Digital Realm: Parametric-enabled Paradigm in Architectural Design Process

Naglaa A. Megahed*

Architecture and Urban Planning Department, Faculty of Engineering, Port Said University, Port Said, Egypt

Abstract: With the rise of digital design tools in architecture, this study aims to participate in the current debate taking into account a holistic approach of the parametric paradigm and some of the major potentialities that emerge from its use in the discipline. This paper therefore aims to review this new paradigm and propose a conceptual framework based on its models, levels and systems that support the architectural design process. This framework may help architects realize the potential of parametric tools by using and thinking of parameterization as a general procedure from the initial stage of form-finding to the process of manufacturing. However, the paper argues that the parametric-enabled paradigm is often incorrectly mistaken as an emerging architectural style rather than a computational tool. Therefore, a critical awareness of both the potentials and limitations of parametric paradigms is imperative in the effective use of these models and in understanding how they will continue to change the architectural profession.

Keywords: Architectural design, geometry, optimization, parametric models, parameterization

DOI: 10.7492/IJAEC.2015.018

1 INTRODUCTION

During each period of civilization, architecture has reflected the level of societal development by integrating the state of the art from various fields of human activity. In contemporary architectural design, parametric tools are the latest advancement in digitally aided design. Thus, the question of whether parameterization can assist the architectural design process is an important topic to explore.

Parametric modeling is a relatively new science, originally developed for solving the complex geometry of automotive design. Recently, this new paradigm has been applied to assist the architectural design of complex building patterns, envelopes and structures. Further, these recent and continuous developments have begun to exert a significant influence on the architecture profession (Schumacher 2012; Svoboda et al. 2014). It has become a well-utilized tool in many types of design, especially after the emergence of modeling software and the accurate results of optimization. The computer can aid designers in exploring a wide range of options that the designer would not or may not have the time to explore on their own by traditional methods (Jester 2014; Lee et al. 2012). This digital realm raised the questions of how architects could use digital and parametric tools and at what stage parameterization should enter the architectural design process. This debate also leads to the other questions posed in this study:

- Could digital tools improve the architectural design process or are they just a way to express modernity and fashionable paradigm? If so,
- How are these tools utilized in the architectural design process, and what influence do they have on the form-finding process?
- Could parametric modeling convert the design process from form-making to form-finding? If so,
- Is the most effective use of parametric software simply to generate unusual forms? If so,
- Are we now entering a completely digital architecture age in which form follows software?
- Finally, what should be the extended role and influence of architects?

These are some of the questions that are raised by all those involved with parameterization in the architectural profession. The answers to these questions are closely linked to each other, and are still the subject of significant research in the field.

*Email: Naglaaali257@hotmail.com
Although a lot of scholars’ papers discuss the parametric paradigm in architecture, a holistic approach has been neglected in this literature until now. Most importantly, limited efforts have been made to develop a multidisciplinary framework that helps architects gain the required knowledge to realize the parametric paradigm. In this context, this review paper proposes a more holistic view and tackles the abovementioned research questions.

2 RESEARCH METHODOLOGY

In order to present a holistic approach of the role of parametric-enabled paradigm in architectural design process and answer the research questions, the study begins with a brief review of the current developments in parametric design, models and techniques as well as their relations to the architectural design process. In addition, the results obtained from this review are used to propose a conceptual framework that supports design exploration and the customization of the desired performance. Then, the expanded role of the architect is discussed and some misconceptions regarding parametric applications are presented.

3 BACKGROUND: ARCHITECTURAL DESIGN DEVELOPMENTS

Beyond just a process of finding solutions, architectural design also involves redefining design problems and searching for better solutions (Yu et al. 2013). Whether or not it utilizes the aid of computers, the process involves design activities which can be categorized as either routine or non-routine. However, during the last decade research into the architectural design process utilizing ideas and models drawn from digital technologies has resulted in a better understanding of design as a process, particularly routine design and recently have the potential role to support creativity throughout non-routine activities (Gero 1990; Gero and Maher 2013). This digital realm has enabled designers to work with highly complex geometry and enormous data to explore a whole new design field that requires computation techniques. According to Woodbury (2010), parametric tools support the creation, management and organization of complex digital design models. By changing the parameters of an object, a potentially infinite range of possibilities can be created (Kolarevic 2003).

