Sub-systems	**Design Activity**	**Pattern Layer**	**Knowledge Data Base**
Representational	Data collection Analyze Ideation	Top-Down Bottom-Up	a.SCatch Research Engine Energy_10 CITYZOOM Window Information System GENETIC ALGORITHMS Hybrid Ideation Space DDDoolz
Proportional	Conceptualization Synthesize information	Top-Down Bottom-Up	DONKEY GOAL CB daylight systems design FLUENT AUTOLISP ConDes Design Performance Viewer
Indexical	Evaluation Detailing	Top-Down Bottom-Up	PLA(id) GENWIN SUSTARC PREVENT eQuest SEMPER
Operational	Drafting Presentation	Top-Down Bottom-Up	EnergyPlus VISCON

Figure 33: Parametric Design Thinking model (PDT), Proposed by author

The PDT model starts with understand the sub-systems of design which is supported by series of design activities. The design activity layer starts with data collection “procedure” not essentially a “step” because in representational sub-system, the design activity consists of data collection, analyze and ideation with the support of knowledge data base in the shape of design patterns. These patterns according to the scale and complexity of the project could be altered. The alteration of patterns is the positive outcome of having diverse methodologies and tools for each design problem. This procedure goes on for commencing sub-systems and there is no end product because, since the beginning of procedure the start and the end is visible, manageable, understandable and applicable. This flexibility in design is the outcome of parametric thinking because any small alteration in any sub-system or design activity will affects the whole procedure of design and this alteration and differentiation is not hidden in contrast with traditional design processes. The improved characteristics of design process in PDT framework could be illustrated as:

1. There is no linear process like manufacturing system for design because design is about creating values not products.
2. The projected framework is not an introverted system in strict boundaries and stages, the system possibly has the degree of flexibility according to design alterations.
3. The scale of the project is applicable in PDT framework because, the patterning system allows the designer to choose among density of patterns according to the scale of project.
4. The balance between design and research is tried to be kept during the procedure, and each enabler in itself acts like a process in order to be able to create solutions and patterns.
5. The term complexity is embedded in the PDT model and it could possibility be adapted to complex problem solving procedures which is the main necessity of contemporary architecture.

6. The framework is specially generated for architecture design in contrast with traditional design processes that applied for different discourses. Contemporary era necessitated specialization in each field and the implementation of pattern layers and different enablers in PDT model gives the sense of specific architecture design system to it.
7. PDT framework is abstract of practice and theory because it is generated by researching in existing and ongoing design activity among architects not only the theorists in order to prevent any unpractical reflection.
8. Computer aided design tools act as practical enablers in PDT model in order to bridge design activities to avoid incomplete and ineffective linear process of traditional design.

Parametric design thinking framework is the beginning of long journey for contemporary design procedure and there is a common ground for further studies in detail. There is set of data in Appendix C about the application of CAAD tools in each stage of design activity and could possibly be a common ground for future investigations. The main achievement of this model could be estimated as bringing different parameters into the structure of design procedure and reflection of the term “technology” on detailed phases of design by means of improving the gap between theory and practice by means of implementing existing tools. The term technology is conducted as a discipline of systematic thinking rather than a simple product. This model in the future could be tested and implemented for designers and even in architecture schools step by step. It is not possible to detach design process from design education and the contemporary education system as well as architecture discipline needs to have training systems based on technological and assistive tools.

The proposed framework could be investigated through its sub-systems and in future could be restructured based on updated practicality, also it could be groundwork for parametric design and computational design to embed their achievement in the body of design process. It is expected that this research would be a common ground and an initial starting point for achieving a practical parametric design procedure model in architecture design and education. Study on design process could never end, because it is the base of architecture education since the beginning of design institution.

It is believed that the collaboration of different disciplines under the shelter of systematic procedure could enhance the quality of architecture design and the application of contemporary tools not only in theory but mainly in practice will help to understand design activity as intersection of research, process, management, practice, technology, and diverse effective discourses and parameters. This thesis could also be useful for the future researchers who are willing to study on parametric design related issues.

