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Adopting Parametric Modeling as an Efficient Conceptual Design Representation Tool

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ABSTRACT

Architectural education in its relation with computational technologies is both becoming a part of having the potential of renovation with the knowledge of emerging technologies. Digital modeling and visualization of architectural buildings has become the benchmark in the work of architects and is essential in architectural education. In this framework, this paper, will be presenting a joint Spanish/Egyptian design research workshop carried out between Institute for Advanced Architecture of Catalonia (IAAC) and Egyptian Universities. The aim of the workshop was training Egyptian graduated architects for professional practice of parametric design by developing their capabilities in computational design process. A multi-day workshop was conducted outside of formal university course settings. In this studio, topics of parametric design and parametric modeling were interrogated through design process. Parametric modeling software and Generative Components were introduced. The architects were required to explore material properties in order to create 3 D responsive architectural shelter structures. In this design research studio held by students, the topics of parametric design and associative thinking are cross - examined to explore their effect on the practices of architectural design and education by adopting parametric modeling as a tool for design representation. Results revealed that parametric design enhanced creativity within the trainees according to thorough evaluation. Also, it has improved their design process, bridged the gap between physical and digital model and enhanced their capabilities to modify and develop their architectural designs.

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Introduction

Parametric design is a process based on algorithmic thinking that enables the expression of parameters and rules that, together, define, encode and clarify the relationship between design intent and design response.¹

Parametric design is a paradigm in design where the relationship between elements is used to manipulate and inform the design of complex geometries and structures .In addition, parametric design is a dynamic, rule-based process controlled by variations and parameters in which multiple design solutions can be developed in parallel. According to Woodbury² (2010), it supports the creation, management and organization of complex digital design models. By changing the parameters of an object, particular instances can be altered or created from a potentially infinite range of possibilities.³

The term parametric originates from mathematics (parametric equation) and refers to the use of certain parameters or variables that can be edited to manipulate or alter the end result of an equation or system. The term "parameters" means factors which determine a series of variations. In architecture, parameters are usually defined as building parameters or environmental factors.

Parametric design is not unfamiliar territory for architects. From ancient pyramids to contemporary institutions, buildings have been designed and constructed in relationship to a variety of changing forces, including climate, technology, use, character, setting, culture, and mood. The computer did not invent parametric design, nor did it redefine architecture or the profession; it did provide a valuable tool that has since enabled architects to design and construct innovative buildings with more exacting qualitative and quantitative conditions.⁴

While today the term is used in reference to computational design systems, there are precedents for these modern systems in the works of architects such as Antoni Gaudí, who used analog models to explore design space.⁵

In order to understand parametric design, we will discuss in the following the development from the digital modeling to generative modeling and processes.

Digital Modeling

Digital modeling and visualization of architectural buildings has become the benchmark in the work of architects and is unavoidable in architectural

¹ Jabi, Wassim (2013). Parametric Design for Architecture. London: Laurence King. ISBN 9781780673141.

² Woodbury, Robert (2010). Elements of Parametric Design.Routledge. ISBN 0415779871.

³ Kolarevic, Branko. "Computing the performative in architecture." (2003).

⁴ http://www.aiacc.org/2012/06/25/parametric-design-a-brief-history/.

⁵ Frazer, John (2016). "Parametric Computation: History and Future". Architectural Design (March/April).

education.⁶ From the original 2-D programs used for drawing architectural designs, the software used for computer-aided design has now turned into intelligent 3-D software packages based on parametric modeling. These new possibilities have led to new movements in architecture and defined the field of nonstandard architecture.

While parametric design, one of the digital approaches to design, was a technique that ensures the holistic control and management of objects, the algorithmic design, is a method by which simple components are used to obtain complex shapes and structures. The instruments that make possible algorithmic and parametric design approaches or that created them were scripting languages found in 3D modeling packages (e.g. Mel-Maya, 3DMaxScript and RhinoScript) and relational with modeling environments like GC (generative components)to obtain spaces and shapes.⁷

Development of digital design did not end with simple parametric modeling; it has taken a step ahead by using generative algorithms. Several software packages offer graphical algorithm editors (e.g. Coffee, Grasshopper), which are directly linked to 3-D modeling tools and allow interactive parametric modeling.

This new parametrically based approach in architectural design enables architect to search for a completely new level in form generating process and modeling in order to integrate design process with fabrication of architectural elements.