Recently in the fabrication industry, a new generation of 3D parametric modeling tools have become available. In addition, new software and techniques for CAM modeling and computer numerically controlled (CNC) fabrication hold the potential to make it easier to implement modeling of buildings and their subsystems. As a result, famous and international architectural offices are deeply committed to researching the potential role of digital technologies (Feng 2013; Jester 2014; Oxman 2008).

3.1 Variations in the Architectural Design Process

Due to the open-edit nature of the design process, which is often based on the trial-and-error method, problems and solutions cannot be clearly identified and separated. Each set of problems and solutions cannot be broken into parts that can be solved separately; instead, it has to be treated as a whole (Gero and Maher 1988). Moreover, there is no perfect solution, only preferred solutions. This means that the architect needs to be able to decide when to stop exploring different ideas (Parthenios 2005; Xia 2008). This phase will basically determine the building’s shape, space, envelope and other expressive parameters as well as essential factors regarding the environmental forces. In this context, variations in design are a fundamental part of the design process (Hernandez 2006; Lin et al. 2013).

As is generally the case in architectural design, different designers have their own design strategies; for example, some designers prefer to start from functional analysis, while other designers focus on geometric modeling as the priority. However, parametric design is a dynamic, rule-based process controlled by variations and parameters in which multiple design solutions can be developed in parallel. It is up to designers to decide how many of these conditions to consider (Yu et al. 2013).

3.2 Evolving Parametric-enabled Paradigm

In order to understand what “parameter” means, it is helpful to look briefly at several definitions of this term. Generally, the term “parameter” originates in mathematics; it is a derivative of the word “parameter” which is technically defined as numerical or other measurable factors. Parameters are the constants in an equation, a set of equations or a computer program that limits what the equation will produce (Hudson 2010). While today the term “parameter” is generally related to the computational world, it has existed much longer and has always influenced great architecture. Advancements in technology have made parametric modeling more powerful, but the thought process behind the software has existed for centuries (Coyne 2014; Jester 2014). However, as architects have adopted parametric modeling as a design tool, the definition of the term “parameter” has become confused (Davis 2013).

For architectural design, the parametric-enabled paradigm is a key concept in modern design. This paradigm is a process based on algorithmic thinking that enables the expression of parameters and rules that define, encode and clarify the relationship between design intent and design response (Woodbury 2010).
4 PARAMETRIC-ENABLED PARADIGM: A HOLISTIC APPROACH

This section presents a holistic approach of the role of parametric-enabled paradigm in architectural design. To fully understand this role, this section is going to deal with three aspects: a) presenting the conceptual framework of different parametric models throughout the architectural design process; b) identifying strengths, limitations and misconceptions regarding the paradigm, and; c) clarifying the expanded role of the architect during the digital realm.

4.1 Models of Architectural Design Process

According to the previous background, digital realm presents flexible tools to search for the most suitable variations in the design process. Parametric modeling has become increasingly prevalent in architectural design in recent years. Previous studies have argued that parametric tools advance design processes in different approaches (Attar et al. 2009; Burry 2003; Caetano et al. 2015; Chokhachian and Atun 2014; Dino 2012; Kolarevic 2003; Rybczynski 2013; Holzer et al. 2007; Kotnik 2010; Larsson et al. 2012; Oosterhuis et al. 2004; Oxman 2008; Stavric and Marina 2011; Woodbury et al. 2006). In spite of all the differences in modeling and editing software, parametric design tools are utilized mainly in multidisciplinary design optimization (Aish and Woodbury 2005; Yu et al. 2013). This study tries to review these optimization approaches and presents a conceptual framework based on the available literature on different parametric models. This framework divides the models of design process into two main approaches (see Figure.1). The first approach concerns the parameterization of geometric optimization and the second approach refers to digital fabrication and project management. Generally, these approaches that support the variation in parametric design include formation models, generative models, performance models and fabrication models. However, the framework does not focus on one specific model; instead, it provides a panorama for all parameterization models in the architectural design process with a scope broader than merely discussing model’s detail to provide the required knowledge for architects to understand the research debate. The components of the framework are summarized below.