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APPENDICES

Appendix A: Frequency Table for Awareness of the Applicant about Enablers

INTEGRA		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Never heard about	40	80.0	80.0	80.0
	Heard but not using	10	20.0	20.0	100.0
	Total	50	100.0	100.0	
VISCON		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Never heard about	44	88.0	88.0	88.0
	Heard but not using	6	12.0	12.0	100.0
	Total	50	100.0	100.0	
SUSTARC		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Never heard about	40	80.0	80.0	80.0
	Heard but not using	10	20.0	20.0	100.0
	Total	50	100.0	100.0	
FLUENT		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Never heard about	44	88.0	88.0	88.0
	Heard but not using	6	12.0	12.0	100.0
	Total	50	100.0	100.0	
AUTOLISP		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Never heard about	50	100.0	100.0	100.0
GENETIC		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Never heard about	38	76.0	76.0	76.0
	Heard but not using	12	24.0	24.0	100.0
	Total	50	100.0	100.0	
PREVENT		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Never heard about	38	76.0	76.0	76.0
	Heard but not using	10	20.0	20.0	96.0
	Currently using	2	4.0	4.0	100.0
	Total	50	100.0	100.0	
a.Scatch		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Never heard about	32	64.0	64.0	64.0
	Heard but not using	14	28.0	28.0	92.0
	Currently using	4	8.0	8.0	100.0
	Total	50	100.0	100.0	
Energy_10		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Never heard about	42	84.0	84.0	84.0
	Heard but not using	8	16.0	16.0	100.0
	Total	50	100.0	100.0	
eQuest		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Never heard about	42	84.0	84.0	84.0
	Heard but not using	6	12.0	12.0	96.0
	Currently using	2	4.0	4.0	100.0
	Total	50	100.0	100.0	
EnergyPlus		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Never heard about	34	68.0	68.0	68.0
	Heard but not using	10	20.0	20.0	88.0
	Currently using	6	12.0	12.0	100.0
	Total	50	100.0	100.0	
Hybrid Ideation Space		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Never heard about	36	72.0	72.0	72.0
	Heard but not using	14	28.0	28.0	100.0
	Total	50	100.0	100.0	

PLA(id)		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Never heard about	22	44.0	44.0	44.0
	Heard but not using	18	36.0	36.0	80.0
	Currently using	10	20.0	20.0	100.0
	Total	50	100.0	100.0	
ConDes		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Never heard about	46	92.0	92.0	92.0
	Heard but not using	4	8.0	8.0	100.0
	Total	50	100.0	100.0	
DONKEY		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Never heard about	50	100.0	100.0	100.0
DDDoolz		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Never heard about	50	100.0	100.0	100.0
GOAL		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Never heard about	46	92.0	92.0	92.0
	Heard but not using	4	8.0	8.0	100.0
	Total	50	100.0	100.0	
SEMPER		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Never heard about	50	100.0	100.0	100.0
CITYZOOM		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Never heard about	46	92.0	92.0	92.0
	Heard but not using	4	8.0	8.0	100.0
	Total	50	100.0	100.0	
Space program		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Never heard about	50	100.0	100.0	100.0
CB daylight systems design		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Never heard about	46	92.0	92.0	92.0
	Heard but not using	2	4.0	4.0	96.0
	Currently using	2	4.0	4.0	100.0
	Total	50	100.0	100.0	
GENWIN		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Never heard about	42	84.0	84.0	84.0
	Heard but not using	4	8.0	8.0	92.0
	Currently using	4	8.0	8.0	100.0
	Total	50	100.0	100.0	
Research Engine		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Never heard about	44	88.0	88.0	88.0
	Heard but not using	2	4.0	4.0	92.0
	Currently using	4	8.0	8.0	100.0
	Total	50	100.0	100.0	
Design Performance Viewer		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Never heard about	50	100.0	100.0	100.0

Appendix B: The Sample of Questionnaire

Design Process & CAAD Tools

By the advent of computational problem solving methods and their application in architecture it seem that there is still no obvious realm of proposed design process based on parametric thinking and computational problem solving; also the traditional design processes seems to be not practical enough in computational design thinking procedure.

The main aim of the research is to question implementation of existing tools through design process and the survey is generally organized for the ones who are practicing architecture and designing professionally.

