Exploring Integration of Parametric Design Methods into Interior Architecture/Design and Architecture Education

Rabia Tuğba Polat

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Approval of the Institute of Graduate Studies and Research

Prof. Dr. Ali Hakan Ulusoy
Director

I certify that this thesis satisfies all the requirements as a thesis for the degree of Master of Science in Interior Architecture.

Assoc. Prof. Dr. Zehra Öngül
Chair, Department of Interior Architecture

We certify that we have read this thesis and that in our opinion it is fully adequate in scope and quality as a thesis for the degree of Master of Science in Interior Architecture.

Prof. Dr. Nil Paşaoğluları Şahin
Supervisor

Examining Committee

1. Prof. Dr. Nil Paşaoğluları Şahin

2. Prof. Dr. Özlem Olgaç Türker

3. Asst. Prof. Dr. Sevil Aydınlık Başar

ABSTRACT

Nowadays, the new environment brought about by communication and information technology denotes a change in interior architecture/design and in its educational activities. Due to the advancement of technology and changes in the design process, new ways of thinking that go beyond interdisciplinary approaches are required in both practice and education. With the advent of parametric design, interior designers and students may actively engage in all phases of the design and development process, essentially extending the process up to the point of production.

This research tries to explore the diversified use and integration of parametric design methods in interior architectural/design education and hence determine its benefits and shortcomings. The study firstly reviews the literature with an emphasis on comprehending the parametric design phenomenon and secondly studies a series of cases utilizing parametric design methodologies in various interior architecture/design and architecture programs. A systematic framework for analysis of parametric design has been developed as a result of the literature review and hence it has oriented the exploration of multiple cases accordingly. Data were collected through an in-depth exploration of multiple cases of different interior architecture/design programs besides architecture programs worldwide over their websites. Accordingly, 25 cases were examined to see whether parametric design techniques were integrated into interior architecture/design as much as architectural design education without replacing the traditional education methods. It has been revealed that there are 23 case studies in the architecture program but only 2 in the interior architecture/design program with parametric design.

As a result of this study, it has been achieved that parametric design techniques have limitedly integrated into interior architecture/design programs compared to how substantially it has been studied in architectural programs. The findings show that the implementation of this method in different course groups has many benefits and contributions. The use of digital techniques, and search for form; particularly observed in design studio courses, modelling and reuse of parametric design explored in parametric design courses, variations in generating alternatives attained in extracurricular activities and algorithmic thinking in design studio courses were explored as the most popular approaches in the implemented cases. This study concluded that the parametric design method possibly integrated into interior architecture/design education without displacing the established educational approaches.

Keywords: Parametric Design, Interior Architecture, Interior Design, Architecture, Interior Architecture Education, Design Studio, Design and Technology.

ÖZ

Günümüzde iletişim ve bilgi teknolojisinin getirdiği yeni ortam, iç mekan tasarımı ve eğitim faaliyetlerindeki değişim üzerinde de etkili olmaktadır. Teknolojinin ilerlemesi ve tasarım sürecindeki değişiklikler nedeniyle, hem uygulamada hem de eğitimde disiplinler arası yaklaşımların ötesine geçen yeni düşünme biçimleri gerekmektedir. Parametrik tasarımın ortaya çıkmasıyla birlikte, iç mimarlar ve öğrenciler tasarım ve geliştirme sürecinin tüm aşamalarına aktif olarak katılabilir ve üretim aşamasına kadar sürece dahil olabilir.

Bu araştırma, iç mimarlık eğitiminde parametrik tasarım yöntemlerinin çeşitli kullanımını ve entegrasyonunu araştırmaya ve dolayısıyla faydalarını ve eksikliklerini belirlemeye çalışmaktadır. Çalışma, öncelikle parametrik tasarım olgusunun kavranmasına yönelik kapsamlı bir literatür taraması aracılığı ile başlamakta ve ardından çeşitli iç mimarlık ve mimarlık programlarında parametrik tasarım metodolojilerinin/yöntemlerinin entegrasyonunun tespiti için örnek çalışması ile devam etmektedir. Literatür taraması sonucunda geliştirilen sistematik çerçeve örnek programların incelenmesine yön vermektedir. Veriler, derinlemesine bir literatür taraması ve web siteleri üzerinden dünya çapında mimarlık programlarının yanı sıra farklı iç mimarlık programlarının incelenmesi ile toplanmıştır. Bu bağlamda, toplamda 25 örnek incelenmiş ve parametrik tasarım yönteminin iç mimarlık eğitiminde geleneksel eğitim yöntemlerinin yerini almadan nasıl entegre edilebileceği araştırılmıştır. İncelenen örneklerden parametrik tasarım yöntemini entegre edenlerden 23'ü mimarlık programı ancak sadece 2 tanesi iç mimarlık programıdır.

Araştırma sonucunda parametrik tasarım yönteminin iç mimarlık programlarında yeterince yer almadığı tespit edilmiştir. Ancak incelenen örneklerdeki bulgular bu yöntemin farklı ders gruplarında uygulanmasının birçok olumlu katkısı olduğunu ortaya koymaktadır. Dijital tekniklerin kullanımı, özellikle tasarım stüdyosu derslerinde form bulma/oluşturma, parametrik tasarım derslerinde parametrik tasarımda modelleme ve yeniden kullanım, ders dışı etkinliklerde(atölye çalışmaları, yarışmalar v.b.) ve tasarım stüdyosu derslerinde alternatif üretmedeki farklılıklar ve algoritmik düşünmenin de tasarım süreçlerinde tercih edilen en popüler yaklaşımlar olduğu tespit edilmiştir. Çalışmanın sonucunda parametrik tasarım yönteminin, mevcut eğitim yaklaşımlarını değiştirmeden iç mimarlık eğitimine dahil edilmesinin mümkün olduğu belirlenmiştir.

Anahtar Kelimeler: Parametrik Tasarım, İç Mimarlık, İç Mekan Tasarımı, Mimarlık, İç Mimarlık Eğitimi, Tasarım Stüdyosu, Tasarım ve Teknoloji.

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Chapter 1

INTRODUCTION

1.1 Background of the Study

Currently, the new environment created by communication and information technology signifies a change in interior architecture/design and the activities of its education. There is a need for new ways of thinking that transcends interdisciplinary methods in practice and education due to the development of technology and changes in the design process. The demand for novel forms, innovative design strategies, environmental considerations, and technical and structural innovations have increased the challenge for designers (Alalouch, 2018). Today, parametric design is gaining prominence in the world of design and education. Parametric design, its tools, and techniques trigger a new way of deep learning in interior architectural design education. Parametric design involves the exploration of multiple solutions to architectural design problems using parametric models. Designing based on/in assistance with parametric modeling tools is known as parametric design (Oxman, 2017). The use of parametric models in parametric design allows for the investigation of many solutions to architectural design problems.

In parametric design, designers use declared parameters to define a form (Hernandez, 2006b). Parametric modeling entails the depiction of geometric entities and their relationships via related components and characteristics within a hierarchical chain of dependencies. Each geometric attribute is represented by a parameter in this hierarchy.

It is allowing an automated generation of several instances of a basic design form (Turrin et al., 2011).

Modern architecture education attempts to prepare students to enter the profession of tomorrow with confidence. This enables a more in-depth understanding of the design objectives and supports students in their decision-making to develop solutions. Based on the notion of parameters, parametric design is a novel approach to architectural education. It makes use of parameters to characterize the relationships between design components to provide a variety of formal alternatives (Iordanova, 2007). In this regard, the parametric design offers students several chances to streamline the design process.

Furthermore, design studios involve more than just skill development; they also necessitate reflection on and generation of knowledge. However, there may be a mismatch between skill development and knowledge application. Students find often hard to understand how to compose architectural space in a systematic and controlled way, using architectural elements such as surfaces, lines and volumes (Vamvakidis, 2016). Accordingly, parametric design assists the student to construct the basic model of the project concept utilizing the project elements and accessible data throughout the parametric design process.

Moreover, there are a diversity of benefits to following parametric design methodology such as when employing deductive induction approaches via parametric design strategy, it helps students to use the principles of learning by doing, analytical thinking, growing thinking capacity, and modeling. Thus, when students master such inventive tools, they grasp a new level of thinking that would allow them to build previously

inconceivable concepts as well as creativity. It must be noted that this is a strategy that has lately been adopted and employed in several design sectors, as well as in education. Accordingly, it is critical to explore how it might be effectively utilized in interior architecture/design education besides handstand on student learning outcomes when they use parametric modeling.

1.2 Problem Statement and Research Question

Parametric design as a new design method allows interior architects and students to participate more deeply in the entire design and development process, thereby effectively extending the process beyond production. Therefore, it is argued that the parametric design as a new design technique will greatly change the learning methods of students and will provide them with state-of-the-art of knowledge and relevant skills. However, it should also be noted that this method should not completely replace the traditional methods of education. Furthermore, despite the fact that the parametric design method is more widespread in the world, it is still not widespread in educational facilities and hence very seldom applied in interior architecture education besides not sufficiently integrated. Thus, due to the shortage of this approach in interior architecture/design education, this study intends to shed a light on the integration of parametric design issues into interior architecture/design education.

Therefore, this study quests the integration of parametric design method into interior architecture/design education by askng:

“To which extend parametric design method could be integrated into interior architecture/design education without replacing the traditional education methods?”

1.3 Aim and Objectives

Accordingly, this study aims to explore the diversified use and integration of parametric design methods in interior architectural education and hence to determine its benefits and shortcomings. Moreover, it attempts to reveal the current situation by studying multiple examples of its integration into both architecture and interior architecture/design education worldwide. Furthermore the other disciplines such as fashion design or industrial design is excluded from this study because this research has an interior space related focus and with this point of view it included only interior architecture/design and architectural education. Accordingly, objectives of this study to achieve the stated goals are;

- To study integration of technology into education in general and parametric design technologies into education in particular.
- To examine international educational programs from different regions such as Asia, Europe—and America where parametric design approach is applied/integrated into architecture and interior architecture/design education.
- To explore various ways of integrating parametric design methods into interior architecture/design and architecture education by examining multiple cases worldwide.
- To explore the benefits of parametric design integration into interior architecture/design and architecture education.

1.4 Research Methodology

This is a theoretical research that is conducted through a qualitative research methodology. Data were collected through an in-depth literature review and by examining/studying multiple cases of different interior architecture/design programs and architecture programs worldwide over their websites amd publications.

25 cases were examined to explore the possibility of integrating parametric design techniques into interior architecture/design education without replacing the traditional education methods. There are 23 case studies in the architecture program and only 2 in the interior architecture/design program. Many cases were scanned to find design üniversities which the scarcity of parametric design method integration into interior architecture/design programs has created a research and implementation gap. Accordingly, the study not only analyse different course groups such as design studios, applied courses (i.e theory with a project or a workshop, etc.). It is also analyse/review parametric forms of design as a development tool in the extracurricular activities in order to explore the existence and different approaches of parametric design as a part of the architecture and interior architecture/design curriculum. The research was conducted with the content analysis method in order to highlight the keywords and concepts that match the factors.

Data were collected from publications, websites, and reviewed the literature in order to explore their perspectives on a number of topics. Each different institution/program has been labeled as a case study and with a number (Case Study #) consecutively. And then each case study has been analyzed by focusing on the approach and implementation by the help of the developed framework as a result of an in-depth literature review (Figure 1).

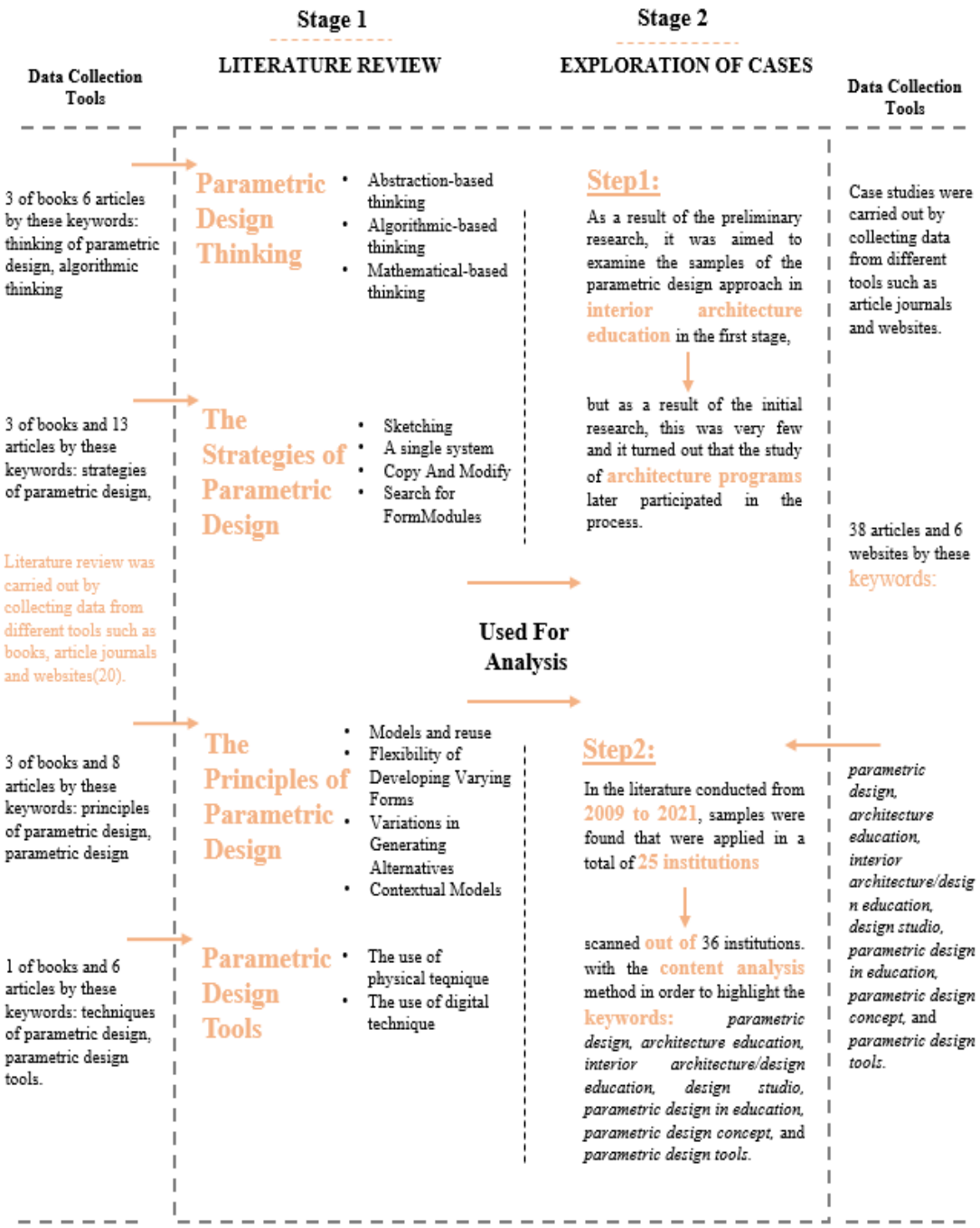


Figure 1: Research Methodology of the thesis, by author

1.5 Limitation

As a limitation, this thesis only reveals the integration methods of parametric design into education at the reviewed 25 cases and at various course types and extra-curricular activities available at these cases. International educational programs have been reviewed from different regions throught the world. Thus, it has been find such that Asia, Europe, Australia and America are the continents where parametric design approach is applied/integrated into architecture and interior architecture/design education. According to a review of numerous institutions in all areas, it has been revealed that any samples were 'not found in the African continent. Programs implementing parametric design approach at Turkey is excluded from this study due to an existing study that has already analyzed the interior architecture/design departments in Turkey. It has been provided that the following approaches exist at Çankaya University, Yasar University, Fatih Sultan Mehmet Vakif University, Izmir University department of Economics, and Başkent University. Study have revealed that, parametric design has made its way into interior architecture/design courses and it is a novel venture for architectural departments, and even more so for interior architecture/design departments particularly between 2015 to 2020 (Şekerci, 2020). And hence the current study reviews programs in other countries but did not include programs in Turkey in order to avoid duplication or to avoid any conflict of interest. Furthermore the other disciplines are excluded from the study because this research has an interior space related focus and with this point of view it included only interior architecture/design and architectural education.

1.6 Significance of the Study

The process of parametric design, and its integration into the interior architecture/design education without fully disrupting existing teaching techniques, is

an essential aspect. It is significant to examine the effects of parametric design in traditional education relative to the student, which determines its advantages and disadvantages compared to traditional education. A thorough analysis of the literature with an emphasis on comprehending the parametric design phenomenon and a series of case studies utilizing parametric design methodologies in various interior architecture/design and architecture programs is significant in order to understand the influence of integration of parametric design methodologies/approaches in education and hence on students' skills.

1.7 Structure of the Thesis

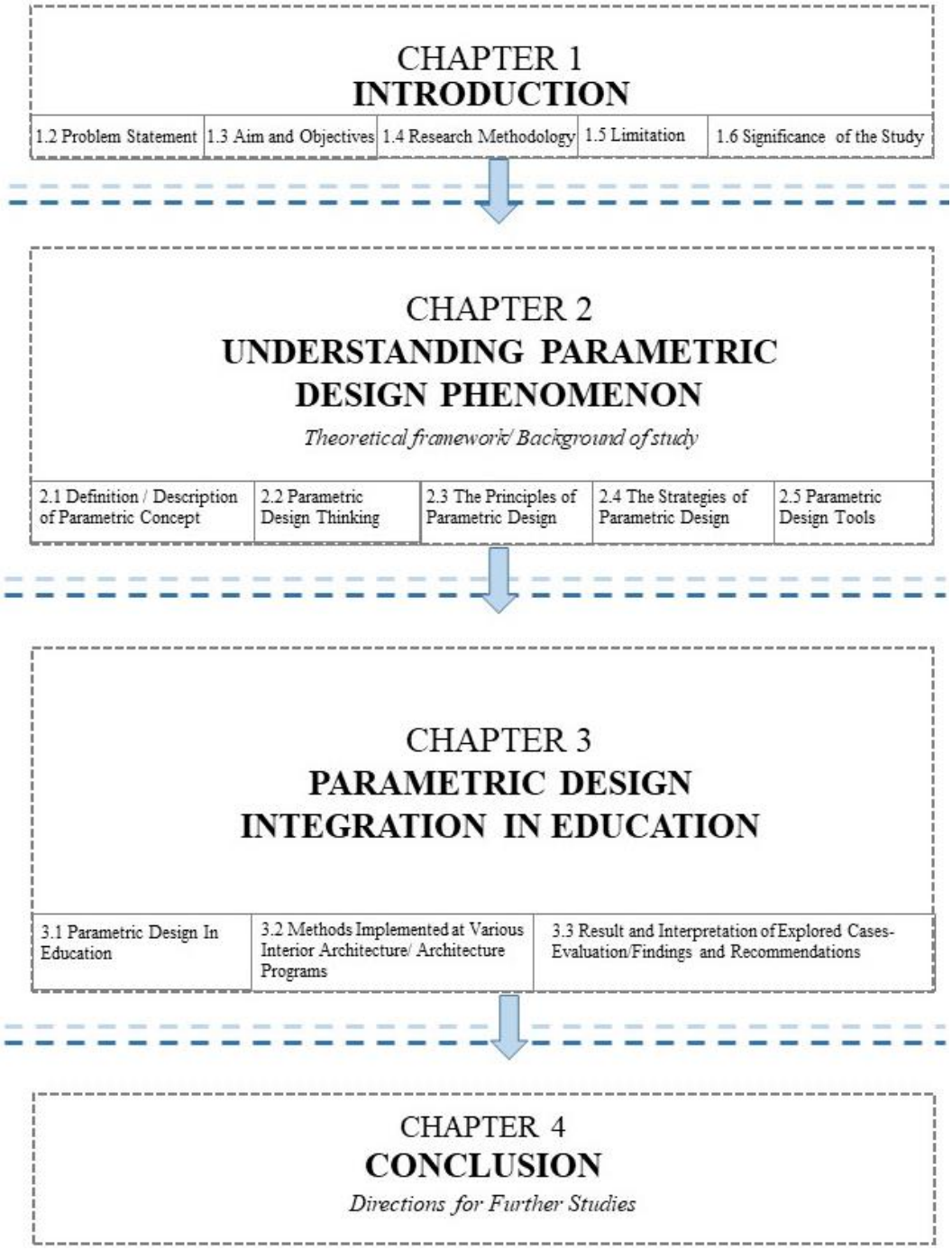


Figure 2: Structure of the thesis, by author

Chapter 2

UNDERSTANDING PARAMETRIC DESIGN PHENOMENON

Nowadays, the new environment created by communication and information technology needs new ways of thinking that transcend interdisciplinary methods in design due to technological developments and changes in the design process. Parametric design in recent years has become one of the most important design tools. According to Kolarevic (2013); the use of parametric modeling has increased with the rise of the sustainability theory. Parametric design is an old notion that has always been present in architecture and design. Parametricism is a phrase used to describe a new epochal global architectural style as well as all design disciplines such as planning, architecture, interior architecture/design, graphic arts, and product design. Climate, regulation, culture, and usage all have a role in the design process (Ağırbaş, 2020).

Furthermore, digital media quantitative tools in architecture have been deployed in a variety of ways during the last thirty years, affecting the entire area of architecture architectural form. At first, digital media were only useful as a representational medium for presenting ideas. Architecture has been confronted with new tools for various activities within the architectural design process in digital media as a result of the growth of digital tools and technology (Schnabel, 2007).

Parametric design, which comes from various design fields, supports a different type of architectural idea. For today's architects and designers, the drive to create modern' and 'futuristic' forms has led the way for new techniques and tools. Thus the technique of designing in an environment where design variations are effortless, thereby replacing singularity with multiplicity in the design process, is known as parametric design (Chokhachian, 2014). Accordingly, the fixed attributes are considered to be limited, while the variable attributes are known as parameters. Moreover, curvilinear geometries, in which the forms, dimensions, and sizes of structures may be adjusted according to needs, are of significant interest to designers in today's world of contemporary architecture and design, where new approaches and searches have developed.