4.1.1 Parameterization for geometric optimization

This approach concerns the parameterization of geometric optimization in order to generate many arrays of parametric designs which describe alternative solutions to structural systems and environmental factors within constrained optimization. In this context, there is a broad range of parametric models, ranging from simple to complex, which aid designers. These models include formation, generation and performance, which can be applied to architectural content and design tasks from the early conceptual stage.

A) Formation models.

Digital and parametric tools have transformed the concept of form into the interactive and continuous concept of formation (Oxman 2008). Regardless of their implementation and sophistication, all formation parametric models can be categorized into the following two types: those that perform variations and those that generate new designs via a combination of parameterized geometrical entities. In addition, a formation parametric model can also be a combination of both types (see Figure.2), although this is very unusual due to the complexity of the model (Hernandez 2006).

- Variational Geometry Model (VGM). This is a simple kind of parametric model based on the declarative nature of the parameters to construct shapes. The idea behind a VGM model is that the geometrical components are controlled by means of changing the values of the parameters or constraints without changing the topology.
- Associative Geometry Model (AGM). This is the second type of parametric models that create more complex structures. It offers another degree of complexity beyond the parameterization of the geometrical components, which is done by constructing combinations according to specific rules. In the AGM, the important aspect is the spatial relations and rules of combination between the primitive components which determine different design compositions.

B) Generative models.

These models have recently enabled architects to explore and generate thousands of design possibilities within new CAD environments in an unprecedented manner. These modeling systems are based on shape grammars, evolutionary models and other computational design principles which utilize primitive shapes and have shape-specific rules. They are structured to stimulate the designer’s creativity by guiding the designer through possible design spaces constrained by algorithms (Caetano et al. 2015; Krish 2011; Oxman 2008).
Shape grammars. They are specific classes of rule-based expert systems in artificial intelligence which generate geometric shapes (Tepavčević and Stojaković 2012). An implemented shape grammar allows the rapid production of alternative shapes following one grammar, which provides a computational approach to formalizing generative systems of designs. This generative process consists of (a) shape rules that define how an existing shape can be transformed; and (b) a generation engine that selects and processes rules (Liao et al. 2015; Oxman 2008; Pauwels et al. 2015).

Evolutionary models. This is another state-of-the-art evolutionary algorithm model for finding the optimal building model based on mimicking rules. The use of bio-mimicry approaches to inform the parametric model is how the evolutionary model differs and works. However, these models require detailed building parameters to be specified (Oxman 2008; Yang et al. 2012).

Performance-based model. The parameters are not just numbers relating to Cartesian geometry; they also have great potential in
addressing performative issues as a tool that allows the navigation of the parametric search space with respect to measurable performance criteria. This computational tool models building performance in areas such as structure, energy, daylighting, artificial illumination and acoustics. There is a wide range of digital tools for simulation, analysis and evaluation of most performance aspects. The idea of animation as simulation provides architects with an additional opportunity to explore new methods of visualization (Attar et al. 2009; Burry 2003; Ciaszar et al. 2006; Dino 2012; Kolarevic 2003; Rybczynski 2013). However, a few of these models recently began to provide generative and modification capabilities that are interactive with the previously illustrated models.

Current theories and technologies of digital design suggest a shift from analytical simulation to simulation for synthesis and generation. These approaches identify generative processes with performance. Instead of analysing the performance of a design and modifying it according to results, performance-based simulations can directly modify the geometry of the original designs. In such approaches, the desired performance can be activated as a performative mechanism to generate and modify designs digitally. Thus, when focusing on the interrelations between structural morphology and energy-related aspects, geometry becomes a key interdisciplinary interface (Oxman 2008; Turrin et al. 2010).

4.1.2 Parameterization for digital fabrication and project management

In a deep sense, parameterization is not new. What is new is the parallel development of an architectural design industry that facilitates fabrication technology and enables mass customization through digitally controlled variation (Aish and Woodbury 2005).