Note: In this survey the term 'CAD' stands for "Computer Aided Design" and 'CAAD' stands for "Computer Aided Architecture Design"

* Required

Gender

Mark only one oval.

- Female
- Male

Nationality *

____

Occupation

Mark only one oval.

- Office director
- Consultant
- Team Member
- Freelance architect
- Other: _______________

How many people is currently part of your team?

Mark only one oval.

- 1 (you work individually)
- 2-4
- 5-9
- 10-20
- More than 20

Which type of formal education have you received?

Mark only one oval.

- ◯ Undergraduate
- ◯ Postgraduate
- ◯ Vocational
- ◯ Other: ____________

For how many years have you been working as designer or draftsman?

Mark only one oval.

- ◯ Less than 1 year
- ◯ 1-3 years
- ◯ 4-6 years
- ◯ 7 years or more

Which CAD program do you primarily use in design procedure?

Check all that apply.

- ☐ Rhinoceros
- ☐ Generative Components
- ☐ Revit Building
- ☐ Paracloud
- ☐ Architectural Desktop
- ☐ Archicad
- ☐ Digital project
- ☐ Grasshopper
- ☐ AutoCad
- ☐ FormZ
- ☐ Maxxon Form
- ☐ Maya
- ☐ MicroStation
- ☐ Allplan
- ☐ Catia
- ☐ Vectorworks
- ☐ Processing
- ☐ Other: ____________

For how many years have you been working with you current CAD packages?
Mark only one oval.

- ⬭ Less than 1 year
- ⬭ 1-3
- ⬭ 4-6
- ⬭ 7 years or more

How often do you use CAD in your design work?
Mark only one oval.

- ⬭ Very rarely
- ⬭ About half your working time
- ⬭ Occasionally
- ⬭ Most of you working time
- ⬭ Constantly

10. **How often do you use CAD tool in the following design phases?**
Mark only one oval per row.

	Very often	often	occasionally	rarely	never
Data collection	⬭	⬭	⬭	⬭	⬭
Analyze data	⬭	⬭	⬭	⬭	⬭
Synthesize information	⬭	⬭	⬭	⬭	⬭
Ideation	⬭	⬭	⬭	⬭	⬭
Conceptualization	⬭	⬭	⬭	⬭	⬭
Drafting	⬭	⬭	⬭	⬭	⬭
Evaluation	⬭	⬭	⬭	⬭	⬭
Detailing	⬭	⬭	⬭	⬭	⬭
Presentation	⬭	⬭	⬭	⬭	⬭
Learn & Education	⬭	⬭	⬭	⬭	⬭

11. **In this question you are asked to put design phases in an order that you follow in your own design procedure**
(Each phase should be assigned only one number)
Mark only one oval per row.

	1	2	3	4	5	6	7	8	9	10
Detailing	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
Ideation	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
Learn & Education	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
Evaluation	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
Analyze data	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
Data collection	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
Drafting	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
Presentation	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
Synthesize information	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
Conceptualization	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

12. **How is your awareness about the existence of below mentioned tools?**
Mark only one oval per row.

	Never heard about	Heard but not using	Currently using	Not using any more
INTEGRA	⬭	⬭	⬭	⬭
VISCON	⬭	⬭	⬭	⬭
SUSTARC	⬭	⬭	⬭	⬭
FLUENT	⬭	⬭	⬭	⬭
AUTOLISP	⬭	⬭	⬭	⬭
GENETIC ALGORITHMS	⬭	⬭	⬭	⬭
PREVENT	⬭	⬭	⬭	⬭
a.SCatch	⬭	⬭	⬭	⬭
Energy_10	⬭	⬭	⬭	⬭
eQuest	⬭	⬭	⬭	⬭
EnergyPlus	⬭	⬭	⬭	⬭
Hybrid Ideation Space (HIS)	⬭	⬭	⬭	⬭
PLA(id)	⬭	⬭	⬭	⬭
ConDes	⬭	⬭	⬭	⬭
DONKEY	⬭	⬭	⬭	⬭
DDDoolz	⬭	⬭	⬭	⬭
GOAL	⬭	⬭	⬭	⬭
SEMPER	⬭	⬭	⬭	⬭
CITYZOOM	⬭	⬭	⬭	⬭
Space program	⬭	⬭	⬭	⬭
CB daylight systems design	⬭	⬭	⬭	⬭
GENWIN	⬭	⬭	⬭	⬭
Research Engine	⬭	⬭	⬭	⬭
Design Performance Viewer (DPV)	⬭	⬭	⬭	⬭
Window Information System (WIS)	⬭	⬭	⬭	⬭

What are your reasons for using CAD programs?