2.1 Definition / Description of Parametric Concept

Parametric design is not a new concept and always forms part of architecture and design. Consideration of the power of change such as climate, regulation, culture, and usage is always part of the design process. The history of the term parametric design in architecture came up in the seventies, with the emergence of methods to describe curves through parametric equations. As a result, links between various data sources may be created, and the foundations for creating geometric forms utilizing parametric design tools can be created (Ghosh, 2017).

The form in parametric design is not defined first but is classified in a particular template and controlled based on the determinant parameters. Therefore, a new design can be generated from a basic template ‘only’ by entering parameter numbers that correspond to the project data. In the creation of parametric designs, concept project’s environmental data and other factors determined by the designer, constitute the

parameters of the concept project in their processes. By changing these parameters, formal changes can be made in the desired place and alternative products can be obtained (Basu & Ghosh, 2016). The founder of the parametricism style, Patrik Schumacher, states that:

> " The term 'Parametricism' implies that all elements of architecture are becoming parametrically malleable and thus adaptive to each other and to the context. District objects are always connected with one another and rarely contact each other; they never detect or sense each other. Instead of aggregating a few platonic solids (cubes, cylinders, etc.) into simple compositions — as all other architectural styles did for 5000 years — we are now working with inherently variable, adaptive forms that aggregate into continuously differentiated fields or systems. Multiple systems are correlated with each other and with the environment." — (Patrik Schumacher, 2012, p.13).

In parametric design, designers use preset parameters to define a form. Sufficient reasoning is required to construct a sophisticated geometrical framework that is integrated into a complex model that is flexible enough to do alterations. They can also assist designers in creating better products by offering more context for how their ideas will be used, allowing them to make more informed design decisions. According to Mario Carpo (2013), "Freeform 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, 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. " (p.169) In parametric design, the form is classified in a template and controlled by determinant parameters rather than being defined first (Putro & Pamungkas, 2019). Parameters allow designers to express and explore ideas beyond being constrained by their sketching skills. Producing complicated forms by

hand or with a standard 3D modeling application is challenging since it takes a lot of effort and time (Ağırbaş et al., 2018).

The parametric model adapts or reconfigures to the changing values of the parameters without editing in response to the changes (Hernandez, 2006a). Parameters can be used to produce and explore ideas, allowing designers to generate more ideas, receive feedback sooner, and iterate faster. Parametric design is a design paradigm in which the relationship between elements is used to alter and inform design, resulting in complex geometries and structures (Woodbury, 2010).

Furthermore, each of the modifications to be made in the primary model requires the lower layers of the model; however, the parametric design tool may make these changes without the need for the designer to do so (Burry, 1999; Jabi, 2013). Parameters allow designers to make variations that can pursue creativity as well as extend the boundaries of knowledge (Iordanova, 2007). Parameters can be used to produce and explore ideas, allowing designers to generate more ideas, receive feedback sooner, and iterate faster. In parametric design, designers use preset parameters to define a shape. Sufficient reasoning is required to construct a sophisticated geometrical framework that is integrated into a complex model, that is flexible enough to do alterations (Peters & Peters, 2013). The impact of parameters and the hierarchy established by the developer are agreed upon by most definitions of parametric design. Parametric design, in the example, explores the numerous laws of geology and topography while highlighting the interaction of architecture and nature (Figure 3).

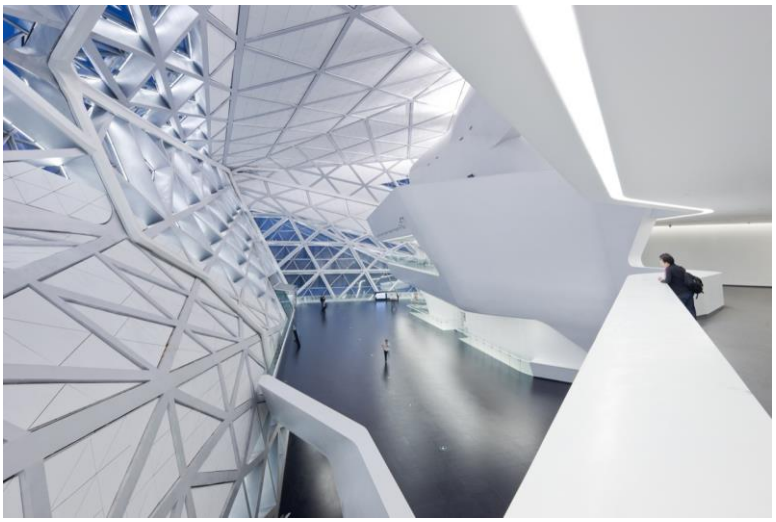


Figure 3: Gallery of Guangzhou opera house / Zaha Hadid Architects (2010) (URL 1)

The structure's undulating walls and ceiling are made up of stepping elements that allow light to enter the interior (Figure 4).

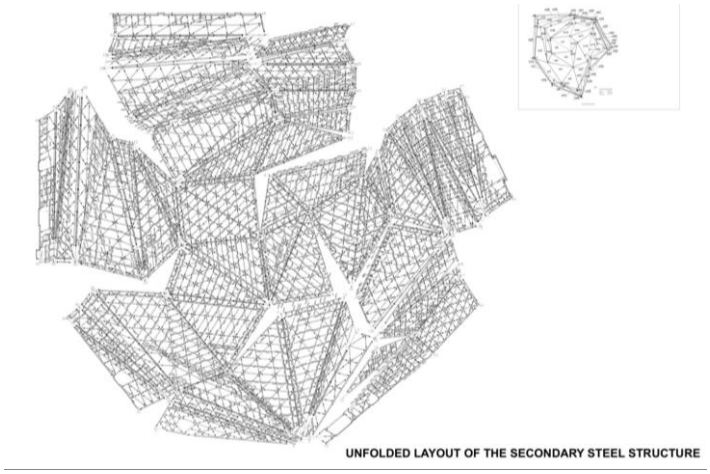


Figure 4: Gallery of Guangzhou opera house / Zaha Hadid Architects (2010) (URL 1)

The designer does not design the form or begin with a preconceived or pre-determined design solution when using the parametric design method; rather, he or she begins by articulating parameters that define a form and constraints, or rule-sets (Karle & Kelly, 2011). The development of a new form is triggered by more of these parameter values. This enables the designer to experiment with a wide range of compositions that the

initial composition's variability affords. The designer then delegates responsibility to the most appropriate form, which the designer chooses and advances for further development (Alalouch, 2018). The transition is symbolized by the parametric design. When the parameters are altered, the modifications in the design have an impact on the final product, resulting in the production of various combinations. The designer has the opportunity to choose the most suitable of the many alternatives produces.

To sum up, parametric design, according to Hernandez (2006, p.322), is "the process of creating in an environment where design variations are effortless, therefore replacing singularity with diversity in the design process." In addition, a parametric modeling approach enables arhitects/interior architects or industrial designers to model design classes and aspects of the revision process from a systematic perspective. Architects or designers will be able to integrate both their concepts and how they will evolve in their environment using them.

2.2 Parametric Design Thinking

Parametric design thinking is growing as a theoretical issue (Oxman, 2017). Parametric design thinking is more than a new digital approach; it's about comprehending parametric structures of skills that can be expressed and characterized as generic parametric schema(Hernandez, 2006b).

Parametric Design Thinking is a novel methodology that combines with other major generative approaches and enablers. This assimilation can be thought of as combining viable components of parametric design thinking to address parametric design's constraints. It creates links between characteristics within a system and is a technique

of linking functional and symbolic systems into a concept design clear of digital tool specificity.

Moreover, parametric thinking represents a substantial shift in professional practice (Karle & Kelly, 2011). Thus, a conceptual design process can be enabled by asking questions and creating a set of rules with conceptual variables. The diagram must be viewed as both a portion and a whole to be considered parametrically. Perceptual, sensory, and emotional factors are all considered thinking of parametric design (Hernandez, 2006a).

- Perceptual parameters are formed by creating an objective and subjective characterization of the starting point that guides the investigation; The purpose is to gather data on how the starting point is viewed.
- Sensory parameters are created by assessing the subjective definition, that guides the research by processing and analyzing the data acquired in each sense individually. Grouping these analyses is to ensure that they share a common attitude toward recognition. Defining an approach on a large scale, shapes the attitude generated through the senses. The purpose of this method is to create a language.
- Emotional parameters are produced by the fact that sensation's language can describe a physical or abstract environment. The aim have a functional role, as well as form, material, texture, color, and other aesthetic features. To build a reference-able setting or to produce design information, a symbolic work might be separated into exhilaration, stagnation, stress, and so on.

Another framework for creative thinking in the design is the formation of a new schema. According to describe the parametric schema's functions:

- Providing a platform for creativity
- Providing a space for diversity
- Providing a space for transformative processes

Abstraction-based thinking, mathematical-based thinking, and algorithmic-based thinking are 3 different ways to create a parametric design. Thinking with abstraction, theoretically, and algorithmically are three elements of parametric design thinking. Parametrical designers, according to Woodbury, would allow more than just a basic understanding of architecture. An infinite number of design variations can be created in parallel using parametric design (Woodbury, 2010).

2.2.1 Abstraction-Based Thinking

An abstraction is a term that refers to a general idea instead of a specific example. In popular parlance, abstraction is associated with ambiguity; it can be difficult to deduce much from an abstract concept. Abstract ideas in design are frequently protean, in the sense that they are used as a starting point for a variety of possibilities. Both meanings of the word apply in this context: a broad notion can be realized in a variety of ways, and a vague framework can be given a variety of meanings, each of which can have various realizations (Woodbury 2010).

2.2.2 Algorithmic-Based Thinking

Thinking algorithmically means that the scripting language provides functions that can add, repeat, modify or remove parts in a parametric design. Algorithmic principles are the foundation of parametric systems (Dino, 2012). An algorithm is a series of instructions with a fixed period to accomplish a certain goal. Algorithmic Thinking is a collection of rules defined as a set of explicit instructions written in source code which launch computational procedures, that build digital forms (Figure 5).

It is creating a collection of organized steps (sequencing) and then performing them in a specific order to solve a problem or complete a task in a repeatable manner. It is a way of problem-solving that involves precisely describing the procedures that must be followed. Designers create algorithms rather than providing up with a great solution to a problem. They are instructions or rules that, when followed precisely (by a designer or a computer), lead to solutions to the original and related issues. When constructing algorithms, the thought process argues for employing explicit, well-defined, and efficient problem-solving stages (Kalogiannakis; Papadakis, 2020).

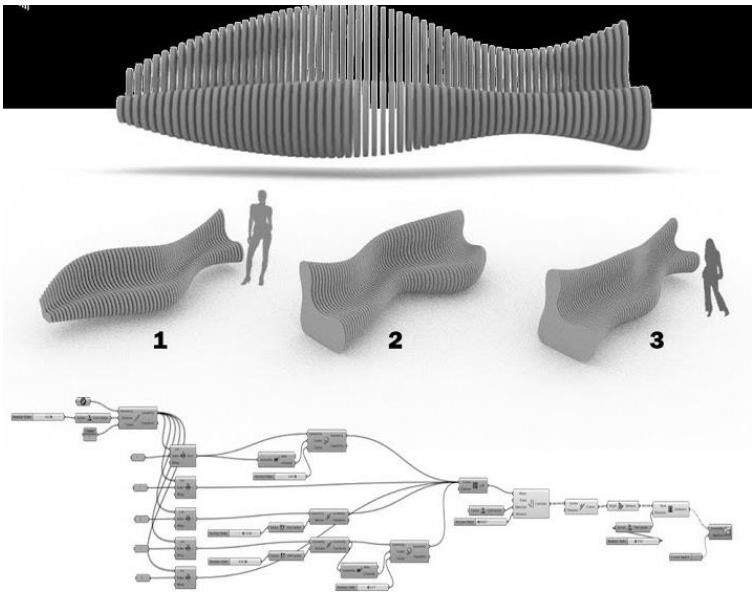


Figure 5: An example of a Grasshopper algorithmic sequence is Parametric Bench Design Concept, ParaStorm LAB. (2018, November 16) (URL 2)

2.2.3 Mathematical-Based Thinking

Theorems and concepts used to establish the programming languages for design description and creation are referred to as "mathematical thinking." In a parametric design system, Woodbury believes that designers require a distinct kind of understanding that can "predict lasting effects to comprehend the variety and framework of the mathematical toolkit and to move between the intended impact and

mathematical creativity that designs it" (Woodbury 2010). They produce mathematical theorems that the designs thus defined are subsequent to their fundamental assumptions by designers using construction such as grid systems, snaps, circle intersections, and tangents.

There have always been designers who have taken more than small steps toward mathematical maturity. Gothic structures may be comprehended and were clearly conceived sticated geometrical construction sequences based on a few essential parameters. According to Davis, based on the definition of the parametric equation in mathematics, which is a set of quantities expressed as an explicit function of a number of parameters, states "A parametric model is a set of equations that express a geometric model as explicit functions of a number of parameters" (Davis, 2013).

Antoni Gaudi's form-finding was primarily limited to developable surfaces, which he used to create a creative effect (Figure 6). It is known as the solution to the equation, and the partition of a line segment into tiny and large sections in the same ratio as the large part to the entire.

Figure 6: Gallery of AD classics: La Sagrada Familia / Antoni gaudi - 1. (1852–1926) (URL 3)

Basically, considering all three types of thinking, abstract thinking enables the parametric design to use a generative approach to create similar options. Scripting is employed for the section where the theories and building are required for the script language in mathematical reasoning (Woodbury, 2010). Algorithmic thinking is evident in the representation of the design, which necessitates a series of actions to remove and add pieces of a parametric design (Oxman, 2017). However, in order to get the most ways, designers must understand and use algorithmic thinking. These three activities suggest a wide range of possibilities.

2.3 The Principles of Parametric Design

The principle of parametricism is that there are various new styles, each of which has its manner of comprehending and handling functions. The most decisions in parametric design are made with the help of principles, and strategies follow. So the main goal of this section is to unwrap the principles of parametric design in order to better grasp, explain, and comprehend the process by incorporating qualitative and quantitative characteristics into a systematic design procedure. The formal and functional criteria that govern the characterization of the design's formal development and resolutions are included in the operational definition of parametricism (Woodbury, 2010). Thus, the link between design elements is shown as parameters that may be reformulated to

create complex geometries, these elements are based on the elements' parameters, and new shapes are generated simultaneously by adjusting these parameters. The terms "parameters" and "geometrical relationships" refer to numbers and spatial relationships(Schumacher, 2011).

Patrik Schumacher developed a theoretical framework for critisizing and interpreting parametricism principles in his book titled "Autopoiesis of Architecture: A New Framework for Architecture" (Table 1). Parametricism's basic principles are as follows:

Table 1: Parametricism Principles (Schumacher, 2011)

FORMAL PURPOSE	Negative principles:	Avoid using stiff models (lack of malleability)
		Simplistic repetition should be avoided (lack of variety)
		Avoid putting together a collage of unrelated, discrete parts (lack of order)
	Positive principles:	All forms must be flexible (intelligent: deformation = data)
		All systems must be distinct (gradients) and interdependent (correlations)
FUNCTIONAL PURPOSE	Negative principles:	Stay away from inflexible functional stereotypes.
		Functional zoning is a way to avoid segregation.
	Positive principles:	Both functions are activity/event scenarios with parametric parameters.
		All tasks interact with one another.

To design with parameters, a set of parametric principles must be established. A parametric design should follow four principles in this framework: the first is that parametric elements should be a combination of modeling and reuse of parametric design. The second is that the models should be able to develop flexibility in developing varying forms; this means that all of the forms should be flexible, have parametrically variable degrees of freedom, and can take on a variety of forms. The third one is that the model has variations in generating alternatives; this means that characterized by its ability to develop alternatives inside a parametric schema through differences in alternative geometry. Finally, models should be contextual; this means that they should be characterized by their behavior and reactions between subsystems.

2.3.1 Modeling and Reuse

The parametric framework is a basic cognitive capability of the designer's creativity. The parametric framework can be updated and adapted during the design process. The new learning approach of remaking and refining is posited as the behavioral role and reasoning skills of a generic framework (Oxman, 2017). Designers have the ability to alter and update their rule-based representations at any point during the design process. According to Woodbury, "parametric modeling introduces fundamental change: 'marks', that is, parts of the design, relate and change together in a coordinated way" (Woodbury, 2010).

The design system is distinguished and correlated during parametric design procedures. As a result, designers can go back to any stage of the process and change parameters or criteria to change their design or pursue an alternative one. This enables them to leave the design process free and flexible from a methodological standpoint. As an example of this, It is a futuristic garment designed by designer Matija Cop and

influenced by gothic buildings with interwoven characteristics. These clothes are skilled in a structural game with foam pieces involving construction techniques. It reveals an iterative articulation, as each element has a proportionate relationship to the total. The forms flow and have a mystical expression, making a statement that goes beyond emotions and deeds. The design uses laser-cut rectangular chunks of soft, and foam to create a sequence of tabs and slots that link and lock properly without using stitching or adhesive.

According to Cop (2018), "Objects can be destroyed and recreated in an utterly different form whenever one wishes," Furthermore, "the material properties make both surfaces soft and easily adjusted to the body" (Figure 7).

Figure 7: An architectural attire designed by Matija Cop (2018) (URL 4)

2.3.2 Flexibility of Developing Varying Forms

All of the forms are flexible, have parametrically varying degrees of freedom, and can adopt many different forms (Chokhachian, 2014). There is a lot to discover, and there isn't just one notion or modulation range. It can impose additional constraints, such as fabrication constraints, form, and or and then read these constraints into the study and

pre-constraint form using this method. The Hangzhou Olympic Sports Center utilizes less steel, models energy performance, and creates flexibility in two ways:

1) besides connecting the metal shell and concrete bowl around each other at each level so the two systems function in unison; and

2) by giving sufficient structure at the top of the bowl to reduce the roof cantilever.

Because the model was parametric — that is, it was computationally designed to respond to various inputs such as the number of rows of seats, their distance from the field, and line of sight standards — design changes could be made in a very short time, eliminating the "build-test-discard" method used in traditional modeling (Figure 8).

Figure 8: Hangzhou tennis center (2020) (URL 5)

The design of the stadium envelope is based on a modular system of sculptural steel trusses which provide shade and house the arena’s technical systems. To design the exterior, an integrated parametric system was created to conceptualize, simulate, and

document complex geometric systems. Physics simulation tools were used to test basic structural behavior (Figure 9).

Figure 9: Hangzhou tennis center (2020) (URL 5)

2.3.3 Variations in Generating Alternatives

The parametric design method is characterized by its exploration power to generate alternatives inside a parametric schema. The parametric schema facilitates the exploration of variants such as shape relationships, structural organization, size, and formal patterns using form-generation procedures. Thus, the parametric schema facilitates the exploration of variants such as shape relationships, structural organization, size, and formal patterns using form-generation procedures (Oxman, 2017). His statement also defined it as a strategy of parametric design. Parametricism creates a usable set of elements that may be easily changed, resulting in an unlimited number of possibilities. According to Zaha Hadid architects, four stations on the connection train tracks running up to Innsbruck's northern series of mountains are part of the project. This design method relies on adapting to individual site circumstances

at various points while articulating a consistent overall architectural language. Variations in the project for the Hangzhou Olympic Sports Center exist on the outside of the enclosure.

Different geometric effects were achieved by manipulating the point cloud limitations. It is also possible to change the number of petal modules. The design team was able to rapidly investigate design options and variants within the conceptual limitations thanks to the parametric description of the outside geometry. Branko Kolarevic (2013) explains the potential and rationalization for parametric design:

> Parametrics can provide for a powerful conception of architectural form by describing a range of possibilities, replacing in the process stable with variable, and singularity with multiplicity. Using parametric designers could create an infinite number of similar objects, geometric manifestations of a previously articulated schema of variable dimensional, relational, or operative dependencies. When these variables are assigned specific values, particular instances are created from a potentially infinite range of possibilities (Kolarevic, 2013).

The major technique of managing the form was through quantitative control of the point cloud. The design team was able to investigate various exterior surface layouts using parameters for altering the point cloud (sorting, morphing) (Miller, 2011). While much of the review was based on aesthetics, other factors such as shading, irrigation, structural performance, and sporting technical systems all play a role in determining the final form (Figure 10).

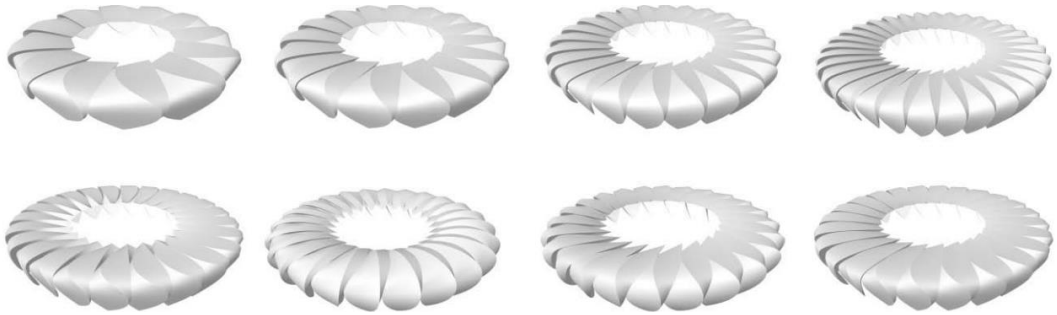


Figure 10: Hangzhou Tennis Center (2020). Variations on the exterior envelope (Miller, 2011)

A parametric depiction of a design is typically obtained using dimensional multiplication and variation, or quantitative methods. Color, scale, orientation relative to the form, and even more qualitative limitations might all be changed parametrically. Innsbruck Nordpark Cable Rail station is an excellent example of this. It has achieved this level of adaptability to a variety of site environments while maintaining genotypic coherence among phenotypic variability. The spatial quality of each station is determined by two contrasting aspects called "Shell & Shadow." Over the top of a concrete foundation, a lightweight organic construction floats. The landscape serves as a relief, etched with numerous movements and circulations.

The shell structures' considerable flexibility allows them to change to these varied parameters while remaining part of about the same formal group (Figure 11).