Generative Modeling

Instead of drawing a structure, generative modeling uses numbers as the input data. Designs are generated by means of mathematical operations, dependencies and functions. Any structure designed in this way contains a great number of variables within its internal structure, which may be used as the next step in the design process. This kind of modeling allows manipulation in the development and generation of the design which is not possible when using standard 3-D modeling tools. For example, let us take the range of integers 1-10 and use a random number configuration to generate three different numbers representing the spatial coordinates of three distinct points in space. The generated spatial points define a Non-uniform rational Basis spline (NURBS) geometry which is a mathematical model commonly used in computer graphics for generating and representing curves and surfaces. Every time the spatial of any of the input points x, y or z change, the generated surface automatically changes its geometry and adapts to the new variables. Modeling which uses associated and generative modeling is called generative algorithm modeling. This process has the term algorithm in its name because

⁶ Pun, Siu-Kay (2010). Facilitate Learning of Visual Language Skills in Engineering Students. In 9th WSEAS International Conference on Education and Education technology (EDU'10) in Secected Topic in Education Educational Technology, Ed. Fujita, H., Sasaki J (pp. 77-82).

⁷ Yazicioglu, D. A. (2011). The Integration of Interior Architecture Education with Digital Design Approaches. Online Submission, 8(5), 637-658.

objects are generated using algorithms in this type of design and their output for the further stages of design is also generated by means of algorithms.⁸

In generative design, algorithmic procedures are often used to produce arrays of alternative solutions based on predefined goals and constraints, which the designer then evaluates to select the most appropriate or interesting.⁹ Generative design is a parametric computer modeling technology that is typically operated using an alternative interface for a Computer Aided Design application. A 3D geometric shape is constructed by associating elements with each other through a number of commands with different parameters. The end-product is a parameter-based entity which can be easily modified, thus turning the whole geometric shape. When it comes to architectural design, Grasshopper is one of the most commonly used generative design editors as shown in Figure 1. This editor is connected to Rhino 3-D objects and offers a range of mathematical tools for generative modeling such as operators, conditional statements, functions and trigonometric curves.¹⁰

The needed combination of 3D visualization, parametric representation and programming presents challenging issues for workshop courses' design for graduate students to get acquainted with parametric design.

Figure 1. Basic 2D and 3D Rhino to Grasshopper Generative Computing Modeling¹¹



⁸ Stavric, M., & Marina, O. (2011). Parametric modeling for advanced architecture. *International journal of applied mathematics and informatics*, 5(1), 9-16.

⁹ Prousalidou, E., & Hanna, S. (2007). A parametric representation of ruled surfaces. In *Computer-Aided Architectural Design Futures (CAADFutures) 2007* (pp. 265-278). Springer Netherlands.

¹⁰ Knabazi, M. (2009), Algorithmic Modelling with Grasshopper, available: www.khabazi. com/flux.

¹¹ Guidera, Stan. "AC 2011-2728: CONCEPTUAL DESIGN EXPLORATION IN ARCHITECTURE USING PARAMETRIC GENERATIVE COMPUTING: A CASE STUDY."

Methodology and Task Description

In the workshop courses, small group seminars on particular topics were held as needed. Most instructional effort went into one-to-one sessions with students on their specific design problems. There were continuous reviews of progress, with a final review demonstrating all student work. Encouraging participants to post their work, both during and after the event was an effective way of recording their improvement.

The Task

The task was to design a self-supporting roof over a usable space in order to provide shade and privacy. The project idea was to use Mesh Fibers under the influence of varying environmental and material properties, to produce controlled boundary and spatial conditions. Different designs created by groups of two or three trainees. These conditioned designs and repeatable aggregation patterns of the fibers allowed to scale up prototypes in an effort to produce onsite an ephemeral architectural shelter with three-dimensional mesh envelope. The choice of the material was encouraging facility in flexibility during model making. The idea was to study a relationship between the geometric characteristics of a shape and physical characteristics of a material, and to prepare their parametric record to generate a digital geometric model.

Work Stages

The first stage of the project included learning about the method of freeform surface modeling using NURBS-based tools. Experiments consisted in spreading digital surface on the profiles in search of the most convenient shape, i.e such that its spatial configuration ensures stability to the roof. Such surfaces were modeled, whose arrangement of the folds and the center of gravity would ensure the maintenance of balance without placing unnecessary supports. Mostly freeform surfaces with complex geometry were obtained. Software was also installed and students were applying their training on their design. During the second phase of the projects, works were carried out aiming at dividing the digital surface into its constituent parts. Draft physical models of the project sequence were built by hand. Each time the designed projects with records of the properties were drawn, and the obtained numerical parameters were recognized together with the photographic documentation.