A) Fabricating model

Another interesting type of modeling consists of fabricating models with the aid of parametric design used in digital fabrication and project management in which the design merges into fabrication in a process of direct transfer of data from a 3D modeling software to a CNC machine. These models make it possible to shape standard building materials using standard machining processes in order to create customized architecture (Kolarevic 2003; Larsson et al. 2012). This model employs digital design and fabrication strategies based on computational concepts through the following processes.

- Reverse engineering and digital manipulation. While the digital environment can be invaluable when deriving, representing and promoting designs to construction, a great number of architects still rely on physical modeling techniques as a rapid and tangible way to arrive upon a desired formal scenario. Digital scanning techniques and computationally based programming software have recently allowed architects to scan a physical model for promotion into a digital model which, in turn, allows for further physical manipulation (Panchuk 2006; Schodek et al. 2005).

- A file-to-factory process. The concept of the digital chain or file-to-factory process has been explored by researchers and also in several teaching projects during the last few years (Larsen and Schindler 2008). This concept refers to the seamless merging of the design process into fabrication through direct transfer of data from a 3D modeling software to a CNC machine that translates the numerical data into production paths, cutting the material in the desired shape. These processes allow for a new degree of design control and inspire a renewed architectural interest: in production that incorporates more customized details (Larsson et al. 2012; Oosterhuis et al. 2004).

B) Building Information Model (BIM).

One of the most important features of parametric modeling is that it supports the incorporation of technical knowledge and expertise during the design process. The BIM can also be used to perform analysis and simulation. Among these different simulation disciplines, the design of sustainable buildings and energy simulation has attracted the most interest among architects. In this context, BIM technology seems to be a natural companion to building simulation applications (Svetel et al. 2014). The result is a data-rich model that integrates all the information on the construction, including architectural design, structural design and the process of construction and maintenance. In addition, architects, structural engineers, builders and owners can effectively generate and coordinate complex digital documentation (Cavieres et al. 2011; Svoboda et al. 2014).

4.2 Strengths, Limitations and Misconceptions

Following the outline of parametric models and their conceptual framework that support design exploration and optimization in the whole architectural design process, the paper identifies the limitations of the parametric paradigm as well as some of the major potentialities that emerge from its use in the discipline.

4.2.1 Strengths of the parametric paradigm

This paradigm possesses major potentialities as digital realm opens up new fields of possibility. Most importantly, computer numerical control machinery enables the fabrication of complex designs directly from computer representation. The cost of such fabrication is
dropping dramatically and thus opening new realms of practical possibility (Woodbury et al. 2006), especially with recent software that enables quick analytical feedback to geometry in order to customize the preferable performance. Current technologies are, to a certain extent, capable of the integration of design synthesis formation processes that are directly informed by performance-based simulations. The process is comprised of a generate/evaluate/modify cycle in search of the optimal performance (Dino 2012; Hudson et al. 2011; Hu 2014). As a result, mass production will soon be overhauled by the principles of customization. With fabrication models, CAD/CAM digital environments are designed to suppress intermediary analogue representations (2D drawings, 3D visualizations, 3D physical models, written specifications or other), taking advantage of a common digital language (Malé-Alemany and Sousa 2003; Oosterhuis 2012). Thus, as it enters an exciting new phase, architecture will never be the same.

4.2.2 Limitations of the parametric paradigm

Parametric applications, models and paradigms play an important role in the process of architectural design. However, they have some limitations as well. While many programs are becoming available to architects, the ability to properly understand and use the software is the most important factor, and will vary between designers. Parametric systems are principally based on algorithmic principles, which may require additional effort. In addition, buildings and projects, in general, are conceived within a complex web of regulations, various technical constraints and environmental conditions, and are meant to operate in a highly dynamic socio-economic context. Thus, much of the effort in parametric design resides in establishing the relationship between parameters. Varying these parameters produces different designs within a family of designs. The power of algorithms lies in the ability to solve a wide range of computational problems, including, but not limited to, sorting and searching, data structure operations and combinatorial problems. Therefore, the complexity of parametric design becomes even more compounded in the case of designing bigger structures or entities (Aish and Woodbury 2005; Cormen 2001; Coyne 2014; Dino 2012; Kolarevic 2003; Peters 2011; Woodbury et al. 2006).