Figure 11: Nordpark Cable Railway by Zaha Hadid Architects (URL 6)

Most architectural systems and elements can be parametrically flexible, according to parametric design. This entails a philosophical and fundamental shift in architecture's fundamental parts. Instead of relying on rigid geometrical forms like modular, cubes, cylindrical, spheres, and pyramids, emerging types of parametricism rely on animated geometrical objects like splines and subdivs. These are the fundamental geometric foundations for movements like 'hair', 'cloth', 'blobs', and metaballs,' which react to 'attractors' and may be made to resonance with one another via 'attractors.'

2.3.4 Contextual Models

Once we have subsystems differentiated, we must assume that each architecture design includes several subsystems that are layered into model relationship envelopes. All of these subsystems must be in sync with the system as a whole (Chokhachian, 2014). There is a way of acting and reacting between subsystems. These principles provide a framework for critisizing and improving the design over time. Büro Ziyu Zhuang created a church in Qingdao, China, with walls and a tower made of lots of spaced-out aluminum ribs as an example. There are 11 mainframes among them, and 60 subframes that connect the former pieces. The mainframes establish the façade's outside contours, while the subframes define the inner chambers' curves. Along the longitudinal axis, the entire structure is cut at consistent intervals. Light can enter via the spaces that have been formed. It bounces back and forth in the white slices as it travels between them, and creates equally and softly into the inside. The variable sunlight and its relationship to the spaces and interfaces provide varied visual effects throughout the day (Figure 12).

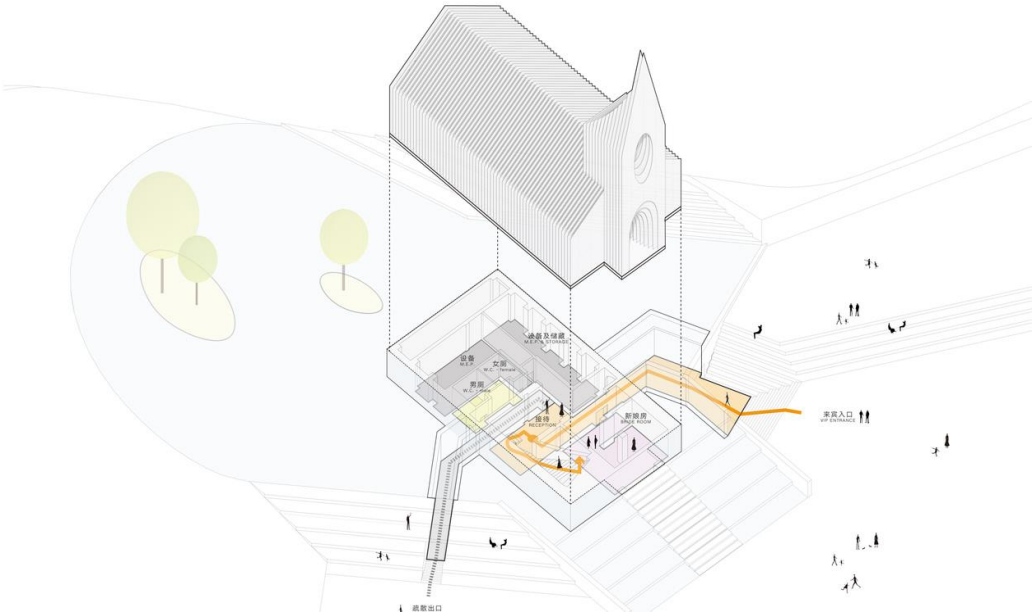


Figure 12: Büro Ziyu Zhuang’s chamber church, STIR world - architecture, design, and art magazine (2022) (URL 7)

The interplay of connecting and refraction lends a sense of holiness and pleasure to the "cave." The cave's purpose is to serve as a place of refuge and spirituality. The form is made up of a sequence of metal slices that are placed vertically, each 5 cm thick and separated by 40 cm.

According to the architects, "In contrast to the usual concept of floor functionality, the 60 discrete and gradual slices can be generally viewed as 60 independent portions," (Figure 13).

Figure 13: Büro Ziyu Zhuang’s chamber church, STIR world - architecture, design and art magazine (2022) (URL 7)

As another example of this, Nouvel designed Louvre Abu Dhabi as a 'museum city' in the water, taking a contextual approach to the site. The intricate pattern on the dome is the result of meticulous geometric planning. In the eight overlaid layers, the pattern is reproduced at varying sizes and angles. Before appearing or vanishing, each beam of light passes through the eight levels (Figure 14).

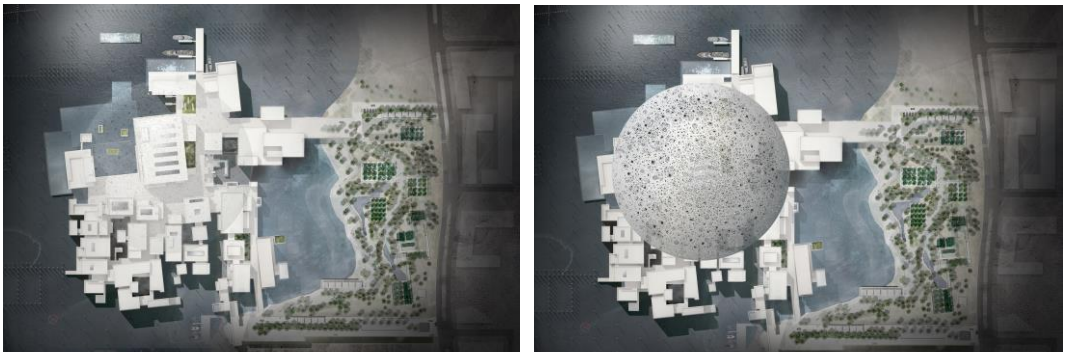


Figure 14: Louvre Abu Dhabi — Ateliers Jean Nouvel. (2017) (URL 8)

The dome's detailed design is replicated in various sizes and positions, giving each light beam to penetrate through the layers. As the sun moves through the day, the results are a dramatic 'Rain of Light' effect. For symmetrical aggregations, modeling strategies are based on the comparison of forms utilizing processes that relate to a

small list of regulations, such as reflective, rotations, or translational symmetry. From simple geometries, the combination of these laws allows for the creation of designs with high morphological complexity (Figure 15).

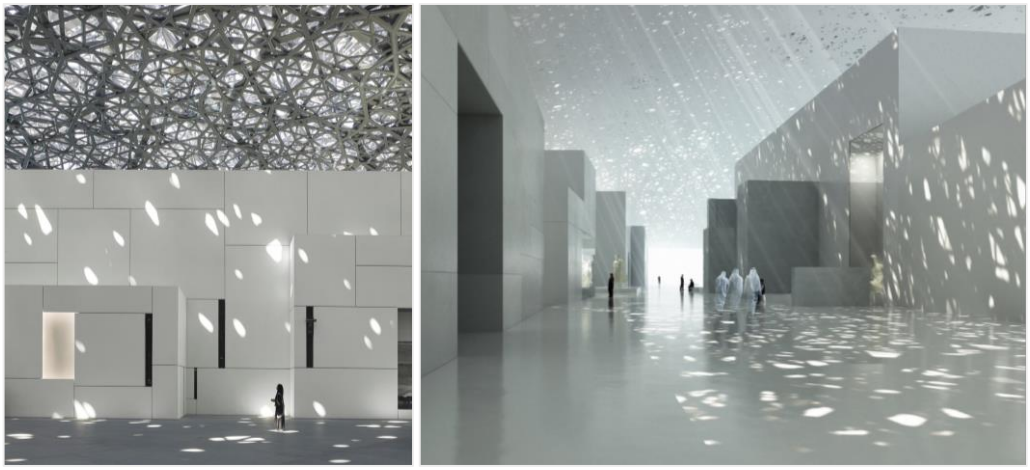


Figure 15: Louvre Abu Dhabi — Ateliers Jean Nouvel. (2017) (URL 8)

Basically, abstract thinking enables the parametric design to use a generative approach to create similar options. Scripting is employed for the section where the theories and building are required for the script language in mathematical reasoning (Woodbury, 2010). Algorithmic thinking is evident in the representation of the design, which necessitates a series of actions to remove and add pieces of a parametric design (Oxman, 2017). However, in order to get the most out of such ways, designers must understand and use algorithmic thinking. These three activities suggest a wide range of possibilities.

2.4 The Strategies of Parametric Design

As the design strategies have to do with both the quality and the inventiveness of the design. Information on how to reach the final aim is contained in strategies. Subgoals are defined by design strategies, which limit the scope of the process (Canestrino et al., 2022). The parametric design method is characterized by its exploration power to

generate alternatives inside a parametric schema. In a parametric solution space, parametric systems allow a variety of explorative, context-based, formal, generative, and performative design strategies for specific design objectives. In contrast to traditional architectural composition procedures, patterns of differentiation can be used to govern parametric design in architecture.

Moreover, Parametric design is more complicated than any other style in design history. Getting the most out of it necessitates combining data flow, new divide-and-conquer tactics, naming, abstraction, 3D visualization, and algorithmic thinking. These are the fundamentals, but mastery necessitates more. These are created independently as separate entities and then combined to form an organization (Figure 16).

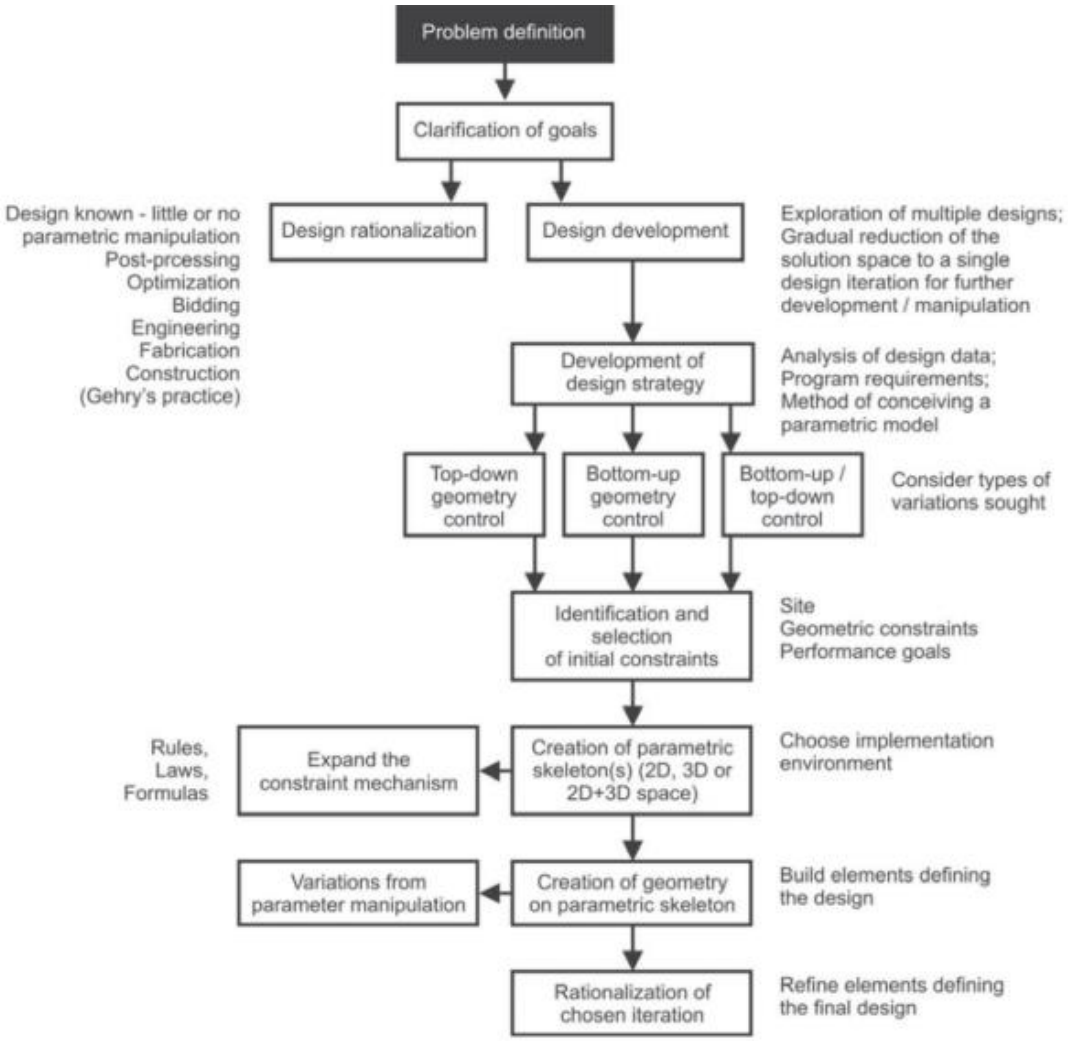


Figure 16: Schema of a Parametric System Strategy (Gane, 2004)

A set of parametric strategies must be defined before designing with parameters. In this framework, a parametric design should use four strategies: the first is sketching, which is a phase in which designers build a parametric design concept over time. The second benefit is that a single system creates a framework of interactions capable of displaying emergent features and embracing a variety of parametric design methodologies. The third is that copy and modifying, which implies starting with a functional model and progressing in increments while constantly checking that the model works, is often less efficient than starting with a functional model and progressing in increments. The fourth is that with parametric design, the creative shape

is generated in accordance with the project's function. Finally, in parametric modeling, the modules are used to create a set or a list of generated integers that are used as input to future procedures.

2.4.1 Sketching

The sketch is featured in a book collection that confirms its importance in design, extols its many qualities, and encourages designers to develop this vital ability. By definition, parametric models are dynamic. Pages of hand sketching are sometimes replaced with a single model. Parametric models, on either hand, are defined, sophisticated systems that require time to create. They are not always speedy. System developers face difficulty in enabling quick modeling so that their tools can better support design sketching (Woodbury, 2010).

Sketching is a phase in which designers develop a design concept over time. As a drawing technique, parametric design aids the designer in revising and refining his concepts. The sketching technique is full of unexpected twists and turns. Because when designer views their new design, other thoughts arise, and the designer's imagination wanders to other possibilities. Even a line that the designer has drawn by mistake can sometimes turn into this. Instead of paper-based sketching, digital applications are used in the design profession. Students in a university program were instructed to create digital designs for bench design, which is a good example of digital sketching. The groups drew preliminary designs for a bench. The students prefer software for their initial digital sketches based on their previous expertise with it. The majority of the pupils were at ease with SketchUp and Rhino. They then used the 'boolean difference' function to find the junctions. As a result, perforated slices were generated (Figure 17).

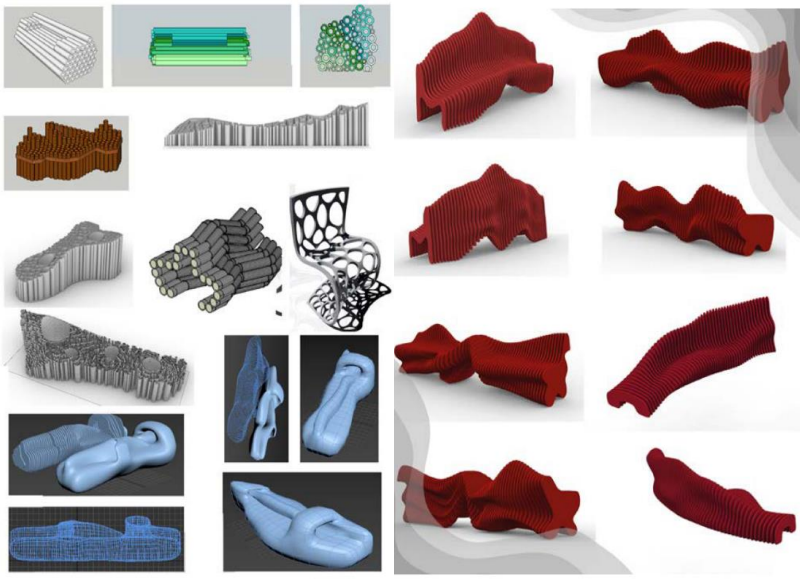


Figure 17: Initial sketches by several groups of students, as well as initial sketches of the sliced parametric bench (Ağırbas, 2020)

In digital sketching, parametric design systems can also be conceived of as flexible. In parametric design tools, for example, the designer may discover something new during the digital sketching process that he hadn't consider previously (Ağırbaş, 2020).

2.4.2 A Single System

The integration of the methodologies into a single system results in a framework of interactions capable of demonstrating emergent properties and incorporating numerous different approaches to a single architectural problem. This approach is commonly used for geometric modifications, scaling, and spatial moves (Canestrino et al., 2022).

2.4.3 Copy and Modify

Designers may recycle their models, but they will devote a significant amount of work to locating existing models and adapting them to their needs. Creating a model from scratch is generally less efficient than starting with a functional model and progressing in increments, constantly verifying that the model works. For instance, The Astana National Library designed by Bjarke Ingels Group was the winner of the global

competition in 2009. When the idea and design structures of the project are examined, it becomes clear that it is supported by major digital design scenarios that were affected by Deleuzian thought (Selçuk; Başkol, 2020). Deleuzian notions such as fold and creation of multiplicities can be read clearly as to form and creation procedures through the project's diagrammatic approach. All of these shapes had layered and folded during each other over and over again as four archetypes, the circle, the rotunda, and the strip had been reorganized and understood through concept formation (Figure 18).

Figure 18: National Library in Astana, Kazakhstan / BIG (2009, August 25) (URL 9)

The perfect circle and the public spiral are two interlocking structures that combine vertical hierarchy, horizontal connectivity, and diagonal view lines to create a building that changes from a horizontal organization — where the library, museum, and supporting processes are placed beside each other — to individuals in the system where they are stacked on top of each other through a diagonal organization A strip volume is generated by covering the changeable arrangement of spaces with a continuous skin, where the façades flow from inside to outside and back again (Basulto, 2009) (Figure 19).

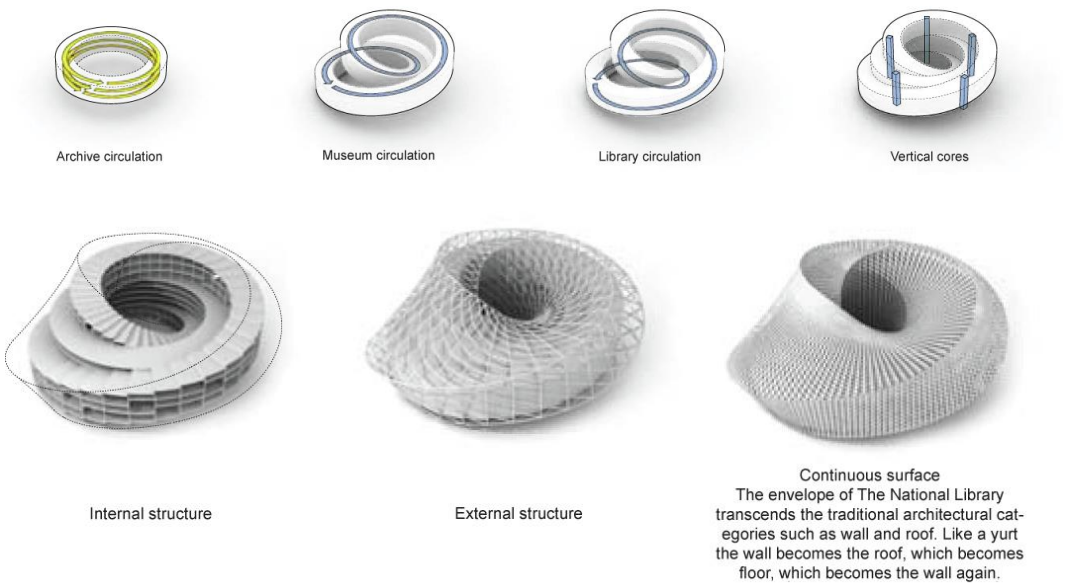


Figure 19: National Library in Astana, Kazakhstan / BIG (2009, August 25) (URL 9)

Another example of copy and modification, is the National Museum of Qatar, Giftshop, and children's Giftshop by Koichi Takada architects (Figure 20). The 40,000 wooden pieces that were put together for the timber walls were individually encoded with a visual number and guideline, assembled by hand, piece by piece without visual fixings. Each piece was glued and fixed by small cleverly conceived brackets to a steel rib-like structure behind the cladding (Figure 21 and Figure 22).

Figure 20: National Museum of Qatar shop interiors / Koichi Takada architects. (2019, May 3) (URL 10)

Koichi Takada's project description;

> Dahl Al Misfir was the inspiration for the museum shops' timber walls. Its organic construction echoes Koichi Takada's concept of reintroducing nature into the building and forging connections between people and nature via design. Koichi Takada Architects developed a design of curves and surfaces that words fail to explain using cutting-edge 3D modeling software.