Check all that apply.

- [ ] Increase competitiveness of company
- [ ] Enhance evaluation of complex design strategies
- [ ] Fulfill company`s strategy to maximize use of IT in design
- [ ] Provide confidence in design
- [ ] Replace expensive and time consuming field test
- [ ] Enhance design in term of providing better understanding of impact of design on building performance
- [ ] Speed up design process
- [ ] Fulfill client`s requirements
- [ ] Other: ....

What are your reasons for NOT using CAD tools?

Check all that apply.

- [ ] Staffs lack in skills and training of the usage
- [ ] Does not enhance design
- [ ] Very sleep learning curves and not user friendly
- [ ] Not aware of existing of such tools
- [ ] Expensive and not cost effective to consultants
- [ ] Does not speed up design process
- [ ] Clients are not willing to pay simulation studies
- [ ] Not required for most clients
- [ ] Do not see the usefulness of such tools
- [ ] Lack of training facilities
- [ ] Other: ....

What are the enhancements of design process by using integrate design supportive tools?

Check all that apply.

- [ ] Achievement of total building performance and system integration
- [ ] Enhance evaluation of complex design strategies
- [ ] Better understanding of impact of design on multiple performance mandates
- [ ] Speed up design process

Are there any barriers to your use of available tools related to architectural design process?
Check all that apply.

- [ ] Tools are too complex
- [ ] Tools are too expensive
- [ ] Tools are not integrated in CAAD software
- [ ] Tools take too much time consuming
- [ ] Tools are not integrated in workflow
- [ ] Tools are not applicable
- [ ] Tools not adequately support conceptual design stage
- [ ] There is no systematic integration between tools
- [ ] Tools are too simplistic, info missing
- [ ] Other: ____________________

Do you see a need for improved tools to support the integration of design process and CAAD?
Check all that apply.

- [ ] Yes, we need improved tools for briefing and data collection
- [ ] Yes, we need improved tools for analyzing and synthesizing data
- [ ] Yes, we need improved tools for conceptual phase
- [ ] Yes, we need tools for preliminary design phases
- [ ] Yes, we need tools for construction drawing phases
- [ ] Yes, we need tools for evaluation phases
- [ ] Yes, we need tools for detail design phases
- [ ] Yes, we need tools for design documentation
- [ ] Yes, we need tools for design presentation
- [ ] No, I find available tools quite satisfactory

Appendix C: The Weight for Implementation of CAAD Tools in Design Phases (For further study)

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Detailing	50	2,70	1,406	.181
Ideation	50	2.97	1.365	.176
Learn & Education	50	3.03	1.288	.166
Evaluation	50	3.13	1.186	.153
Analyze	50	3.23	1.064	.137
Data collection	50	3.70	1.225	.158
Drafting	50	3.67	1.258	.162
Presentation	50	4.07	1.376	.178
Synthesize information	50	4.00	1.135	.147
Conceptualization	50	3.57	1.125	.145

One-Sample Test

Procedure Steps	t	Mean Difference	95% Confidence Interval of the Difference	
			Lower	Upper
Detailing	13.590	2,800	2,39	3,21
Ideation	15.721	3.060	2.67	3.45
Learn & Education	17.799	3.120	2.77	3.47
Evaluation	19.208	3.200	2.87	3.53
Analyze	21.731	3.300	2.99	3.61
Data collection	23.370	3.720	3.40	4.04
Drafting	23.888	3.800	3.48	4.12
Presentation	22.627	4.140	3.77	4.51
Synthesize information	26.835	4.020	3.72	4.32
Conceptualization	25.038	3.720	3.42	4.02