In the third phase, when the results were already satisfactory and the designed projects comprised all the necessary information and parameters, experimenting began with translating these data into a record that a computer could understand. The collected parameters allowed for the preparation of a digital geometric model using Rhino Grasshopper application. It allows for easy preparation of the script and creating individual boxes and connecting wires. Using this application, it was possible to generate 3D models needed for the design representation and for the creation of a prototype and of the final

product. These digital models can later be used to build accurate final physical models using CNC cutters, as shown below in Figure 2.

Figure 2. Showing the Three Steps: 1; Physical Model, 2; Generative Computing Application (Grasshopper, which Runs with Rhino 3D), 3; CNC Final Modified Model



Generating Design Projects Alternatives

Through the designed projects, 3D modeling packages (like Maya, 3DMaxScript and RhinoScript) and generative components such as Grasshopper were used to obtain different spaces and diverse roof shapes. Material properties were explored in order to create real time responsive architectural structures.

The obtained structures are more adaptable, flexible and transformable with different environmental conditions and meet different functions. In the following the five obtained projects are exposed with details in Table 1.



 Table 1. Design Projects Outputs



Assessment of the Five Projects Designs

After printing the CNC models, project evaluation proceeded. A panel consisting of six expert jury provided assessment of the five outputs. Each design was presented as a collage of images on A3 size paper with all design products being similarly scaled for consistency of evaluation (see Figure 3). The judges assessed designs using two evaluation frameworks, consisting of (i) comparative non-criteria based assessment of creativity, and (ii) criteria-based assessment of creativity using novelty, usefulness, complexity, and aesthetics. Each assessment task used a seven point Likert scale (where 1 is the lowest and 7 the highest).



Figure 3. A3 Size Paper Showing All Design Stages

Also the obtained designs were assessed according to four criteria: novelty, usefulness, complexity, and aesthetics. Novelty can be interpreted as 'Originality (of idea)' and its 'Evolution', referring to the degree to which the design itself demonstrates a novel idea. Usefulness refers to the degree to which the design shows the quality of practical application.

Complexity refers to the degree to which the design shows the level of complexity of the design. Complexity relating to the context of parametric design is a criterion to evaluate technical quality. Aesthetics refers to the degree to which the design is aesthetically appealing.¹²

First project showed us that during the design process the geometric certainty concept could be turned into a shape that could be reconsidered. Second project showed us that it was possible to approach the principles of high functionality and integration in nature in a much more basic way with the aim of increasing the system's performance. Also the highest degree of control over the physical characteristics of materials was presented in third project. Other projects showed us that each single component can be changed in connection to various mathematical algorithms and in a way where they all complemented each other. All projects showed us that it was possible by means of the interaction between the capacity of materials and environmental effects and forces to produce interactive and intelligent designs.

¹² Amabile, T. M. (1983). The social psychology of creativity: A componential conceptualization. *Journal of personality and social psychology*, *45*(2), 357.

Table 2 shows that six judges identify design 5 as the most creative relative to the criteria and most judges assessed design 2 as the least creative. Table 3 shows the results of criteria-based assessment of creativity using-novelty, usefulness, complexity, and aesthetics. The results are also similar to the scores for novelty and complexity. Overall, the results show that the level of creativity exhibited in design 5 was assessed as the highest and design 4 achieved the second highest overall score and had the highest degree for usefulness. This evaluation therefore regards design 4 and design 5 as the most creative proposals overall.

The results in Tables 2 and 3 indicate the level of creativity of design 5 which was assessed as being consistently the highest across all evaluations.

This evaluation also regards design 4 and design 5's designs as the most creative proposals overall.

Tuble 2. Comparative from Criteria based Assessment of Creativity									
	Evaluator 1	Evaluator 2	Evaluator 3	Evaluator 4	Evaluator 5	Evaluator 6			
Most creative	Des.5	Des.5	Des.4	Des.5	Des.5	Des.5			
Least creative	Des.2	Des.2	Des.1 or Des.2	Des.2	Des.2	Des.1			
Judges' criteria	Response to criteria	Aesthetic and organization	Visualization	synthesis of the objectives	Novelty of the form	Aesthetic, and simplicity			

 Table 2. Comparative Non-Criteria based Assessment of Creativity

Table 3. Results of Criteria-based Assessment of Creativity Using - Novelty,Usefulness, Complexity, and Aesthetics