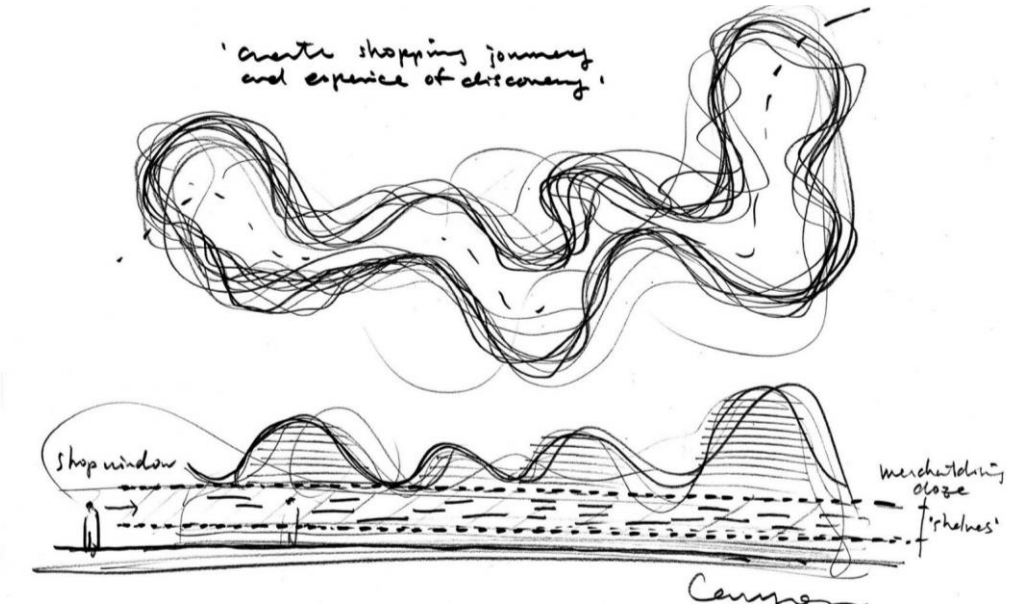


Figure 21: National Museum of Qatar, Giftshop, and children's Giftshop by Koichi Takada architects (2019, May 3) (URL 10)

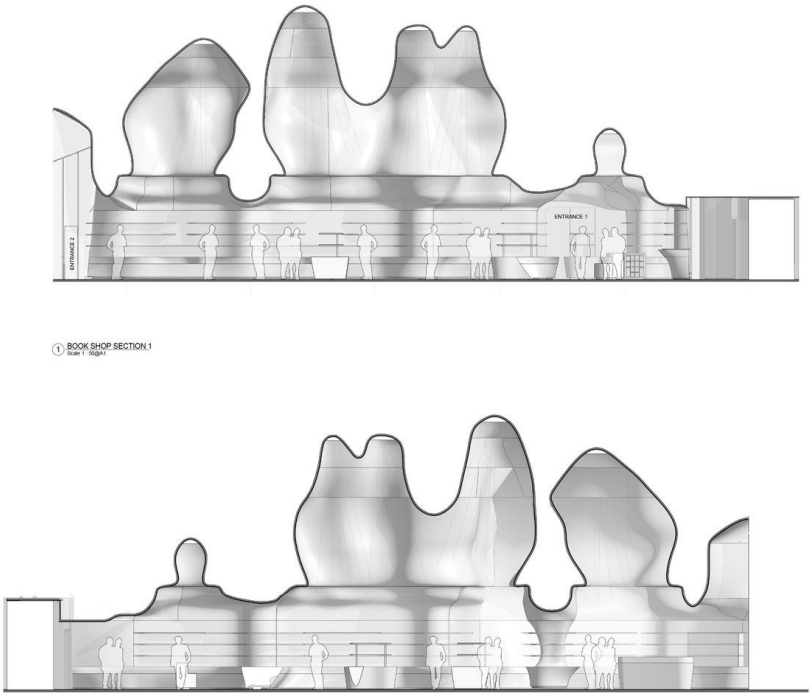


Figure 22: National Museum of Qatar shop interiors / Koichi Takada architects (2019, May 3) (URL 10)

2.4.4 Search for Form

Parametric modeling opens up new design possibilities. Curves and surfaces are the best examples of this. The form-finding procedure is a method of ensuring that outside

forms are compatible with the interior (Yuan and Yi, 2012). These theoretically motivated controls are provided by conventional systems. Design possibilities are expanded through parametric modeling. Curves and surfaces are the clearest examples of this. These are inherently parametric things, which are defined theoretically as parametric processes over sets of sampling sites. These mathematically defined controls are provided by traditional systems. Parametric systems, on the other hand, allow a new set of parameters to be added on top of the existing ones. This opens up a world of possibilities for finding shapes that would otherwise be impossible to find.

Parametric systems, on the other hand, allow a new set of variables to be layered on top of the existing ones. This opens up a world of possibilities for discovering forms that would otherwise be impossible to find. The evolution of design can be viewed as a never-ending process of experimenting with new form-making ideas, utilizing whatever tools and conceptual conceptions are available at the time. Such experimental play is required of new languages and design styles, especially in their early stages. The parametric form evolves throughout time, resulting in living forms. It is crucial to note that many projects have been built using parametric design systems as a design tool under different designs.

According to Schumacher, parametric patterns are "parametrically changeable; eventually diversify," resulting in a wide variety of options (Schumacher, 2008). There are five general theories concerning the search for form ideas, according to Gelernter (1995): To begin, the creative form is created in accordance with the project's function. Second, it is the outcome of the architect's or designer's inventiveness. Third, the architectural shape is influenced by the prevalent spirit of the time, such as international style architecture. The other types, on the other hand, are dependent on

the current social and economic situations. Finally, architecture form is the consequence of eternal design principles that create unique designers, nations, and climates (Gelernter, 1995; p. 14). As a result, the architectural form concept is largely dependent on the architect and the project's purpose. It also depends on the architect's preferred language or story in order to fit the project's objective. As an example, Hadid's accepted and dismissed architectural form principles (Table 2).

Table 2: The Accepted and Dismissed Architectural Form Principles from Hadid's (Schumacher, 2009)

Presence	Absence
Unity Balance: Asymmetry Scale	Symmetry Stable ground Rhythm Embellishment/Decoration

The concept of shape is created and designed by the system. The flexible feature can be used to create a variety of intriguing options; the suggested paradigm is the final one on the right. As Schumacher (2008) stated, this system "follows the design of environment as a process."A good example. This differentiation is based not only on the architect's aesthetic sense but also on the adaptive process to the environment and functionality. It also has a use for new urbanism strategies that provide a strong relationship between different forms, as well as other techniques that qualify projects to be environmentally sustainable and accomplish the objective for which they were designed (Figure 23).

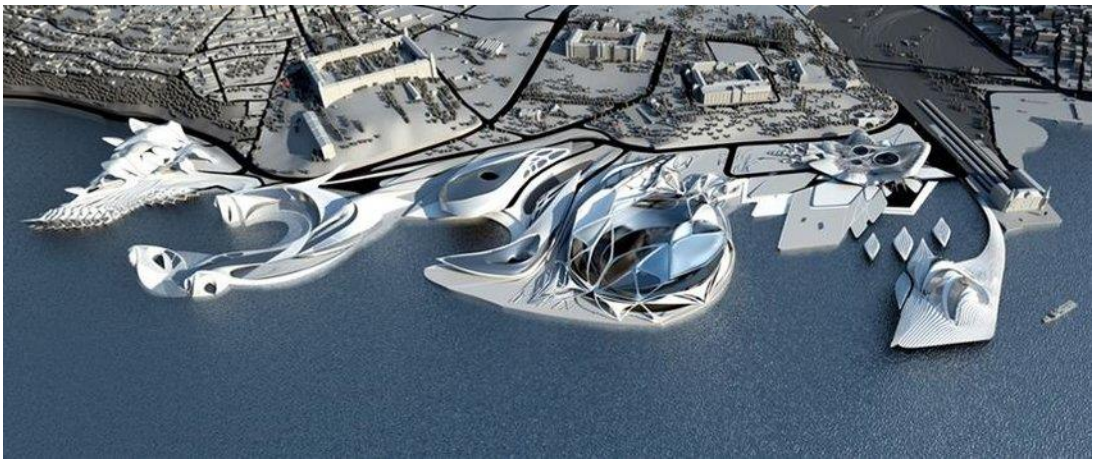


Figure 23: Parametric design by Yale studio; Schumacher, P. (2009) (URL 11)

Forms are parametrically flexible, allowing them to differentiate overtime to fulfill all of the demands of successful architecture (Figure 24). An exterior that is environmentally friendly. The exterior component is adjusted in response to the changing sunshine exposure. The size of the opening and the shade element's projection change appropriately. Despite the fact that this is primarily a behavioral adaptation, the visual benefits of distinction and accentuation are important to the parametric designer (Schumacher, 2008).

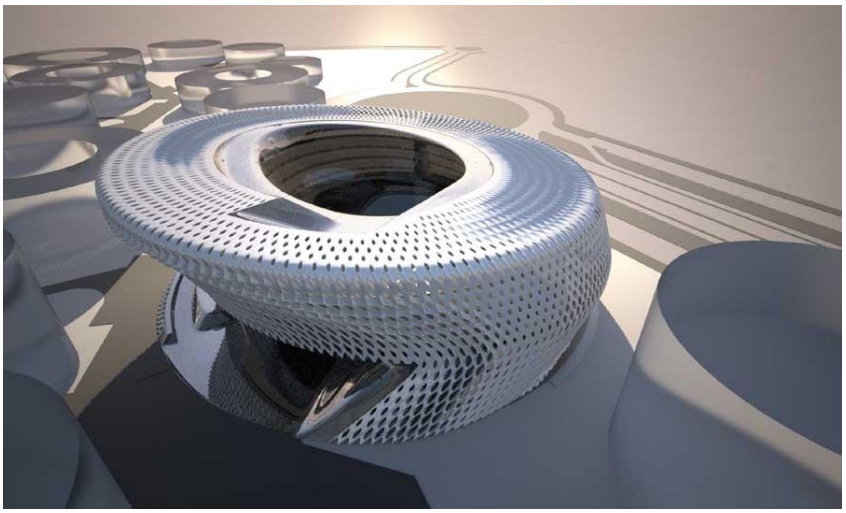


Figure 24: Madrid Civil Courts of Justice's parametric form in Spain, Zaha Hadid's (2007) (URL 12)

A spiraling semi-circular atrium within the building rotates and travels to overlook a public courtyard, providing a natural reference point for guests moving around the space (Figure 25).

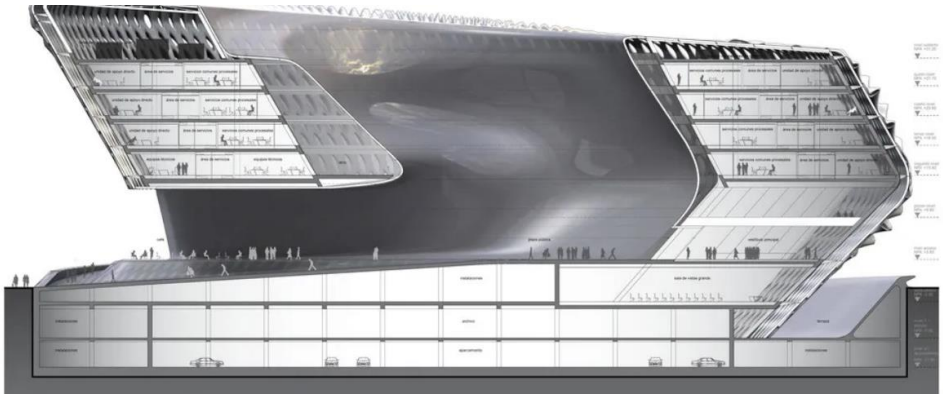


Figure 25: Madrid Civil Courts of Justice's parametric form in Spain, Zaha Hadid's (2007) : Madrid Civil Courts of Justice's parametric form in Spain, Zaha Hadid's (2007) (URL 12)

Another example is the Yinchuan Art Museum by WAA, which was built using GRC (glass-reinforced concrete) techniques that had never been used at this size in China before. This construction method provides for a smooth flow of data from digital modeling tools to manufacture, eliminating the human factor from the process. Each panel was constructed as a form in which material was mixed with fiberglass to make an extremely thin and sturdy mold using CNC milling equipment (Figure 26).

Figure 26: Yinchuan Museum / Waa. (2015, August 6) (URL 13)

2.4.5 Modules

The major reasons that systems give module-making tools are to reduce graph complexity and allow reuse. Making a clone of a single point and linking its input as required is all that's left of copying and reusing a module work successfully requires a lot of effort, and communities of practice generate some surprisingly sophisticated module-making approaches. Modules are used in parametric modeling to establish a set or a list of randomized integers that are utilized as input to subsequent procedures (Canestrino et al., 2022). For instance, some of the disks of Ateliers Jean Nouvel's National Museum of Qatar are 'horizontal,' with their edges resting on other disks at various angles (Figure 27). The building's shell protrudes outwards to shade a central courtyard and shield the interiors from direct sunshine. The disks slice through one another, creating a complicated geometric space architecture (Griffiths, 2019).

Figure 27: National Museum of Qatar — Ateliers Jean Nouvel (2019) (URL 14)

The ‘vertical’ disks constitute the building’s support and transfer loads of the horizontal planes to the base (Figure 28). Like the exterior, the interior is a landscape of intersecting disks. The museum comprises some 539 disks of 30 different sizes (Baldwin, 2020).

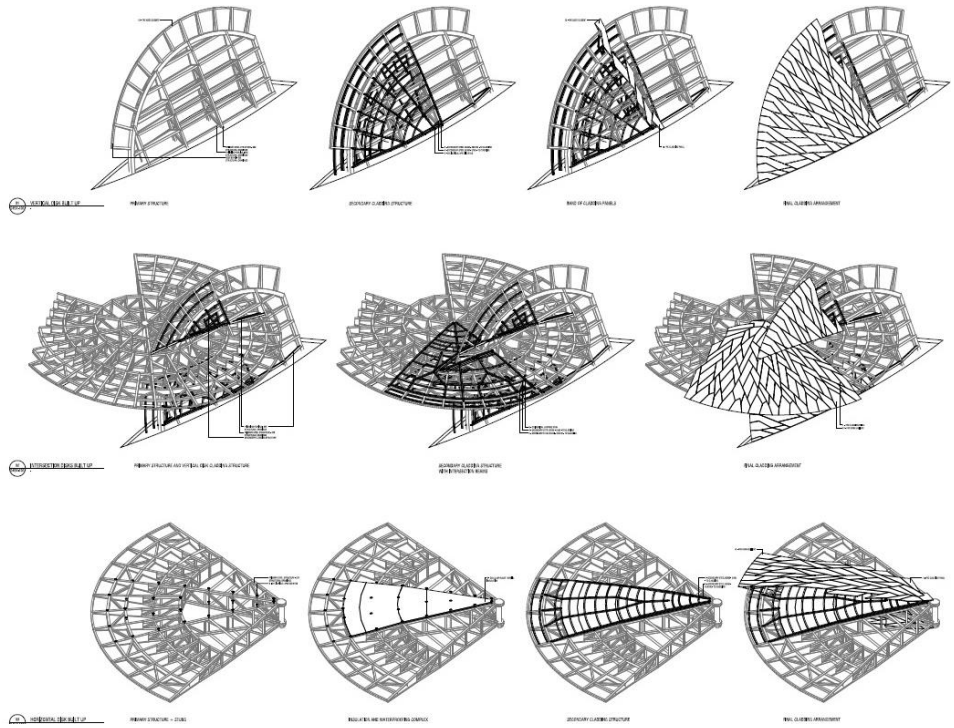


Figure 28: Architectural details: Jean Nouvel’s National Museum of Qatar - Architizer journal. (2020, June 17). Journal. (URL 15)

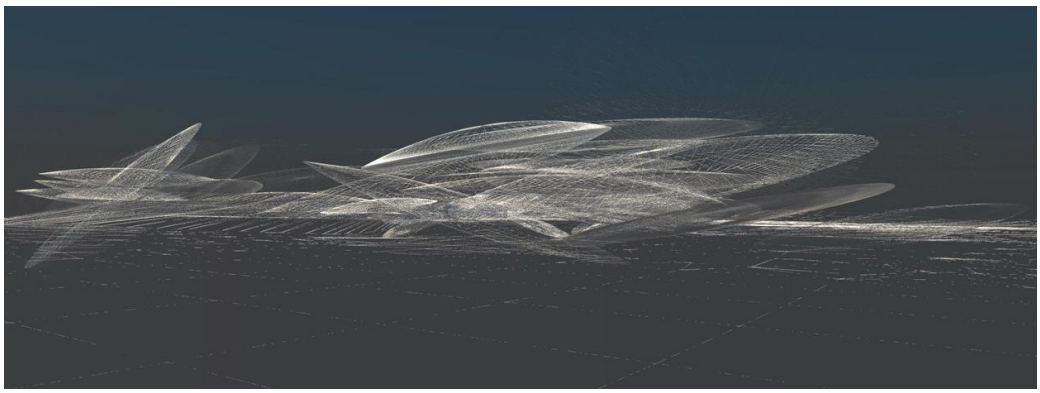


Figure 29: National Museum of Qatar / Atelier Jean Nouvel. (2019, March 29) (URL 16)

Making a module work successfully requires a lot of effort, and communities of practice develop the impact of technological module-making approaches. Modules are a relatively close part of the model development in a complicated design with repeated parts (Woodbury, 2010). The right-hand design is a programmatically organized complex of the 3 left-hand parts (Figure 30).

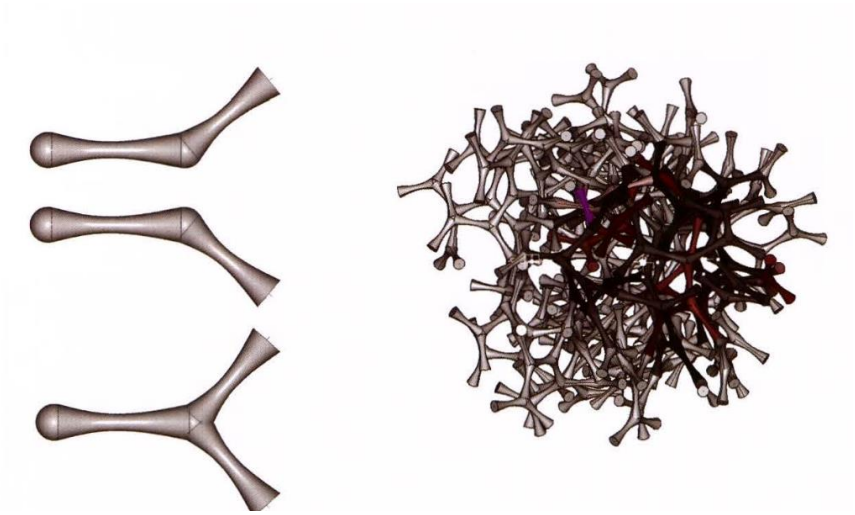


Figure 30: Complex of the three modules (Woodbury, 2010)

Thus, its principles of domains and remapping are critical in determining the range of numbers that can be created. It is based on changing the quantity of a parametric procedure that calculates the distance between a center, a curve, or a group of them. Geometric modifications, such as transformations, scales, and moving in space, are commonly connected with this method. For the best management of the severity of these transformations, ideas like Domains and Remapping are required. The Nanjing International Youth Cultural Centre by Zaha Hadid Architects is an excellent example of parametric modules Palazzo Italia's branched exterior envelope, designed by Nemesi, is based on a concept of an "urban forest." Nemesi has designed a unique and unusual geometric texture for this "skin" that resembles the intertwined random branches (Figure 31).

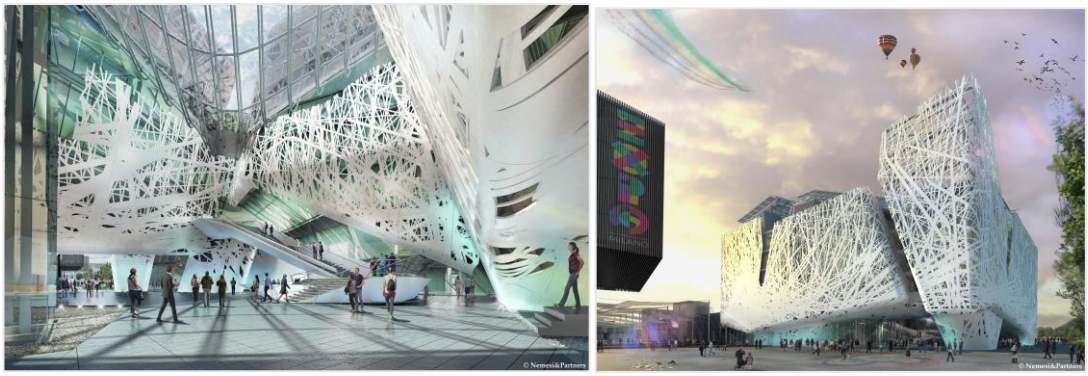


Figure 31: Italy pavilion – Milan expo/ Nemesi. (2015) (URL 17)

As another example, in the recently constructed Broad Museum in California, the interior gallery space of the museum is provided with continuous solar control and modulation system. In the example of this building, this is a fixed system. Termed the 'Veil' by the architects, this continuous parametric rhomboidal surface pattern covers the exterior wall and the roof of the museum. The mesh continuity is differentiated in geometry for lighting control of the Furthermore, the function of the wall surfaces is locally modified for architectural purposes such as opening up the entrance area and in order to provide exterior exposure of the glass wall and public areas of the building.

A large sculptural indentation on the second floor of the fac¸ade further modulates light at the pedestrian arrival point to the exhibition levels of the building (Figure 32).

Figure 32: Broad Museum in Los Angeles, USA, by Diller Scofidio + Renfro. (2016) (URL 18)

Basically, the parametric design method is characterized by its exploration power to generate alternatives. Subgoals are defined by design strategies, which limit the scope of the process. Parametric systems allow a variety of explorative, context-based formal, generative, and performative design strategies.

2.5 Parametric Design Tools

Parametric design is the process of selecting relevant parameters within a design issue and defining a model which could be used to examine the solution space. The model's explanation is created using technologies that assist with design in both the physical and digital worlds. (Gane, 2004) Architects and designers used parametric tools for several objectives during the design process. The process includes 3D modeling, simulations, automation, optimization, digital fabrication, and eventually digital assembly. A good example is Gate of zero, the pavilion of Seckin Pirim in the Maldives, this structure, which has a recurring form, reflects the artist's "one to whole" idea, which is central to his work. To create the pavilion's geometry, the designer used complicated algorithms, parametric design, and computational technologies. The symbol form serves as a welcome to the island for guests. The pavilion, which was inspired by spinning dervishes' skirt form, allows visitors to wander through it and

experience the interior areas. Using advanced parametric modeling and analysis methods, the project was built by combining similar objects of varied scales (Figure 33).