4.2.3 Misconceptions regarding the parametric paradigm

As digital applications developed, morphological manipulations can hardly be separated from the software that defined them. Pierluigi Serraino has written extensively on the theme that form follows software. His assessment is that different software tools afford different ways of design thinking and expression. Like any profession, architecture may be a system in flux. New technologies for CAD environments do not change this reality; instead, such technologies become players in it (Laiserin 2008; Loukissas 2009; Serraino 2002).

Generally, parameterization is a design method, not a style that can be applied to any design process. Computation can eliminate the need for physical modeling or trial-and-error strategies in form optimization, design analysis and synthesis. The goal should be a fine-tuned tool or a set of tools that will truly assist the architect during conceptual design and will be so transparent that the architect focuses on the design and not on the tool. Another misconception is parametric design is the only way to generate complex geometry. As a matter of fact, complex geometry in architecture was present even before computation was applied in architectural design. However, researchers are now directing great attention towards parametric modeling. This is mainly due to the recently emerging visual parametric modeling tools which hide the algorithmic complexity of parametric models behind a visual programming interface (Dino 2012; Parthenios 2005).

4.3 The Expanded Role of the Architect

Recent parametric applications in architectural projects may illustrate how issues of the parametric-enabled paradigm have been explored and have dealt with architecture, which requires rethinking how we traditionally operate as architects. In pre-digital architecture, architects and designers had only traditional tools to design with. While theory and sketching are still important to the design process, it is clear that the field has made an irrevocable shift to the digital realm (Chokhachian and Atun 2014; Jester 2014).

Most of the Late Modernist architects and others use digital parametric tools to maintain a modernist aesthetic. They have been systematically exploring the potential of these fine-tuned tools. Beyond the stylistic architectural product, most project forms are complex topographical models that were difficult in both representation and in fabrication in the pre-digital age and contain many levels of parameterization. Parametric processes are very interesting because of the level of complexity they can allow us to reach. Although some people may think that parametric design is just architects being lazy, as a matter of fact, parametric design and its processes are easy to learn but extremely hard to master. Parametric design is now more a process of learning how to integrate BIM-authoring tools with concept design, analysis and simulation tools. The question then becomes as follows: what is the architect’s role in all of the design phases? Certainly, architects do not have any effect on the invention of digital tools; instead, they have just accepted and implemented them (Abdelmohsen 2008; Chokhachian and Atun 2014; Kolarevic 2005; Rybczynski 2013). In this context, the parametric-enabled paradigm contains a warning that if we do not quickly adapt and take this
opportunity, somebody else will; as a result, the role of architects will be marginalized even further.

As illustrated in parametric models, computers have moved beyond digital drafting and now aid architects in their design exploration and decisions. As a result, the role of the architect is expanding and being redefined. The architect himself is going through a stage of transformation, where he has to extend the scope of his expertise; regulate the mechanisms of knowledge construction and representation; define resources for problem-solving contexts and manage methods of data exchange in this new parametric-enabled paradigm, all while maintaining the traditional role of the architect. Although this new position may weigh on the architect, it is nonetheless important.

The computer can be used to help designers, but the designers themselves must still understand the contextual impacts. Architects that utilize computers must understand that the computer does not replace design fundamentals. It only helps design exploration in a new way, which can act as both a generative and analytical method during this exploration, and had recently gained great acceptance from practicing architects. However, this does not mean that the digital parametric system replaces the designer, but that the human designer externalizes some of his working intelligence into the computer to carry out certain design tasks. At the same time, learning this technology should not divert architects from the fact that they are artists, and thus harnessing this tool should encourage the architects to think beyond the tool. Through their creative work, architects tend to understand culture, society, history and time, which is reflected through buildings that represent signs of people's social values, beliefs and feelings (Abdelmohsen 2008; Chokhachian and Atun 2014; Dino 2012).