	Evaluator	Evaluator	Evaluator	Evaluator	Evaluator	Evaluator	Sum	Mean			
Novelty											
Des.1	5	4	4	5	4	4	26	4.33			
Des.2	2	2	3	3	3	2	15	2.50			
Des.3	4	5	4	5	4	4	26	4.33			
Des.4	6	6	7	7	6	7	39	6.50			
Des.5	5	6	6	6	5	5	33	5.50			
Usefulness											
Des.1	4	3	3	4	4	3	21	3.50			
Des.2	4	3	3	5	4	5	24	4.00			
Des.3	4	3	4	4	4	4	23	3.83			
Des.4	5	6	7	6	7	6	37	6.17			
Des.5	4	4	5	5	6	5	29	4.83			
Comple	exity										
Des.1	2	1	1	1	2	1	8	1.33			
Des.2	2	1	2	1	1	2	9	1.50			
Des.3	5	6	6	6	5	6	34	5.67			
Des.4	3	4	4	4	4	3	22	3.67			
Des.5	6	5	6	5	6	6	34	5.67			
Aesthetics											
Des.1	5	4	4	4	4	5	26	4.33			
Des.2	2	2	2	3	3	2	14	2.33			
Des.3	3	3	3	4	4	4	21	3.50			
Des.4	6	6	7	7	5	6	37	6.17			
Des.5	5	5	5	6	6	6	33	5.50			

Assessment of the Architecture Students

During the workshop, it was declared that parametric design integrates with the majority of students preference as it worked as follows:

- Introduction of information visually more than verbally.
- Organizing information through the sense and not in a logic way.
- Handle information more actively than reflected.
- Identifying information in sequential way more than integrated.

After presenting the project and the process involved using 3D digitization, there was a need to discuss challenges ahead for architectural students so questionnaires were distributed.

Initially, questionnaire for students were underneath three main categories as shown in Table 4:

1) Did parametric design improve the design process

- Was it easy to use 3D modeling packages (like Maya, 3DMaxScript and RhinoScript) and Grasshopper modeling tools to create non-linear procedural model.
- Was it easy to use 3D modeling packages (like Maya, 3DMaxScript and Rhino Script) and generative components such as Grasshopper tools to generate parametrically negotiable solutions across various design professions

2) Did parametric design bridge the gap between physical models and digital models

- Were the generative processes of design, as well as the potential of parametric thinking, a resourceful tool for achieving diversity and complexity in form generation and fabrication.
- Was it easy to use 3D modeling packages (like Maya, 3D MaxScript and Rhino Script) and Grasshopper to prepare files for rapid prototyping and the integration into various fabrication techniques such as laser cutting, CNC milling, and 3D printing.
- Was it easy to use 3D modeling packages (like Maya, 3D MaxScript and Rhino Script) and Grasshopper to benefit from material properties in 3D model.

3) Did parametric design enable students improve their design proposals

• Was it easy to create a digital simulation to simulate all aspects of surface properties and dynamic forces with 3D modeling packages (like

Maya, 3DMaxScript and Rhino Script) and Grasshopper physics engine.

- Was it easy to use 3D modeling packages (like Maya, 3DMaxScript and Rhino Script) and Grasshopper skeleton system and animation tools to control complex architectural forms.
- Was it easy to combine 3D modeling packages (like Maya, 3DMaxScript and Rhino Script) and Grasshopper tools to create a dynamic efficient design.

	Design		Design		Design		Design		Design 5	
Questionnaire	1		2		3	T	4	T		1
Did parametric design improve the design										
process;										
was it easy to use 3D modeling packages										
was it easy to generate parametrically negotiable										
solutions across various design professions										
Did parametric design bridge the gap between										
physical models and digital models;										
Is the parametric thinking as a resourceful tool										
for achieving diversity and complexity in form										
generation and fabrication.										
Was it easy with parametric design to benefit										
from material properties in 3D model.										
Was it easy with parametric design to prepare										
files for rapid prototyping and integration into										
various fabrication techniques such as laser										
cutting, CNC milling, and 3D printing.										
Did parametric design enable students improve										
their design proposals										
was it easy to create a digital simulation to										
simulate all aspects of surface properties and										
dynamic forces with 3D modeling packages										
was it easy to use 3D modeling packages to										
control complex architectural forms.										
was it easy to use 3D modeling packages to										
create a dynamic efficient design.										

Table 4	. Students	Questionnaire	with the	Three	Main	Categories
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 $\underline{\mathbf{A}} = \operatorname{Agree} \underline{\mathbf{D}} = \operatorname{Disagree}$

Results and Discussion

Did Parametric Design Improve the Design Process

More than half of the students agreed that the course enhanced their design development as shown in figure (4). This may be due to the combination of traditional model making techniques and computer 3D modeling. Students generally produce a physical model of their projects to convey a design message.