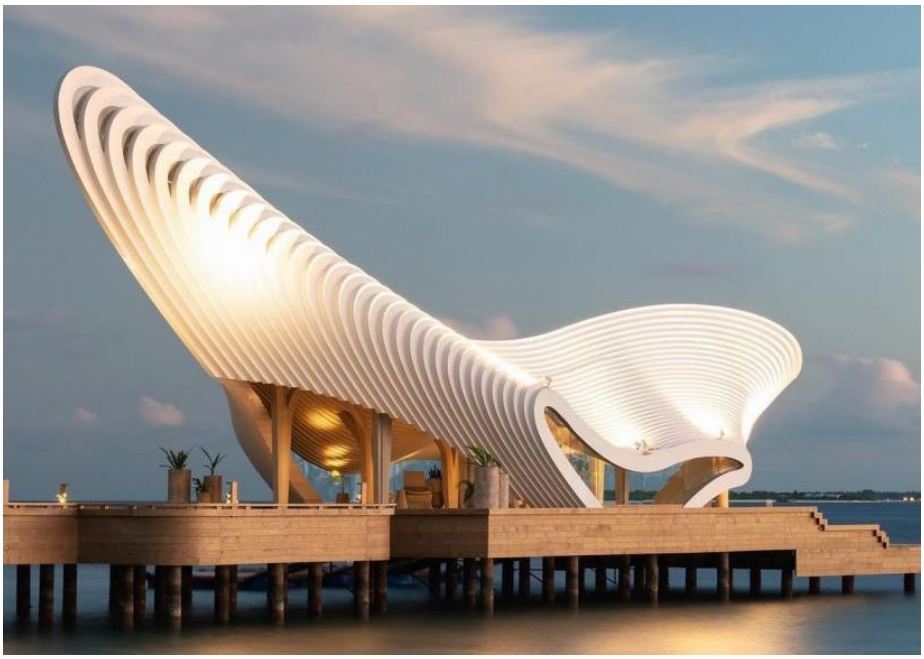


Figure 33: Gate of zero, the pavilion of Seckin Pirim in the Maldives. (2018) (URL 19)

2.5.1 The Use of the Physical Technique

Architectural solutions are traditionally produced 2 different on a drawing board or computer screen, making potential challenges difficult to perceive. When developing in a real setting, physical models are still the most important complementing tools. "For most of our existence, handcrafting objects was the only option we had. It necessitated a significant amount of human effort.

Today, parametric is described as the ability to build connections between elements whose sizes and positions are determined by measurements. The fact that one must build several iterations from scratch or foresee the model's behavior fully in the case of dynamic capabilities to produce a physical model meant to portray this

understanding suggests major significance. Sketching is a term used by many architects to describe 'how to think visually.' However, despite the fact that sketches and externalizations, in general, are believed to be vital to the design process, they are not key tasks for skilled architects in the early stages of conceptual designing, according to research on the technique of sketching. Despite the presence of highly sophisticated programs, literature and research on sketching, as well as interviews with architects, show that they always prefer to sketch or make models first. According to Smith,

> "In most processes, it starts with sketches… in this practice we do a lot of sketching and we do a lot of models… that's going all the time and then, you know, even if you have got something in CAD or parametric models or script it parametrically... still draw a detail or things like that to make sense of the whole." (Zarei, 2012).

To wrap up this discussion on the function of sketching and physical modeling in parametric design, it's worth noting that many voices have emphasized the importance of software in parametric design; some, like Schumacher, even mention sketching in Maya or Rhino to explore 'radical design goals.' Nonetheless, in today's architectural practice, the role of drawing and modeling is still significant and recognized.

However, whereas its primary function in the previous was generally defined as thinking visually, it is now relocated to other domains such as concept clarification (because sketching is free of software constraints) or creative thinking in a designer under the parametric method.

2.5.2 The Use of the Digital Technique

Models are used to visualize design concepts. Computer software can adjust design model parameters more rapidly and easily than people can with hand drawings, as well as show and graphically represent the results. Parametric CAD tools, which are based

on the idea of boundaries, features, and relationships between parameters or objects, are unique to the architectural world. These computer-aided design systems are also known as "functionality" or "associative geometry" systems. During product definition, a designer can use and alter parametrically or eliminate at any time. CAD/CAM (Computer-Aided Design/Computer-Aided Manufacturing) software keeps track of all the parts of the building and where they go. During which the digital model is created, the program displays a list of parts along with instructions on how to put them together to make the real item. Frank Gehry was a forerunner in this field, with his 1997 Bilbao Museum is a mix of complex, whirling shapes and compelling materials that respond to a detailed program and industrial urban surroundings. It is located on the bank of the Nervión River in Bilbao, Spain (Figure 34), and 2000 EMP serves as stunning instance of CAD/CAM. The Disney Concert Hall was designed by Gehry in 2003.

Figure 34: Guggenheim Museum Bilbao/ Gehry partners. (1997) (URL 20)

It digitalized points on Gehry's hand-built models' edges, surfaces, and intersections to generate on-screen models that can be manipulated like animated shows (Figure 35).

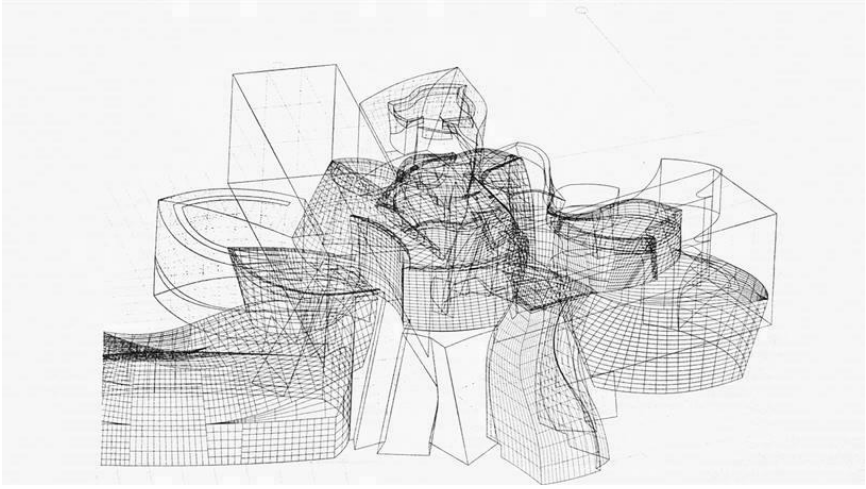


Figure 35: Guggenheim Museum Bilbao (Frank Gehry). (2018, August 17) (URL 20)

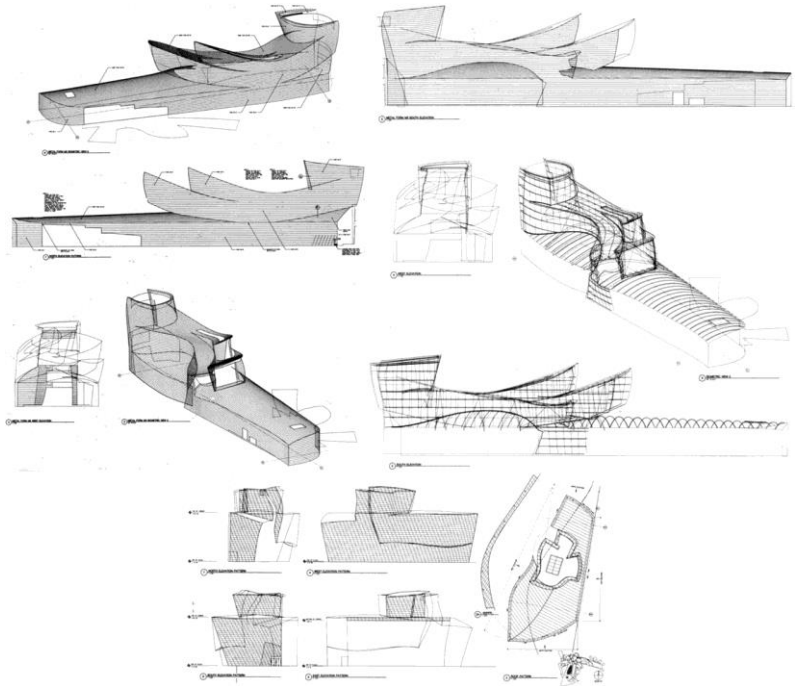


Figure 36: The Guggenheim Museum Bilbao / Gehry partners. (2013, September 1) (URL 20)

The capacity of parametric systems to keep all of the actions that sequentially define the product model is their distinguishing feature. Anyone can join the design team at any time and follow the logical phases of model building. Due to the variability of the

designs and the strict documentation requirements, no architecture projects are currently being produced completely using a collection of algorithms. Designers can use existing programs or construct their specific algorithm to aid in the design process, which could include: • Simulations • Advanced modeling • Automated

- As the modeling is in its advanced form, digital three-dimensional modeling of diverse shapes and complexity is possible with advanced modeling using algorithmic techniques.
- As the automation, programming's goal is to automate time-consuming and repetitive operations. The emergence of digital design (CAD) in design and architecture allowed for more efficient sketching and modeling; yet, the process is still largely based on a huge number of simple instructions with little automation.
- As the simulations, the ability to modify building parameters quickly is enabled by design projects information in the form of an algorithm. Evaluation of structural design, aesthetics, thermal comfort, and energy usage is required for architectural projects. Because of the simulation's accuracy and algorithmic design, a project's design can be quickly changed. Designers are increasingly incorporating optimization into their work to choose a design based on simulations from thousands of options.

It has evolved into a condition that affects the design process, rather than just a drawing or presentation tool. The design tools were first digitized, then made into tools that can be used more effectively by machine intelligence and enable the development of parametric design tools as part of this shift. Designers have been given new approaches and tools as a result of advancements in digital design tools, and these improvements

have led to new ways of thinking. In recent years, the use of digital vehicles in architectural design has risen in both speed and impact. Traditional geometry modeling tools are primarily "design and replace," but free-form forms are tools that allow a designer to construct a final product using simple geometries.

AutoCAD, Sketchup, and Rhino, as well as Autodesk Dynamo Studio, are examples of digital design tools. Tools that allow you to develop the algorithm include parametric modeling tools and design parameters of the designer's thoughts with the path established by modeling the links between design choices (Woodbury, 2010). Examples of these are Grasshopper, 3D and Maya Scripts, and Dynamo.

The most well Rhinoceros plug-in, Grasshopper, eliminates various constraints connected to the basic form's flexibility for specific formal needs and the difficulty of obtaining rapid adjustments to complex models. So Grasshopper is a visual program (visual script), it requires a logical/mathematical approach, unlike traditional applications. Sequences of instructions were defined and transformed into three-dimensional models using a software simulation based on a set of algorithms. Using scripting, we can define and explain with mathematical equations, construct parametric models that can be easily adjusted using the initial values, and quickly create very complicated forms with repetitive geometric features (Curletto, 2014).

Visual and textual algorithms are the two types of parametric design tools. It provides designers with two alternative modeling options in both of these situations. One is utilized to assure the algorithm's creation, while the other is used to display the algorithm's geometry (model). Programs like Rhinoscript (McNecl), Generative

Components (Bentley), and Mayascript are examples of parametric environments that include a software algorithm editor (Autodesk).

Grasshopper (McNeel) and Dynamo are two parametric design environments in which relational modeling is visually defined (Autodesk). Without having to understand code, any form may be created by combining codes with visual logic. The computational design software tools are solely employed to give the structure a form or to generate a new form. As a result, parametric design tools empower architects to serve as a broad platform where a design's design procedures are laid out and a specific example of its development is included in the design representation. Instead of decomposition or deletion, parametric design tools allow designers to change any item or geometry by varying a set of parameters. Parameters can be more than just numbers; they can also represent aesthetic and functional criteria and performance principles, such as structural load resistance and calculating the amount of light intensity in a certain area. A parametric model is a tool used in parametric design, which is considered a process. It describes an entire system made up of geometric sub-parts with variable or fixed attributes (Barrios, 2011). As a result, no ready-made form, even fundamental forms, is advised for parametric design. The entire design is built around a single point. To summarize the discussions, how parametric design works on various issues, as well as the effects of various subsystems and organizational capabilities on it, and how each process in the parametric system has the opportunity to improve technologically, theoretically is schematized and illustrated within the framework (Figure 37).

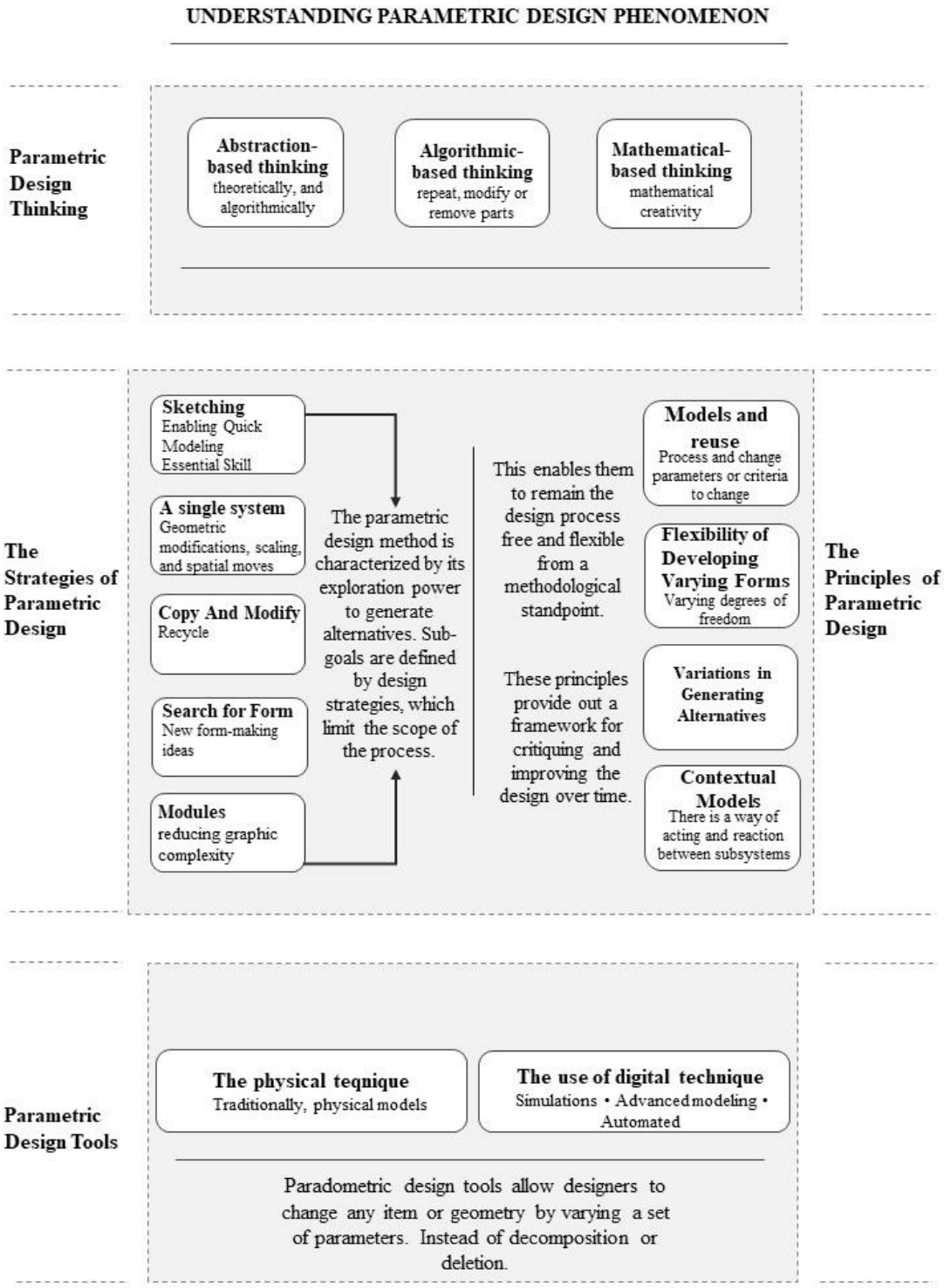


Figure 37: Various subsystems and organizations of the Parametric Design System Model, by author

Chapter 3

PARAMETRIC DESIGN INTEGRATION IN INTERIOR ARCHITECTURE/DESIGN AND ARCHITECTURE EDUCATION

This chapter encompasses the analysis of various ways of integrating parametric design methods into interior architecture/design and architecture education by examining multiple cases worldwide.

As mentioned in the second chapter, the focus was on a variety of topics, including the effects of various subsystems and organizational capabilities on it, and how each process in the parametric system has the potential to improve technologically, conceptually, and within the framework. Each program and institution is assessed using this method based on the criteria that have been established and discovered using the basic framework that came from theory and that was developed particularly for this purpose in the previous stage. Furthermore, international educational programs have been reviewed from different continents worldwide. Thus, it has been revealed that parametric design approach is applied/integrated into architecture and interior architecture education at various institutions located Asia, Europe, Australia and America. According to a review of numerous institutions in all areas, it has been noted that any samples were 'not found in the African continent. It has been revealed that the parametric design concept integrated studies were carried out in a total of 25 institutions as a result of the review of the literature in order to assess their perspectives

on a number of topics (academic scholarships, online full-text databases, websites of different international institutions, and article) which was based on the studies conducted from 2009 to 2021. The research was conducted with the content analysis method in order to highlight the keywords and concepts that match the factors. The keywords for selecting the cases are *parametric design, architecture education, interior architecture/design education, design studio, parametric design in education, parametric design concept,* and *parametric design tools.*

This study concentrates on a particular experience conducted at international educational programs from different regions where the parametric design approach is applied/integrated into architecture and interior architecture/design education. Accordingly, analysis and synthesis have been carried out by reviewing various institutions and programs in 19 different countries. Tabulating shows the analysis that cases of the study and the criteria of selection (Table 3).

Table 3: Tabulating cases of the study and the criteria of selection(by the author)

LOCATION	INSTITUTIONS		YEAR	KEYWORDS
AUSTRALIA POLAND ITALY CANADA HUNGARY UNITED ARAB EMIRATES UNITED STATES GREECE, GERMANY JORDAN PALESTINE THAILAND INDONESIA HONG KONG EGYPT CYPRUS BELGIUM BRAZIL	**University of Sydney** **Gdańsk University** **Cracow University** **University of Calabria** **Université de Montréal** **The University of Pécs in Hungary** **Sultan Qaboos University** **Virginia Tech's School of Architecture** **Kansas State University** **Pilot University of Colombia** **University of Lisbon** **University Of Darmstadt** **German Jordanian University** **Birzeit University** **Rangsit University**	**University Of Yogyakarta** **The Chinese University of Hong Kong** **National Technical University of Athens** **The American University** **University of Nebraska Lincoln (UNL) College** **School of architecture of Nancy** **University of Nicosia** **University of Liège** **University of Novi Sad** **Pratt Institute** **University of West Attica** **University of West Attica**	In the literature conducted from **2009 to 2021**, samples were found that were applied in a total of 25 institutions	*parametric design,* *architectural education* *interior architecture education,* *design studio,* *parametric design in education,* *parametric design concept,* *parametric design tools.*

Diverse course groups were reviewed such as design studios under the architecture and interior architecture/design programs, practical/applied courses, and theoretical courses. In due course, as a result of this stage, the aim of this study is to develop recommendations and guiding strategies for the integration of a parametric design approach into interior architecture/design education. Accordingly, in the following part of this chapter, generic review results are presented first and the case-specific findings are explored later.

3.1 The Role of Parametric Design in Education

Rapid technical and societal changes over the last two decades have had an impact on all design-dominated fields, posing difficult problems for architectural education. With the advent of digital design tools, the architectural paradigm is undergoing a different theoretically and practically mind-shift.

According to Malé-Alemana and Sousa (2003), it has been argued that the design based on parameters entails the building of a model that operates as a system of interrelated information (Malé-Alemany & Sousa, 2003). With this, its ability to incorporate characteristics that respond to various disciplinary domains, the parametric model encourages the convergence of all of these interests while also supporting cooperation and dynamic processes. Lawson (2011) states that,

> "If there was one single attribute that could be used to recognize good designers, it would be the ability to integrate and combine" (Lawson, 2011, p.66).

Parametricism relates to algorithmic design (Schumacher, 2009). The parametric design method necessitates the use of an algorithmic thinking system based on variable parameters, metrics, and rules (Oxman, 2008). Students identify parametric design with Zaha Hadid's organic forms since the phrase refers to a futuristic building type in modern avant-garde architecture (Davis, 2013). The inventive use of the software as a design tool by practitioners like Zaha Hadid, Frank Gehry, and Greg Lynn in the 1990s compelled architecture schools such as MIT, Columbia, UCLA, and SCI-Arc to update their technology infrastructure and teaching techniques (Sarkozı, 2019). As computers made it easier to create different geometry, biomorphic forms, and smooth surfaces, an early architectural practice based on digital technology developed "new fluid modeling plasticity," which astonished architecture students at the time (Mutlu Tunca

& Demirbas, 2021). Since then, the design culture has continued to evolve and adapt at the same time, and "what was once a unique concept has become commonplace as other institutions follow the early adopters' lead" (Allen, 2012). However, the creative process of parametric design is the creation of the rule system; the parametric scheme itself is used to create the desired shapes (Figure 38).

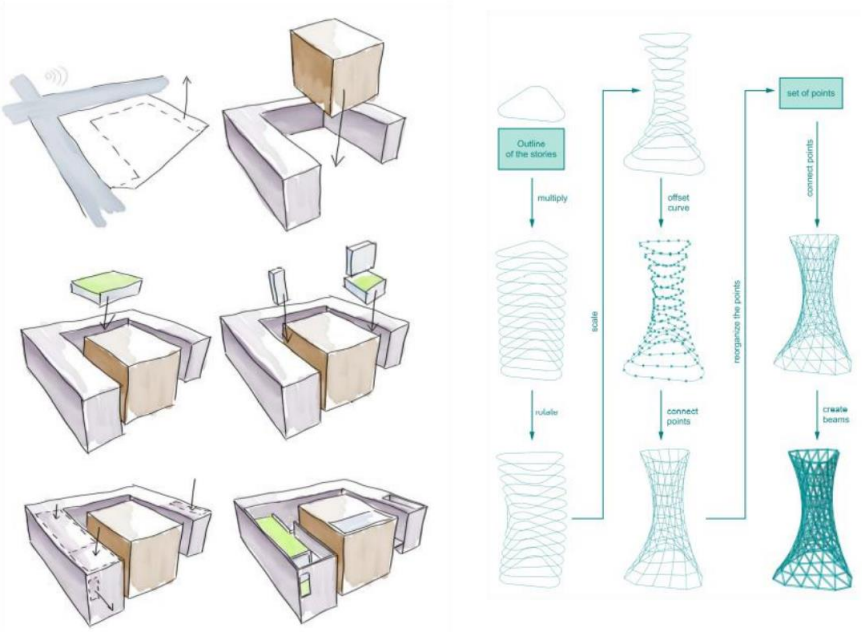


Figure 38: Scheme Of Traditional And Parametric Architectural Design Process (Sarkozı, 2019)

The traditional design and architecture process relies heavily on the architects' typological understanding. They look into a previous approach for a similar thing, examine it based on the demands and conditions, employ and combine the finest ideas, and change them to match the current task. Traditional architectural design and parametric design are not mutually exclusive. Designers not only employ the traditional architectural cognitive model when appropriate in parametric design but many parametric design tools are also built on previous solutions. The reason behind this is that parametric design largely employs mathematical and geometrical directives, aided by advanced programming solutions (Sarkozı, 2019; Veeramanickam &

Mohanapriya, 2014). The produced model is automatically updated and renewed. Students also may not be able to identify how they arrived at their answer and solved a specific challenge at the conclusion of the workshop, or who the individual contributors were who made their design effective. Thus, unlike the traditional education model, because all parameters and elements are related to the initial model, it may be concluded without going back to the beginning and and this provides a positive contribution to the integration of interior architecture/design education.