5 RESULTS AND DISCUSSIONS

Architecture and its supporting technologies are accompanied by rapid change. Implementing this vision means some of the existing variables are deleted and others are added. In most cases, as an architect begins to work on a real architecture project, he deals with the available technology to construct his architecture. In addition, the implementation of new digital technologies in the design processes is, in a sense, a rational development, from the initial stage of form-finding to the process of manufacturing (Oosterhuis 2012; Stavric and Marina 2011). However, there is no precise definition and there are other related terms and synonyms related to these technologies. Parametric design is another tool that architects have to learn (Rybczynski 2013). Such parametric culture opens up a new line of theoretical discourse that emphasizes the relationship between architecture and other disciplines. With the introduction of the parametric-enabled paradigm, one is able to observe a major shift in architectural thinking which will fundamentally change our perspective of architecture and its relation to mathematics (Kotnik 2010).

This paper presents a holistic approach for understanding the current state of the parametric-related paradigm in its broader context. This approach is based on parametric models which may be incorporated into the architectural design process in the near future, together with some critical remarks about their relevance to architecture (see Fig. 3). In my view, there are two reasons to think about parameterization: the first concerns geometric optimization, and the second concerns models of digital fabrication. Considering the interaction between parameters and constraints, designers switched between the different models of the proposed framework to facilitate the discovery of new forms and enhance designs for better performance and project management.

In recent years, many researchers have investigated the possibility of linking parametric tools with structural analysis and optimization processes. In doing so, architects and structural engineers can explore and examine their designs from the conceptual design phase (Holzer et al. 2007). This requires precise thinking in order to build interactive models that are flexible enough for doing variations. Therefore, the designer must expect which kinds of variations he wants to explore in order to determine the kinds of transformations the parametric model should do. This is a very difficult task due to the unpredictable nature of the design process (Dino 2012). However, parametric design requires some thinking at the beginning to identify the logic behind the design and establish the relationships between objects. In turn, it is much easier to modify a parametric design than it is to make a change in a non-parametric one. The success of a parametric model lies in the interactive establishment of the constants of the design. These constants become applicable to different scenarios and the result of this interactive process is the design of customized objects; the whole process is circular and repetitive (Aish and Woodbury 2005; Woodbury 2010; Yu et al. 2013).

In architecture, there are many parametric models that cover objective issues, but nothing has yet to cover the aspects that model human sociability and responses to environments. These limits in parameterization explain why parametric design only flourishes in the production of elegant geometric forms which are more responsive to algorithmic control, but which encounter more difficulty to produce architecture controlled by issues of history and culture (Coyne 2014). This, in turn, may explain why parametric modeling has not been applied in all architecture, engineering and the construction industry. In addition, more human effort beyond just using a computer is required to build accurate parametric models. In this context, many architects may love digital parameterization, but they may
still love their pencils and papers even more. Critics should allow the paradigm to just evolve on its own and then time will tell if parameterization has a long-term future in the profession of architecture.

6 CONCLUSION

During the last few years there has been an extraordinary improvement in digital tools used to present or communicate the results of architectural projects. Parametric models enable digital designers to create more complex structures and remarkable built environments, as well as new understandings of architectural spaces, both real and virtual. By setting up the logical control in the parametric model, multiple design variations can be generated, modified and evaluated in terms of efficiency, quality and design exploration.

The presented paper is first of all meant to provide a more holistic approach that aids architects to understand various parametric models. These models can then be used to propose a step for a conceptual framework which focuses on understanding the impact of the parametric-enabled paradigm in the architectural design process. The assumption is that there are important benefits to the implementation of parametric modeling techniques. However, such benefits are highly dependent on adequate modeling strategies which require additional efforts to establish the interactive relationship between varied parameters, rules and constraints. Parametric modeling will never replace a designer’s intuition and experience, but the software will become a new tool that can aid architects in design exploration and decisions.

REFERENCES


architectural design.
of Applied Mathematics and Informatics, 1(5), 9–16.