Figure 4. Static Analysis of the First Question Results

With the parametric design, first, students are required to produce series of sketches and models of the project. Once the tutors and the student are satisfied with the product, then a physical model of the project is constructed. After this, the 3D digitization of the physical model with rhino and grasshopper allow the student to modify to create more detailed enhanced model.

New geometrical approaches and typologies appear and is reflected in design products. In addition, while with traditional methods it is impossible for a student to understand fully and control all components and parameters, thanks to the digital design instruments, they will be able to take up all data and limitations at the same time. As a result, it will become possible to create and develop 3 D designs with a complex geometry, by using many layers of information in an interconnected way within the limits of algorithmic and parametric approaches, that can provide answers for different needs for performance according to students capabilities in using parametric programs.

Did Parametric Design Bridge the Gap between Physical Models and Digital Models

Most of the students' course agreed that parametric design narrowed the gap between physical models and their digital counterparts in architectural design, Figure 5. It is an attempt to strengthen model-making techniques and to improve 3-dimensional computer modeling.





It can be said from this research, that students should be able to easily display their designs using physical models. Then, they can digitize them in order to develop the design further by producing a digital model. These digital models can later be used to build accurate final physical models using CNC cutters. In order to do that, Students were encouraged to digitized their physical models into faces which were divided into grids that will form 3D surfaces using rhino and grasshopper.

The success of this step relied heavily on the 3D modeling enhancement among students as a result of presented lectures. As a result, a considerable amount of time was spent improving students 3D modeling skills so that the outcome of 3D digitization can be seen and used effectively.

Did Parametric Design Enable Students Improve their Design Proposals

Most of the students agreed that their innovative experience had been made improved by the use of computers; Figure 6. This course encouraged students to increasingly use techniques and digital media to produce more elaborate designs taking in consideration the used material properties such as flexibility and expanding proportions.

Figure 6. Static Analysis of the Third Question Results



Based on these characteristics, generative design environments provided significant advantages for conceptual design as the emphasis is on exploration of alternatives. However, one of the most significant advantages is that generative design environments are dynamic and interactive, providing real-time visual feedback as the geometric and dimensional variations are manipulated. A generative computing application that is rapidly expanding in use is Grasshopper, which runs with Rhino 3D. This expanded can be attributed to two factors. First, the extensive modeling capabilities of Rhino 3D, particularly in terms of nurbs (non-uniform rational b-spline) curve and surface modeling, has lead to its widespread adoption among architectural design alternatives.

Secondly, the graphical interface of Grasshopper provides an explicit representation of the geometric relationships and sequences used to generate the digital model. This explicit representation is linked to the Rhino 3D viewports. This enables designers to receive immediate visual feedback of their design development as these relationships are manipulated by user-defined mathematical and geometric parameters.

With the integration of digital design instruments within architecture design, on the one hand, it will become easier for design to be analytically set up in a computer environment in the shape of dynamic systems, and on the other hand, it will be possible to reshape the process and conception of the design in lateral thinking approach.

Conclusions

The workshop was a model for intense interaction between design students (in our case mostly graduate students) and design practices seeking to engage with new technology. As such, it served to establish and strengthen productive relations between academy and practice. Also, parametric modeling systems require that students learn a new complex of skill and knowledge.

By combining digital and analog design methods, a new approach to architectural design was developed. Study of material in terms of its formation possibilities was examined. These results, translated into the language of geometry, introduced into the Rhino and Grasshopper program, allowed to prepare digital material formations. 3D digital models were obtained, which were structural models at the same time. These are models in which the relationship between the material part and the whole form has been modulated parametrically.

During the design and research experiments, a certain confrontation took place between students and the reality of modern computer tools in the formation of spatial structures architecture.

Also, the evaluation framework presented a crucial starting point for formally understanding creativity in parametric design. These can also contribute to the understanding and exploration of parametric design for realizing creativity.

This studio experience on parametric design caused the initiation of ideas for what the future of architectural education in computational use can be. The capability of parametric modeling with higher levels of computational use and the non-linear process of design becomes an important topic for architecture education, design thinking and model presentation. Within this context, it is thought that integrating digital design instruments into the internal architecture education system will make it possible to train designers with superior capacities to compete with the international job market.

However, the currently present extension of the parametric capabilities in modeling, fabrication and object implementation, resulted in focusing attention to those structural aspects of the design. This forces changes in architectural education and a need to improve the design tools. Training the future designers in the light of these approaches will make it possible to train professionals who correctly use and understand the developing technologies enabling exploration of well performing possibilities with conventional media. They also will have a critical sense, and can create renewable designs with the willingness to innovate. But we have always to keep in mind that architecture has always been and must remain more than measurable parameters.

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