3.1.1 Parametric Design Methods Implemented at Various Interior Architecture/Design Programs

Interior architecture education is developing together with today's technology. Based on the scope of programs; technical drawing and presentation as different tools of communication and the program itself is in the process of progressing by the help of digitalization and the technological facilities in use. It is also a necessity within the framework of educational programs that the course programs developed in this context be examined in a specific order in the light of the newly developed computer environment and computer technologies. There are studies on the use of parametric design tools in interior architectural education (Şekerci, 2020). According to a study that has analyzed interior architecture/design departments in Turkey, it has been provided that the following approaches exist at Çankaya University, Yasar University, Fatih Sultan Mehmet Vakif University, Izmir University department of Economics, and Başkent University. Studies have revealed that particularly between 2015 to 2020, parametric design has made its way into interior architecture/design courses and it is a novel venture for architectural departments, and even more so for interior architecture/design departments (Şekerci, 2020). And hence the current study reviews

programs in other countries but did not include programs in Turkey in order to avoid duplication or to avoid any conflict of interest.

- ***Contribution of parametric design to education***

The practical use of parametric design has influenced its use in the field of education. The concept of parametric design is becoming increasingly important in interior architectural education, which is defined as a certain synergy of both theoretical knowledge and creative sensibility, cognition, and expression (Joklová-Pifko, 2015 p.124-131).

Parametric design, which is included in economical and energy-efficient designs, can provide the most efficiency with the least effort as a method to design an approach that improves the sensitivity to the environment, interior and exterior design criteria with the maximum level of interaction. Due to new technologies, computer-aided design may also be integrated into the design studio curriculum. Students can learn a solid design language and gain a new perspective on interior space design by using parametric design methodologies and magnifying rhizomatic conceptualization and transformation (Tunca & Demirbas, 2021).

3.1.2 Parametric Design Methods Implemented in Various Architecture Programs

The architecture design tools has changed. Architectural education has been significantly impacted by this trend. Mastering numerous digital technologies, from digital drawing to 3D modeling to computation, is required for teaching future generations of architects. The desire for improvement, as well as the design process itself, leads to parametric design as a potentially useful tool. As a result of the introduction of new technology, architectural education has altered as well. Most

architectural schools began by teaching basic computer-aided design software, such as two-dimensional drawing software. As a result, the complexity of computer-aided architectural design has increased in lockstep with the instruments available (Radziszewski & Cudzik, 2019).

- ***Contribution of parametric design to education***

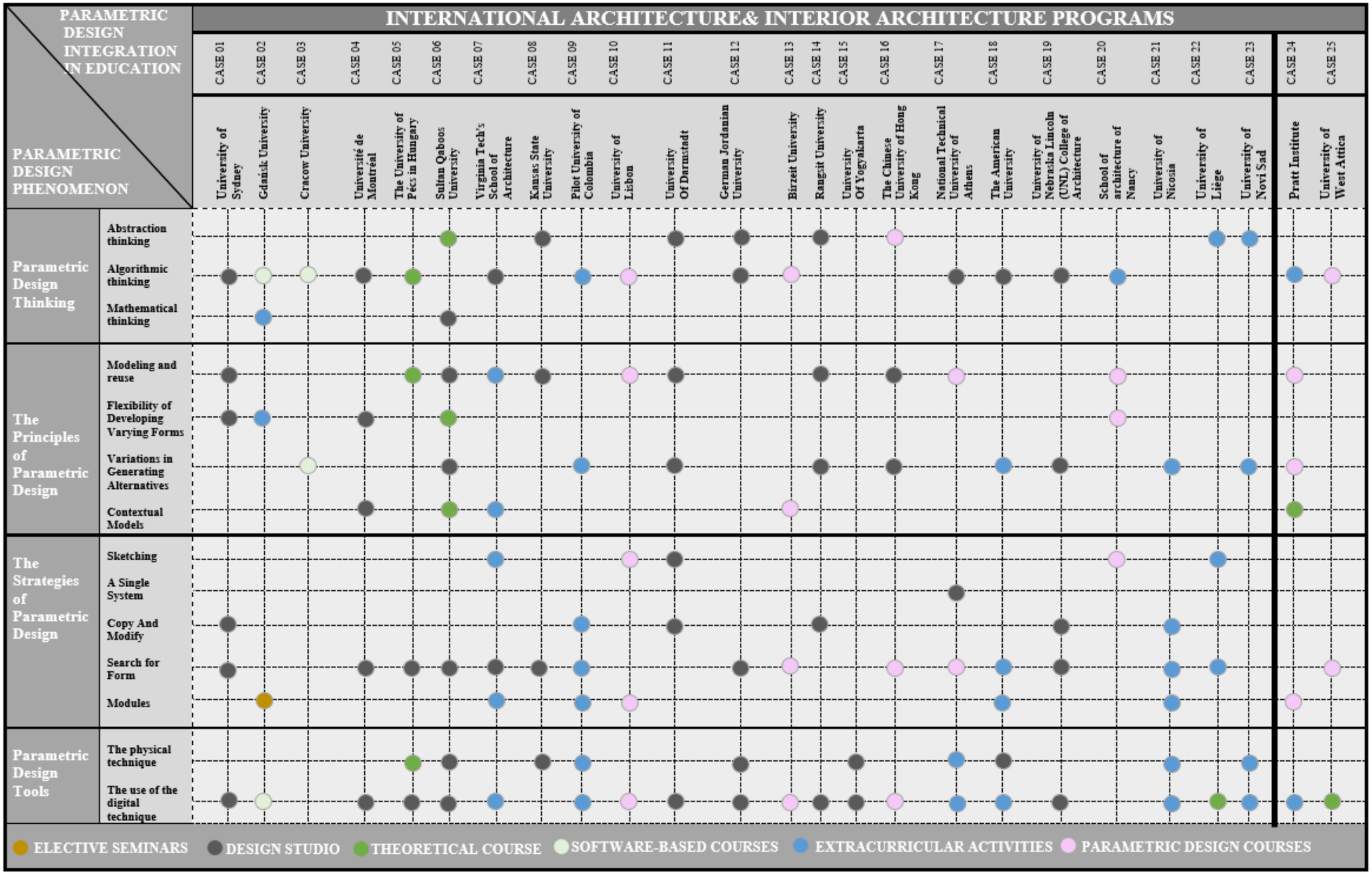
Today's academics at architectural programs are addressing two complementary areas in terms of digital work. First, it recognizes digital design knowledge as the ultimate architectural skill to impart to students, and it concentrates on the computer's strategic and operational capabilities. The logic of design processes is restructured by incorporating digital technology into form-finding methods and implementation tactics. Another path looks into advanced applied computation research, with a focus on scripting, technology, and parametric design. Parametric design is a new variant of architecture that necessitates new skills from designers, and learning parametric design presents new issues for educators (Sarkozı, 2019). Researchers and educators have been studying various sorts of educational techniques to address the requirement to integrate digital design in architectural education during the last decade. The inquiry into how to include parametric methods and technology into design education in this new context prompts a conversation about what skills educators and administrators should gain throughout the design process (Maria et al., 2015). The desire to improve those talents reignites the debate over what constitutes a design studio curriculum (Oxman, 2008). Furthermore, Oxman(2008), also points out that digital design models, such as parametric design and procedures allow for several stages of inquiry, which can only be accomplished by releasing the student from such perceptions.

3.2 Analysis of Various Examples of Architectural and Interior Architectural/Design Education

In this section, a range of 25 cases is examined to see if parametric design techniques might be discovered. There are 23 case studies in the architecture program but just 2 in the interior architecture/design program. There is a scarcity of interior architecture/design programs and this creates a research and implementation gap. This study not only analyse/ different course groups such as design studios, applied courses (i.e theory with a project or a workshop etc.) and theoretical courses, but also analyse/review parametric forms of design as a development tool in extracurricular activities in order to explore existence and differents approaches of parametric design as a part of the architecture and interior architecture/design curriculum. This section collected data from publications, websites, and reviewed the literature in order to assess their perspectives on a number of topics. Each different institution/program has been labeled as a case study and with a number (Case Study #) consecutively. And then each case study has been analyzed by focusing on the approach and implementation.

Accordingly, the data was collected in a matrix format where Cases 1 to 23 are programs in architecture, whereas Cases 24 and 25 are programs in interior architecture/design. It shows which categories of curricular or extracurricular activities at each university are studying parametric design thinking, principles, strategies, or tool in different phases in each one of the studied cases (Table 4).

Table 4: Tabulating multiple cases of interior architecture/design and architecture education and correlating them by parametric design method (by author)



3.2.1 Exploring Multiple Cases of Interior Architecture/Design and Architecture Education to Reveal Parametric Design Method

Around the world, institutions providing architectural design are changing their curricula by adding new disciplines that reinforce technical advancements in the sector. The design industry is constantly adopting new technology from other engineering disciplines. Being updated in academia is a difficult task because it necessitates a comprehensive approach that covers all aspects of the design and its representation – as well as the supporting background, teaching of the latest modeling tools, self-criticism and artistic freedom for decision making, original creativity in form-finding, and the skills to program and operate a variety of contemporary digital fabrication machinery (Riekstins, 2017).

In this current study, accordingly, the data was collected using a matrix that shows which course categories each university is studying in different phases, as well as illustrates whether those applications are integrated parametric design method into the design studio or studied as stand-alone courses at diverse architectural programs at international universities (Table 5).

The matrix is useful to explore and also to learn more about the current state of parametric design integrated architecture education by evaluating the collected data (Table 5). It has been revealed that there are a total of 6 different courses where the parametric method has been integrated i.e. 2% elective seminars, 38% design studios, 7% theoretical courses, 3% software-based courses, 24% extracurricular activities and 19% parametric design courses from 19 different countries and 25 different universities around the world. (Figure 39).

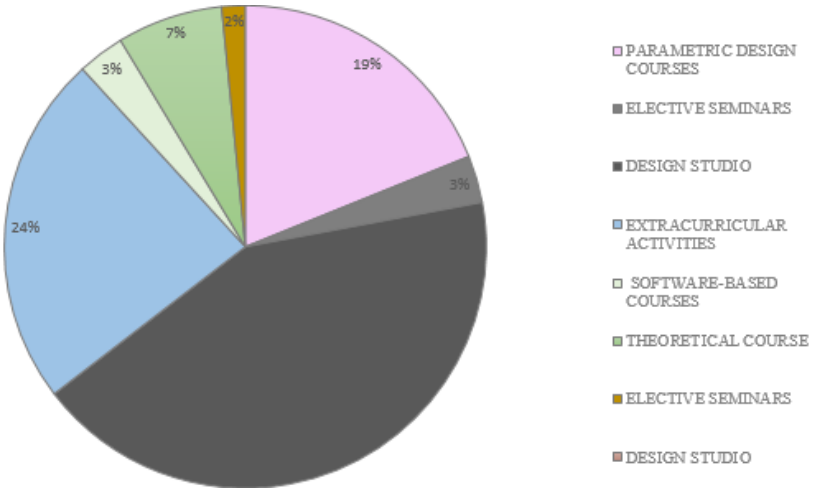


Figure 39: Presentation of the relevant courses derived from the matrix, by author

Furthermore, it has been revealed that the majority of the universities which were analyzed were from United States and then from Poland, Canada, Germany, and Greece consequtively (Figure 40).

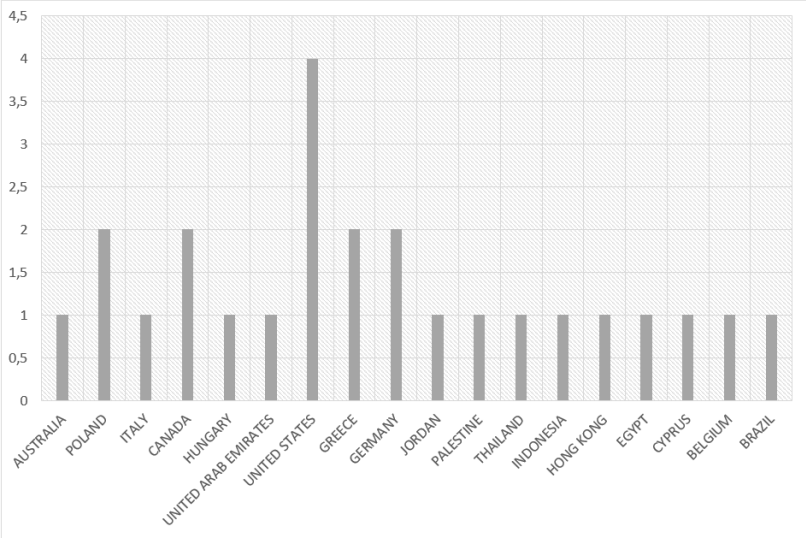


Figure 40: Distribution of various programs at 19 different countries (derived from the matrix by author)

3.2.2 Exploration of Parametric Design Method Integration in Different Cases

Case 1 is the architecture program at the University of Sydney in Australia, parametric design method has been applied in the design studio. Accordingly, the goal

of this 'parametric designing' was for participants to be able to comprehend the influence of each stage and variable on the design and track how it affected the project (Schnabel, 2007). Participants in this study employed programs that focused on the parametric interdependence of spatial perception, fabrication, and form discovery to address a common architectural design challenge. Understanding the perception, framing, and development of spatial knowledge within the architectural design was influenced by cognitive aspects of design creation and their relationship to parametric design methodologies. The studio furthermore has investigated design processes by questioning, creating, and defining the form and function of the final designs utilizing sets of variables and a series of relations. As a result, it looked at how the design goal, its framing of the design problem, and its subsequent development interacted, while also developing a link to building information models (Schnabel, 2007).

It has been exposed that the studio had an integrated digital media component that addressed parametric modeling in architectural design which allow students to both acquire skills and training within their studio and apply this knowledge to their design. The studio was one of the compulsory design studios for the University of Sydney's architectural program modeling. Two groups of fifteen students each chose to participate in this studio, which was supervised by two design teachers and one digital media architectural consultant. The studio was divided into four phases that were interconnected and built on one another. The goal was to gain and integrate parametric design knowledge in order to use it as the foundation for creating their architectural proposal's design.

It has been explored that the first phase of the research involved gathering and analyzing data from the site. To avoid overcomplicating the difficulties, the tutors

encouraged the pupils to limit their investigations to two criteria during this first stage. This allowed the students to concentrate on selecting the hierarchical characteristics that they considered would have the most impact on their building project or the perception of their site. The parameters they chose supplied them with a description based on dependencies and interrelated relationships of relevant information, as well as information about the variables of their guiding design guidelines. The criteria selected aided the students in comprehending their design and the impact that various factors may have on a design plan. After two weeks, this component came to a close with presentations of data, parameters, and results.

As a result, the parametric design studio presented in this study focused on computational architectural design concepts that have influenced modern architectural evolution. This studio exercise developed unorthodox solutions by exploring novel techniques of architectural expression, form-finding, and communication. It combined a studio learning setting with a comprehensive digital media assignment to bridge the gap between skill acquisition and knowledge reflection, as well as to investigate new ways of framing and integrating compound design concerns. The participants were able to develop inside an environment based on rules and generative descriptions with the help of using/implementing digital parametric tools. This improved their grasp of design and learning objectives (Schnabel, 2007).

Case 2 is the architecture program at the Gdańsk University of Technology in Poland, is the teaching program in this case divides parametric design education into a number of classes. It has been explored that as students progress and design projects

get more involved, the level of activities and needed knowledge increases (Radziszewski & Cudzik, 2019). It comprises the following components:

• *Descriptive Geometry and Parametric Design*: During the first two semesters of undergraduate studies, students participate in a descriptive geometry program. Students produced the basics of parametric design and visual programming through introductory exercises involving selected surface qualities throughout the last three laboratories, which take nine hours. The first three-hour laboratory, which is preceded by a lecture, is aimed to introduce students to the fundamentals of programming, software interfaces, and geodesic dome modeling. Grasshopper 3D software and the Weaverbird mesh modeling library were used to create the dome geometry (Figure 41).

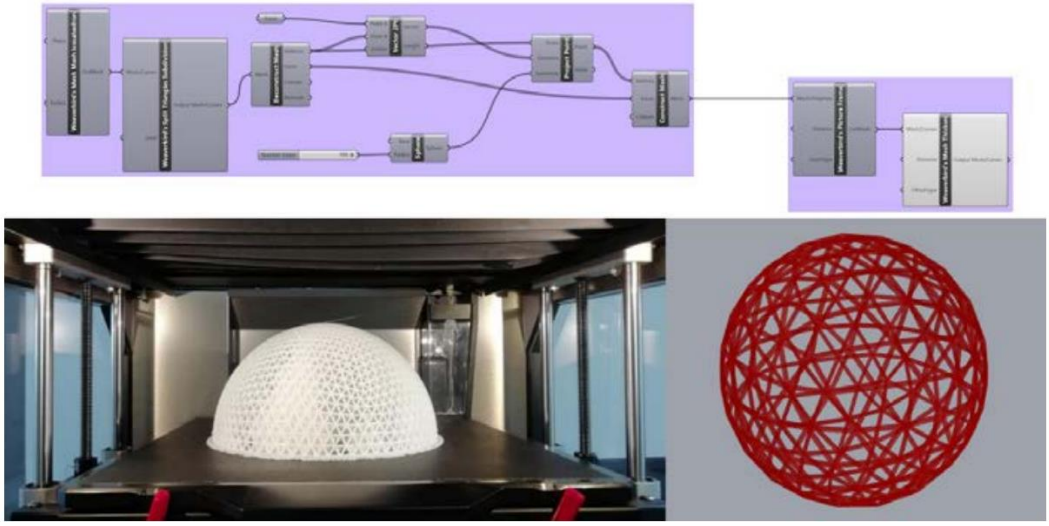


Figure 41: This is an example of a descriptive geometry exercise

• *Advanced CAD*: In this implementation, the parametric depiction of three present architecture pieces is covered in the 15-hour Advanced Computer-Aided Design course, as well as a collection of activities involving abstract geometrical principles. Students get sent a set of methods that enable façade design in addition to

programming the building's façade surfaces. Because of the course's short duration, activities are confined to basic multi modeling, which is used to supplement daylight, energy, building simulations, and the fundamentals of design optimization (Radziszewski & Cudzik, 2019).

• *Elective Seminars*: It has been explored that the courses at the undergraduate level are aimed at teaching technological skills and demonstrating potential research areas. Students were allowed to participate in a 15-hour elective seminar focusing on the design and production of the geodesic dome based on their knowledge of parametric design gained during the second semester of the Descriptive Geometry course (Radziszewski & Cudzik, 2019). Students were challenged to use digital fabrication to create their semi-scale installation based on geometrical understanding and simple and construction qualities of geodesic dome of Richard Buckminster Fuller who is an American architect, and inventor popularised the idea of using geodesic dome geometry in building with his design for the 1967 World Fair, The Montreal Biosphere. (Figure 42).

Figure 42: During an elective course, a geodesic dome was created (Radziszewski & Cudzik, 2019)

• *Workshops*: In this application, it has been exposed that a large-scale item was fashioned from hexagonal timber panels after a small-scale cardboard version was created. The workshop's focus was on digital fabrication optimization and spatial form analysis using building statics. The form (Figure 43) illustrates the elegance of complex geometry and has served as a starting point for continuous spatial studies (Radziszewski & Cudzik, 2019).

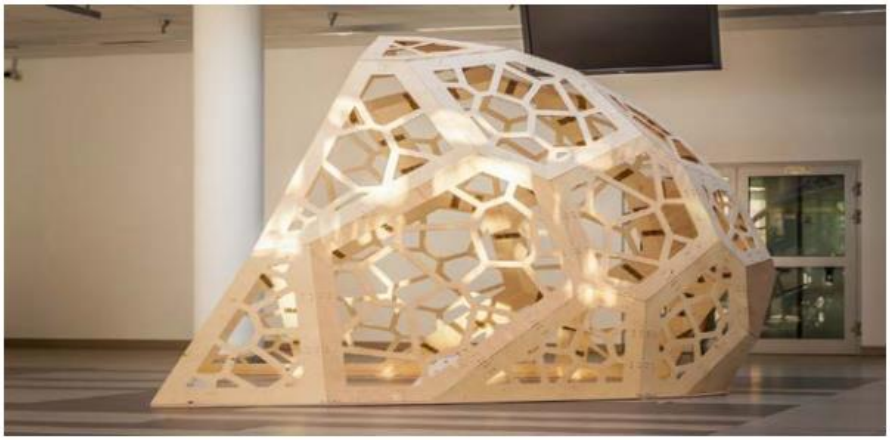


Figure 43: During summer workshops, a pavilion was built (Radziszewski & Cudzik, 2019)

It has been seen that this complete experience only can fully demonstrate the potential of algorithmic design tools to pupils. As a result, it's critical to educate not only on certain tools but also on how to link and use them appropriately. To do this, both theoretical and practical classes should be included in the curriculum. According to Radziszewski and Cudzik “project-based learning is becoming more popular, with students working on a design projects. Students should learn new abilities and gain design knowledge as a result of this approach” (2019, p.453).

Case 3 is the architecture program at the Cracow University of Technology in Poland*:* In this case, algorithmic-parametric design utilizing the Rhinoceros 5 +

Grasshopper program on a variety of design concepts and locales was the focus of the design studio implementing parametric design method (Romaniak & Filipowski, 2018). Selected issues in the realm of computer software didactics related to the fundamentals of algorithmic and parametric design in the education of design students are handled (Romaniak & Filipowski, 2018).

Case 4 is the architecture program at the University of Calabria in Italy, The workshop is an optional component of the University of Calabria's "Architecture and Architectural Composition 3" (Architectural Design) course for students in "Building Engineering-Architecture" who are almost at the completion of their architectural design internship. The program lasted 14 hours over a week, with about half of that time dedicated to the previously noted theoretical and cultural components of the parametric approach. The workshop's teaching strategy is to present students with single parametric modeling methodologies and then ask them to combine them in their projects (Canestrino et al., 2022).

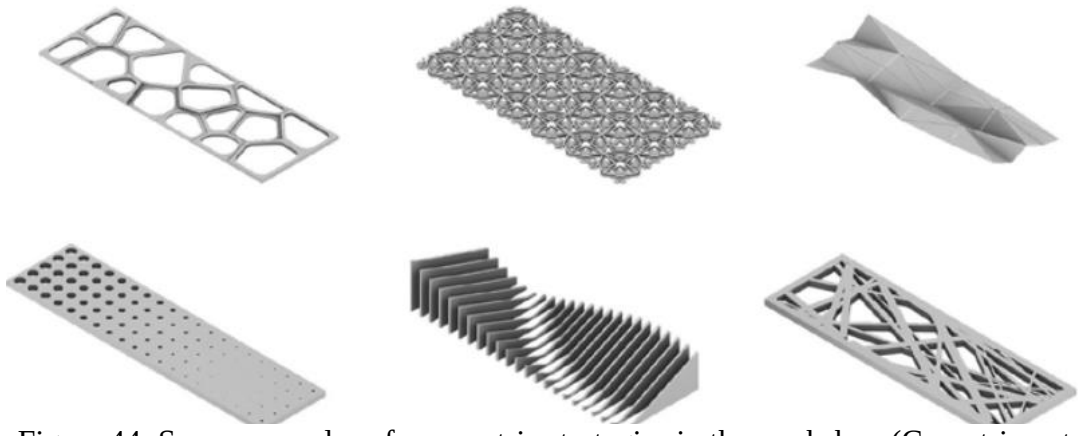


Figure 44: Some examples of parametric strategies in the workshop (Canestrino et al., 2022)

The program also highlighted the importance of reflecting not just on the world of digital technologies, which are necessary for strong design inferences to become architectural forms, but also on how a student approaches these resources (Canestrino, 2021b).

Case 5 is the architecture program at the University of Montreal in Canada: Two teaching experiences were revealed in this case. The first has taken place in the framework of a first-year spatial geometry course, and the second was took place in a digital design studio with the third-year architectural students. The courses were AME-2129 Spatial geometry and ARC-3011 Digital studio where students were fully recognized and accept spatial geometry and programs were tied to real architectural difficulties (Iordanova, 2007).

Moreover, there were three modelings (or representation) methodologies that were discussed and applied to the architectural environment which are:

- A direct description of an object's geometry.
- Structural characterization of a space or volume, for example, using a trajectory and generating line.
- Generative description: i.e. requiring a source figure as well as a method for its modification and moving in 3D space.

Students were expected to investigate a form in their final assignment after working with associative geometry software throughout the semester, and to link nature principles to physical structure and form. They needed to come up with a technique for expressing the form's identified generating principles, program it, and produce at

least two alternative variations depending on the modeled principles. Figure 45 illustrates a few samples of students' work.

Figure 45: Music influences the form generation (Jerome Taillandier's work) (Iordanova, 2007)

Case 6 is architecture program at The University of Pécs in Hungary: It has been explored that in different semesters at the University of Pécs, the subject covering parametric architectural design was referred to as "Parametric constructional design," "Parametric design," or "Constructional skills (parametric design)." It is compulsory for Architecture MSC students and optional for bachelor's students.

There are three key domains of knowledge that this topic should cover and convey to pupils. Firstly, the use of parametric design software is the first of them. Secondly, the cognitive model of the design process, parametric design thinking, is the second important subject of expertise. Finally, considerable theoretical knowledge from other scientific domains, mostly mathematics and computer science, is required for students to be able to use and understand parametric design, however it is not covered in the architectural curriculum. The education technique is based on the simultaneous education of practical and theoretical knowledge, as well as the integrated teaching of these three key disciplines (Sarkozı, 2019).

Students are learning how to tackle architectural challenges and design spaces and buildings using their imagination. They learn how to evolve, reflect, and re-edit their work, and they recognize it as a unique and amazing process. Students at the University of Pécs are not encouraged to use software for design and architecture in the first 2 years because lecturers do not want students' creativity to be limited by the rules and restrictions of the software. They complete each assignments by modifying and adapting their typological knowledge. The teaching method is based on the teaching of both practical and theoretical information at the same time. When students are required to absorb a large number of theoretical aspects at the same time, their attention is typically diminished, especially if they believe it is not required for practical work. Furthermore, mathematics is typically a source of anxiety for architectural students. Because of these factors, teaching theoretical information first and practicing later is ineffective (Sarkozı, 2019). As a result, students create a model during each lesson, as shown in (Figure 46).

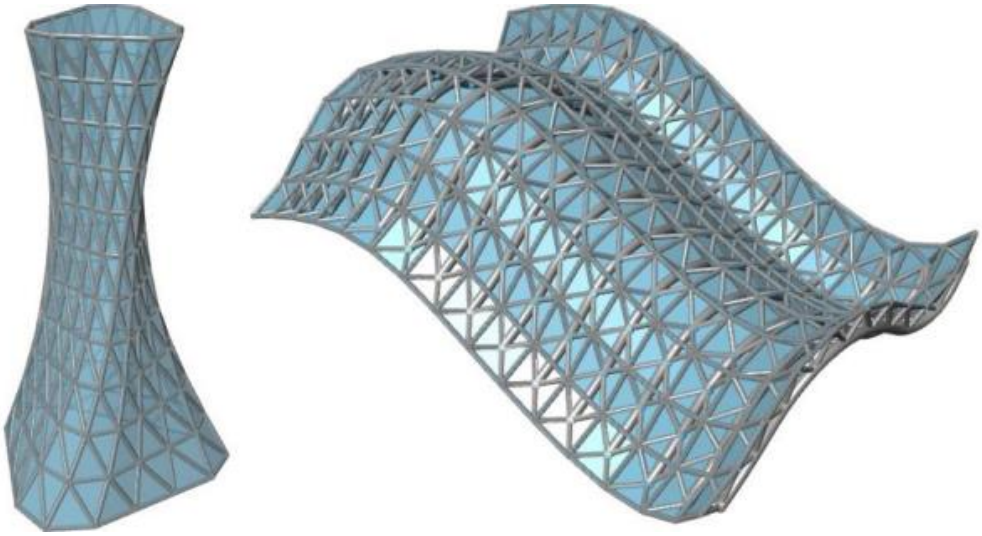


Figure 46: Class Tasks. Rotating Tower And Freeform Truss-Grid Structure (Sarkozı, 2019)

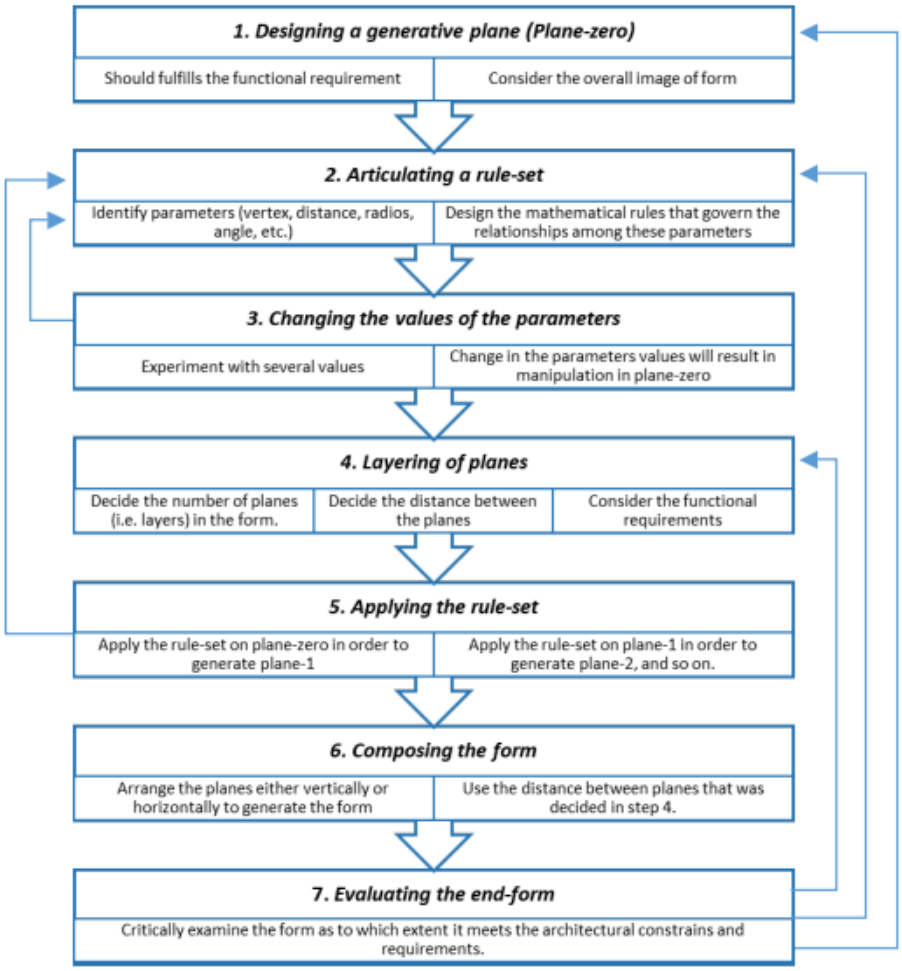
Furthermore, Sarkozi (2019) states that students understand how to use the program while also learning how to tackle a certain sort of problem and the theories that underpin it. The identification of the aim is the first step in any activity. It is a crucial element in the educational process since it encourages students to consider solutions and strengthen their parametric design thinking skills. Students can produce complicated building designs as their job by combining their previous knowledge architectural design skills and newly gained parametric design thinking, as shown in (Figure 47).

Figure 47: Student's Work. Made By Dalma Lovıg And Ákos Karancz (Sarkozı, 2019)

Case 7 is architecture program at the Sultan Qaboos University in Oman– the United Arab Emirates: It has been revealed that the method tries to include parametric thinking in the early stages of the design process. This university used manual procedures based on a series of plane modeling exercises offer that a non-computerized method to incorporate parametric thinking into design studios to beginner design students. The goal of this course is to look into the possibility of using a non-CAD method to introduce parametric thinking to help new architectural design students. The complicated parametric-driven form is decomposed into a generating simple planes

and a rule-set, or formulae, that define the required objective and subjective connections between the plane's points and edges in the context of the implemented technique (Table 5) which depicts the method's flow diagram. It includes the following steps: 1. Creating a generative plane (also known as plane-zero): The generating plane's design is significant because it defines the end-overall form's appearance. Depending on the designer's background and the project's overall aesthetic, the generating plane could be motivated by any source. The proportions of the generating plane must be carefully designed in all circumstances (Alalouch, 2018). Second is to articulates a rule-set; third is to change the valuses of the parameters; fourth is to layer the planes by deciding their quantity, distance between them and by considering their functional requirements; fifth is to apply the rule-set in order to generate plane1 and repeating the rule-set to generate the form.

Table 5: The method presented in this study is depicted in a flow diagram (Alalouch, 2018)



The aim of this method is to assist students to generate alternative forms in a sequential process with a systematic approach.

Case 8 is architecture program at the Virginia Tech's School of Architecture Design in Virginia, USA: It has been exposed that this case study, discussed methods for preparing three-dimensional computer models for 'two-dimensional' fabrication using the laser cutter. Both during and after the workshops, students ask informed questions that demonstrate a searching approach to understand digital form and to conceptualize the virtual space. It has been expressed that students digital skill set continued to grow through the course of the subsequent studio project, which combined ideas of

biomimicry and analytical drawing to develop a form that interacted with light (Aia & Vt, 2011). Students made a physical project in the workshop, such as a handcrafted or digitally created model with Cut and Fold (Figure 48).

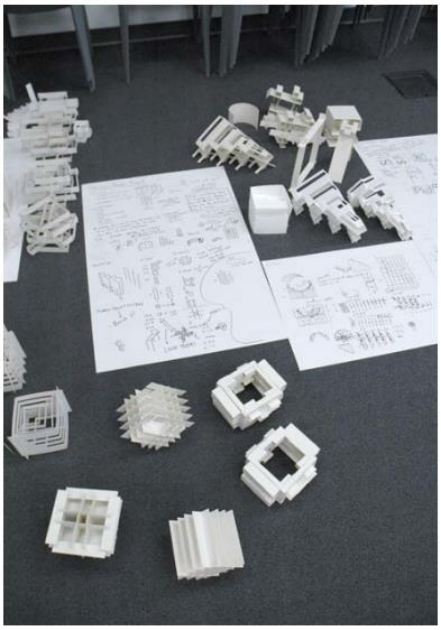


Figure 48: Examples of some models that students make in the workshop (Aia & Vt, 2011)

Analytical Drawings are a type of drawing that is used to show how something works. Students investigated the impact of their design on people's mobility through the space where the project was exhibited as part of the site study process. It has been indicated that students used analysing, drawing and other tools they brought into the Digital Workshops from their design studio work as strategies for thinking, developing and analyzing their designs (Aia & Vt, 2011) (Figure 49).

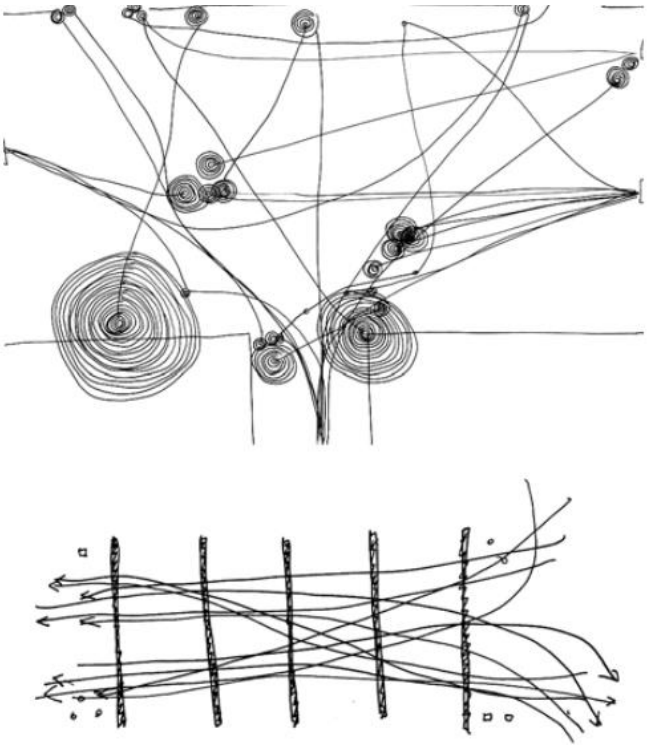


Figure 49: Analytical Drawings by students (Aia & Vt, 2011)

Case 9 is architecture program at the Kansas State University in Manhattan in the United States: It has been exposed that the first academic year was spent in a shared first-year program that concentrated on design fundamentals in three disciplines: urban planning, landscape architecture, and architecture. These studios were fully handcrafted. Students were generally given design concepts in a variety of formats, such as folding, biomimicry, or painting abstraction. It has been stated that students with this experience and place in their studies are well-positioned to build their parametric design thinking skills (Headley, 2013).

Various sequential activities were devised throughout the project's eight-week duration to develop and utilize their parametric thinking ability although students initially thought they would be developing their final design. The sequential activies were listed as follows:

- **Choose a design scale and start articulating variables** (used to generate creative investment)
- **Create a recipe** (Design an initial set of variables for testing and development)
- **Allow others to try your recipe** (Develop an understanding of the difference between how a computer works and how a person thinks)
- **Convert the system to a wall-mounted display** (Returns all projects to one similar scale for comparison and reflection)
- **Produce scripts** (Finalize variables and how they are acted on) Construct it.

From a macro exercise, a CNC drawing was created. The macro experimented with copy-rotate-twist. According to Headley, learners struggled to maintain continuous control of the system while creating beautiful outcomes (2013). This illustrated how important it is for a designer to understand both the sources and the processes that create the geometry (Figure 50).

Figure 50: Drawing from macro exercise by students (Headley, 2013)

Headley (2013) also states that as many students built furniture or artifacts for themselves, creative investment became a significant factor in the work. For instance, a table made by a student for her and her four roommates. Spatial conditions and circulation patterns were used to create the shape (Headley, 2013) The emphasis was on the finished thing being one iteration of a variety of choices that could all be modified and evolved around the system designed by the student (Figure 51).

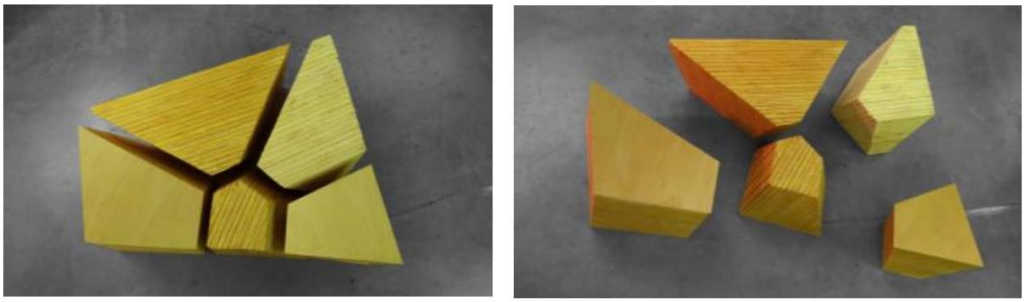


Figure 51: A table made by students by students (Headley, 2013)

On the other hand, one could see that this studio project allowed second-year undergraduates to have in-depth discussions about parametric design and parametric design thinking, and it aided in the development of parametric design as a basic component of their education. The tools were used for both generative and analytical purposes, and they provided students with a grasp of what parametric design is, how this worked, and how to value it, as well as a feeling of how to inform the shapes they generate (Headley, 2013). After a few weeks, a group of 'making' specialists arose beside a group of 'digital' experts and then as students began to work on other design projects in the following projects, it has been observed that their design thinking improved. The student who designed a tessellated garment based on her body's curvature, went on to design a mixed-use building that was tessellated according to program and site conditions (Figure 52).

Figure 52: The student experimented with various factors and scales (Headley, 2013)

Case 10 is the architecture program at the Pilot University of Colombia in Colombia:

In this case, when teachers worked with students they encourage their use of digital tools to better understand the building envelope through TecV. This is a course that focuses on the building envelope, and several extracurriculars that deal with geometry and digital fabrication. Students were instructed to conduct case study research in which they could observe how developments in sustainable architecture lead to functional refinement, increased performance, and typological specialisation. Sun path diagrams are used as a specialization analyzing the sun's movements and the proportions that were required to be used as parameters in the shading device design (depending on the height and angle of the sun). The project is then given a geometric definition to develop a flexible modular system. The project is then given a geometric definition to develop a flexible modular system. Simulators ranged from 3-d modeling in Google Sketchup and 3ds Max to application ranging Ecotect and Design-Builder were used to analyze the designs (Brakke & Velasco, 2008). In general, students receive a grasp of the designers' process, allowing them to build greater awareness of how ideas evolve and are defined in terms of meeting aesthetic and functional goals (Figure 53).

Figure 53: The student experimented with various factors and scales (Headley, 2013)

According to Brakke and Velesco, a similar design process is used in the projects supported at Front. The distinguishing feature is that the geometries form is produced at a higher level, allowing for a more formal aesthetic, daylight performance, and economic knowledge of the projects. As the projects progress, digital tools are used to produce both computer and physical models (Brakke & Velasco, 2008) (Figure 54).

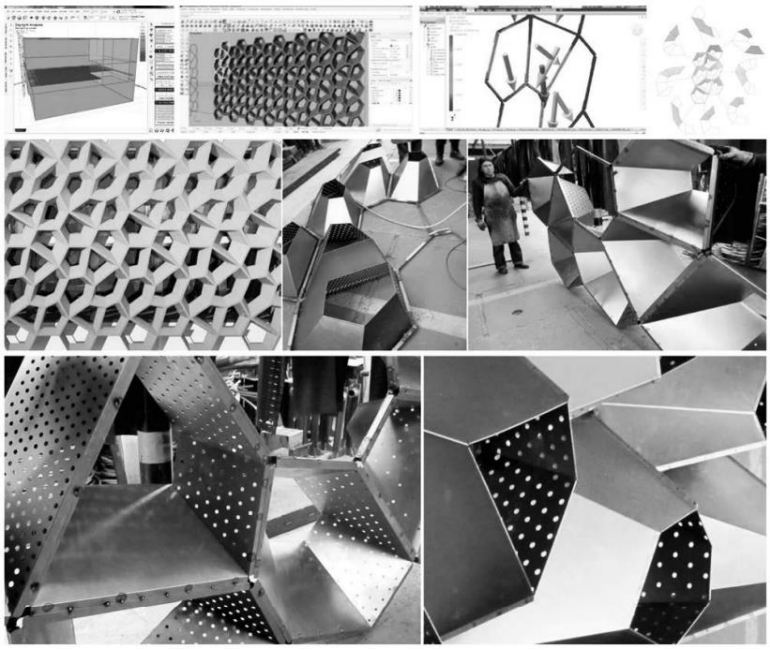


Figure 54: Modeling, simulations, and fabrication of a facade system are all steps in the process (Brakke & Velasco, 2008)

Case 11 is the architecture program at the University of Lisbon, in Portugal: Parametric design was handled in a four-credit architecture course called Geometric

and Generative Modeling. The experimental approach was separated into two phases: training and designing, which were subdivided into particular steps.

The training phase began with the use of Rhinoceros software, progressed to the use of its plug-in, Grasshopper, and finally to the use of Kangaroo and Karamba3D add-on programs. The strategy for the training phase was to use exercises ranging from elementary to complicated shape manipulation. Students then began working with simple parametric models to learn how to include and change rules and parameters (Monteiro et al., 2010). This was crucial for the design process because it gave them the concept of generating design possibilities. To learn about surface manipulation and Boolean operations, students modelled simple forms. They also built complicated shapes by study model development (Figure 55).

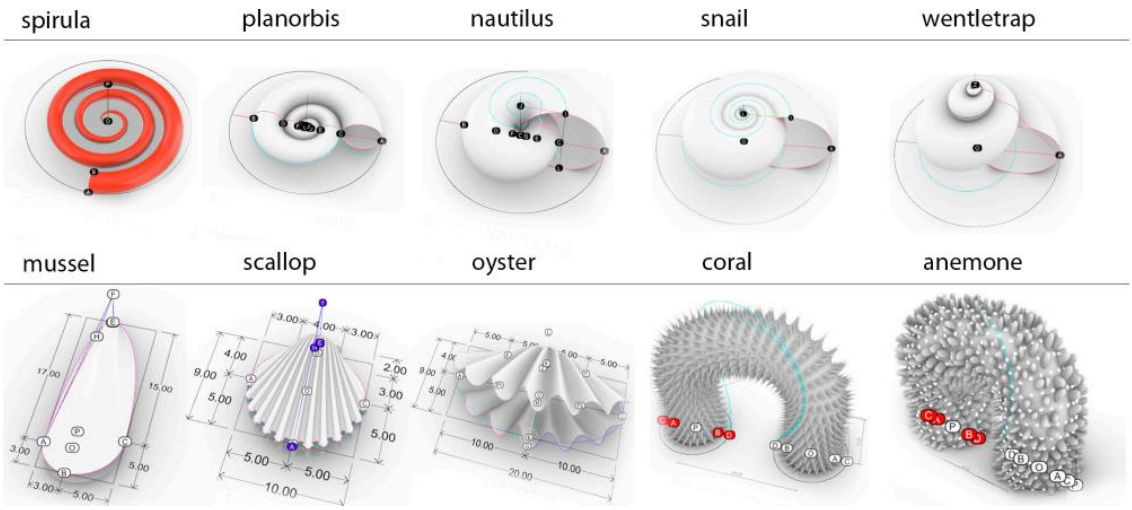


Figure 55: Training for rhinoceros by students (Monteiro et al., 2010)

In another case, the students focused on the design concept and opted to use a piece of wood pallets as a basic module that could be duplicated to create a parametrically managed chain. This would provide them with the much-desired mobility as well as design options. The second week has been criticized for including physical models of

the kind of motions that would occur throughout the geometry, as well as tying this to zoning studies (Figure 56).

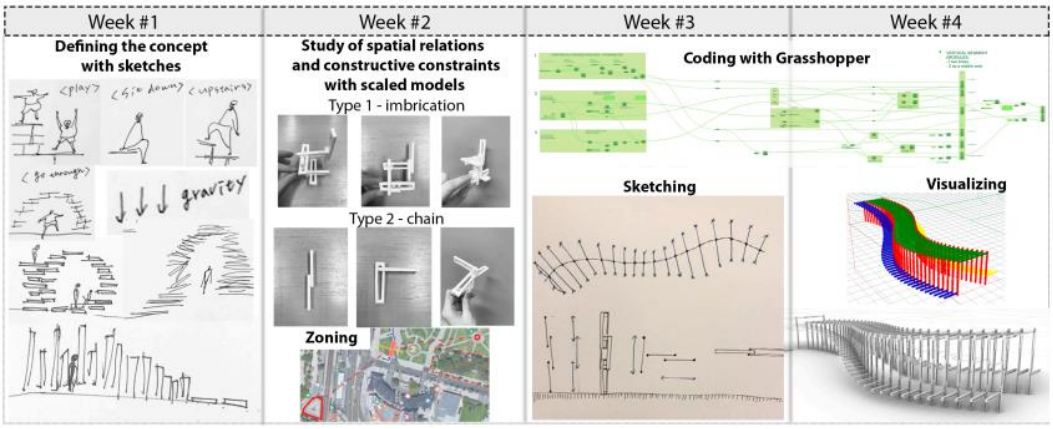


Figure 56: Summary of design actions by students (Monteiro et al., 2010)

It has been mentioned that there are two impasses that stopped the students' progress. The first one appeared after sketching out the notion. They had no idea how to foresee the curved effect, especially when it came to the relationships between the pallet components. One of them came up with the concept of building physical models out of Styrofoam scraps to test the links between the modules. Imbrication and chain were two forms of spatial linkages that students defined. The second happened during the coding process. They had to interpret the motions by looking at the physical models, and they spent a week attempting to figure out how to compose the Grasshopper specification in the simplest way possible (Monteiro et al., 2010).

Case 12 is the architecture program at Technical University Darmstadt in Germany:

In this case, several techniques of teaching parametric design and employing various parameter design tools have been used during design projects depending on the subject (Matcha, 2007). There were two different approaches presented:

• *Individual or climatic elements which define parametric systems*: Understanding geometrical dependencies and restrictions, as well as their application in established rules, is required for creating parametric objects and buildings. Changing the values of the given parameters allows for an unlimited number of variants while also allowing for the development of the "ideal" piece that is tailored to the unique user and distinguishes itself from other items in the same manner that the user distinguishes himself from other users. The issue of parametric systems is expanded beyond the individual user to climatic conditions in the next phase of increasing complexity. Sun, heat, air, water, and other climatic variables are now factors in many climatic settings (Figure 57).

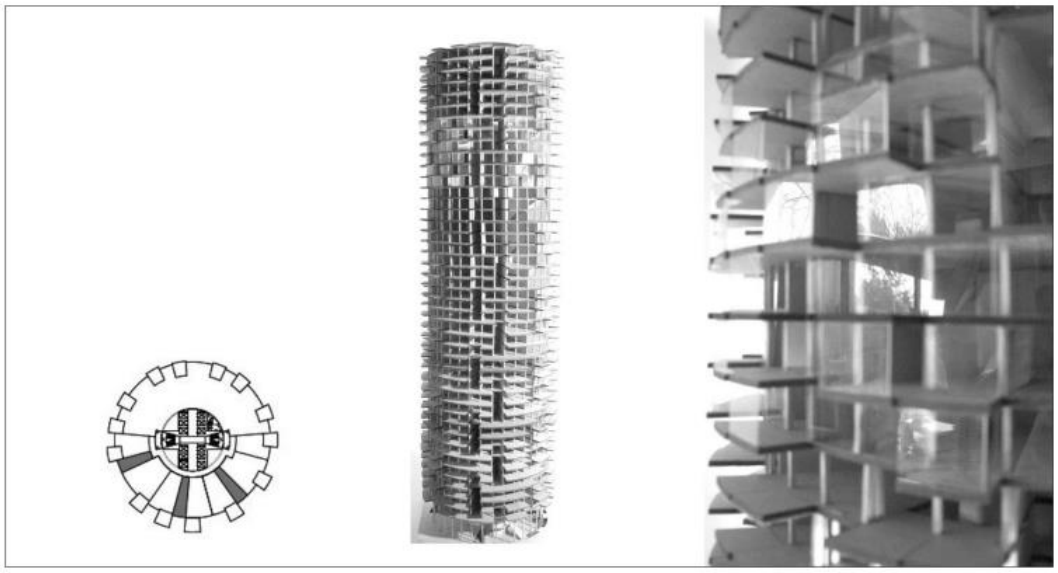


Figure 57: "Highrise in Moscow with parametric facade features," Pascal Kuhn, Technical University of Darmstadt, student design project (Matcha, 2007)

Even if the planning process in architecture is distinct, a building undergoes several adjustments during its construction. Not only would using parametric models implement changes easier to manage, but it would also allow for easy production of alternatives of the design item as well as the flexibility to user and place (Figure 58).

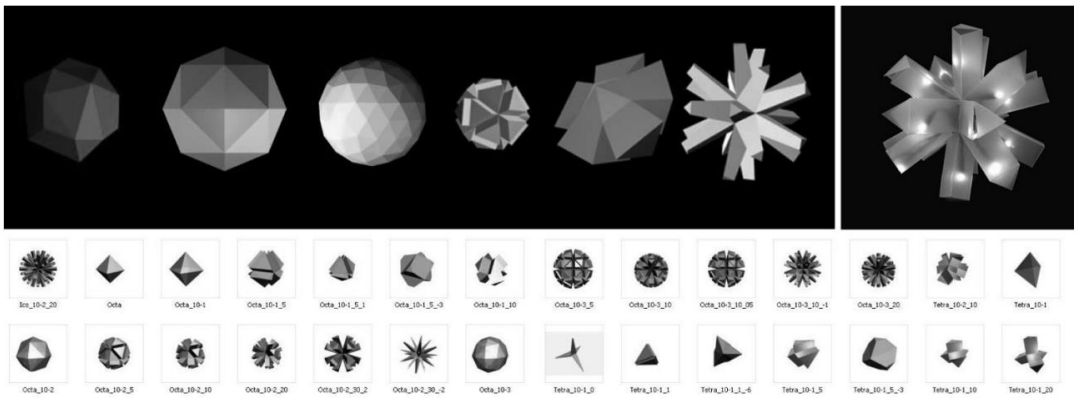


Figure 58: Student design project, "Geometric variations of parametric lighting item" (Matcha, 2007)

• *Natural geometric structures converted into parametric objects/buildings*: This is related to the explorations with natural geometric principles, their analysis, abstraction, and translation into objects and structures.

They began preparing to build a physical 1:1 model after the design had been developed, the physical durability tested in physical models, and the application of the design confirmed through research. The necessity for an annual trade fair booth to represent the architecture faculty at a show in which all university faculties exhibit themselves through their work to students inspired the specific function and funding (Figure 59).

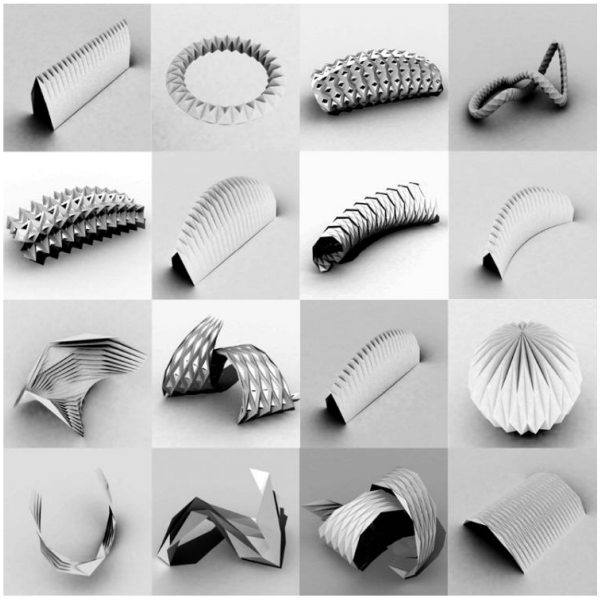


Figure 59: Variations of folding models by students (Matcha & Ljubas, 2010)

Matcha and Ljubas states that,

> *We wanted to present parametric designing and constructing tools, as well as parametric thinking: how to turn a design into clear rules that are based on changeable factors, resulting in a wide family of similar but still distinct items* (Matcha & Ljubas, 2010).

Figure 60: Prototype for a trade show stands representing the TU Darmstadt's Department of Architecture (Matcha & Ljubas, 2010)

Case 13 is the architecture program at German Jordanian University in Jordan: An experiment pedagogic architecture course has been created to improve students' knowledge and abilities to move them toward a more advanced approach to

architectural design that highlights the complexities and potential of parametric tools. It is conducted in the Design Studio in order to achieve the goal of the process.

- The suggested pedagogic experiment's principal instructional mission was to enhance students' knowledge and abilities toward the following objectives:
- To provide an overview of the computational environment's architectural design tools;
- Organize a brainstorming session and focus on the newly developed design methodologies enabled by the computational environment;
- To demonstrate how important it is to communicate the design process;
- To investigate parametric design tools and how they can be used to generate numerous formal expressions; and
- To look into how a technology influences the design process and, as a result, how it affects architectural practice a the built environment (Tifadi and Iordanova, 2006).

To achieve the aforementioned objectives, students were given access to digital parametric tools that allowed them to design in an environment based on rules and generative descriptions (AL-Ratrout & Zureikat, 2014).

Case 14 is the architecture program at Birzeit University in Palestine: A summer course was proposed to introduce students to the possibility of employing digital parametric tools and techniques in architectural design and manufacturing in the architecture department. The proposed course's major purpose is to question current digital methodology paradigms by looking at architectural design through a fresh 'digital lens.' Students were expected to use a parametric 3D computer model to design and build a temporary pavilion, as well as to test their concepts in the real world.

Students were challenged to create a filled virtual 3D model using software including Rhinoceros and Grasshopper as a preliminary step, then build it up into a one-to-one scale physical model in the first portion of the course. Students worked on a temporary pavilion design and investigated the material systems that influence building and production methods. Students can explore and examine their design ideas using this method of working before putting them into action (Serra & Tècnica, 2016). The course focused on two primary topics: parametric design methodologies and digital fabrication technologies.

They were given the task of selecting and exploring a material system. The second section of the course focuses on furthering the design of the chosen pavilion from the first. This was made possible by collaborating on the pavilion's architectural details and using a digital construction approach. At the end of this phase, two concept models were suggested (on a scale of 1:10). The proposed systems combine geometry and structure to generate an integrated shape. Each group worked on a fabrication procedure that is suitable for the chosen material. Students worked on sectioning, contouring, triangulation, and waffle structure as digital manufacturing approaches (Figure 61).

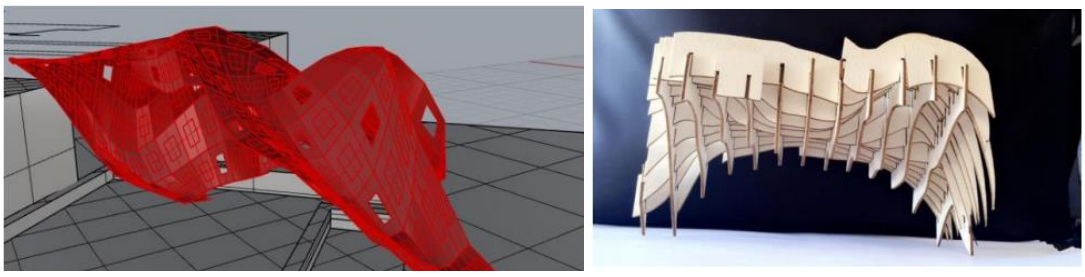


Figure 61: Fabrication of a prototype utilizing (Serra & Tècnica, 2016)

They enjoyed seeing the things they suggested in the prototype built in each scale physical model; the mixture of continuing to work with the digital model and the potential of cutting and assembling its parts; and the mixture of trying to work with the digital model and the potential of cutting and assembling its parts. Serra and Tècnica states that,

> *As students have said, thinking parametrically seems to be quite helpful in this course; they have discovered that this method of thinking is very suitable for the nature of the architecture design phase; a process that is very repetitive or cyclic with building concepts revision* (Serra & Tècnica, 2016).

Figure 62: The chosen pavilion's improved concept model (Serra & Tècnica, 2016)

Students throughout the curriculum utilizing a parametric design approach was a unique experience; this method helped to build their analytical thinking, which informs the usage of parametric design tools; and the engagement with materials and properties.

Case 15 is the architecture program at Rangsit University in Thailand: Rangsit University's Faculty of Architecture, Arch RSU, has studied architectural design using conventional methods since its inception in 1988. It has been stated that the school's move from traditional architecture and design courses to vertical design studios began in the 2016 academic year (Nakapan & Onsuwan, 2018). This was the school's first

time incorporating parametric design into studio work. Vertical design studios enable students from different levels and disciplines to study design courses in a combined context (Nakapan & Onsuwan, 2018; Youssef, 2014). The following four-step process for teaching parametric design was proposed based on this framework:

- Books on parametric design.
- Orientation workshops.
- Developing parametric design abilities.
- Incorporating parametric design into design projects.

As the methodology of the course, only 2nd and 3rd-year students were chosen by the parametric design studio lecturers. The challenge for the second-year students was to redesign the facade of a campus building whereas the third-year students were assigned the responsibility of designing a Museum of Art on a plot of land of their choose, which had to be a public structure no taller than 23 meters. Table 3 represents the number of 2nd-year students who used parametric design at each degree of integration and it is seen that one student did not apply any parametric design techniques at all.

- Four students employed simple parametric design to create their designs. For materialization, simulation, and shape discovery, they all employed parametric design. They did, however, find the form of the facade and then apply a pattern without considering the design's compatibility.
- Normal parametric design was employed by five students. For form discovery, materialization, and simulation, they all employed parametric design. They designed facades with designs that matched the inside and surrounding environment.

- For iteration, none of the student's employed parametric design.
- Digital fabrication was utilized by two students to create 3D models. (Table 6).

Table 6: In the second-year studio, there are different levels of parametric design integration (Nakapan & Onsuwan, 2018)

Level of integration	Number of students					
Level 1: Students not using parametric design at all	1	form finding	iteration	materialization	simulation	digital fabrication
Level 2: Students using minimal parametric design	4	4	-	4	4	-
Level 3: Students using parametric design normally	5	5	-	5	5	2
Total	10	9	0	9	9	2

- Form finding was described as the process of creating the desired form using parametric design.

- Iteration it the creation of a loop with parametric design that creates new forms or solutions.

- Materialization is creation of new effects on materials using parametric design, such as designs on walls or roofs.

- Simulation is the analysis of the effect on the model using modules (such as Ladybug). And in due course light, temperature gain, wind flow, and structural analysis are all factors to consider while designing a structure.

-Digital fabrication is the transferring of digital copies to fabrication equipment (laser cutters, 3D printers) in order to create physical objects.

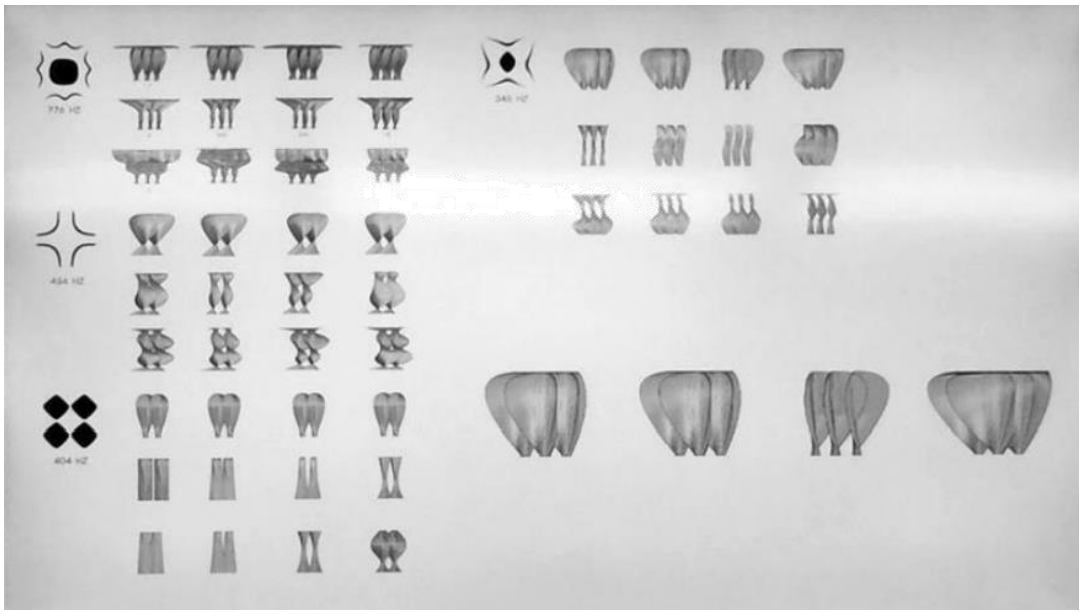


Figure 63: Iteration was utilized to explore with different values to make design options in this student's work (Nakapan & Onsuwan, 2018)

Figure 64: Students' work demonstrating how they used parametric programs to find forms that linked the original forms they had in mind (Nakapan & Onsuwan, 2018)

Table 7 represents the number of 3rd-year students who used parametric design at each degree of integration and it is seen that the two students didn't employ parametric design at all in their projects. It is revealed that:

-Five students adopted the minimal parametric design in their designs. For form-finding, they all employed parametric design. Four of them used parametric design to materialize or create a pattern for the roof, which did not integrate well with the design.

One of them built a double-curved ceiling in the entrance hall, while another student used a parametric design to materialize or make a pattern for the roof.

- Normally, eighteen students employed parametric design. For form-finding fourteen of them employed parametric design. It is also revealed that they employed scripts to make shapes that were similar to the ones they had in mind. Iteration was carried out by four students using a parametric design (Nakapan & Onsuwan, 2018).

Table 7: In the third year of stuthe dio, there are different levels of parametric design integration (Nakapan & Onsuwan, 2018)

Level of integration	Number of students					
Level 1: Students not using parametric design at all	2	form finding	iteration	materiali zation	simulation	digital fabrication
Level 2: Students using minimal parametric design	5	5	-	1	-	1
Level 3: Students using parametric design normally	18	14	4	6	-	5
Total	25	19	4	7	0	6

It has been stated by Nakapan and Onsuwan that the students were generally pleased with the product and expressed a strong desire to continue their studies in the design studio semester (2018).

Case 16 is the architecture program at Technology University Yogyakarta in Indonesia: It is tried to introduce parametric design methods in developing the creativity of architecture students by learning parametric design software for form studies. This studio is a course in which architectural students engage in hands-on learning activities to solve design challenges. Students who have participated this program understand design and how to address design difficulties. This was a lecture activity that entails formulating an issue, suggesting a design, and then selecting an

alternate design as a solution, which is then shown in a digital form or physical model. Following the architectural design studios, the design case in this subject is a 10- to 15-story tall structure (Figure 65).

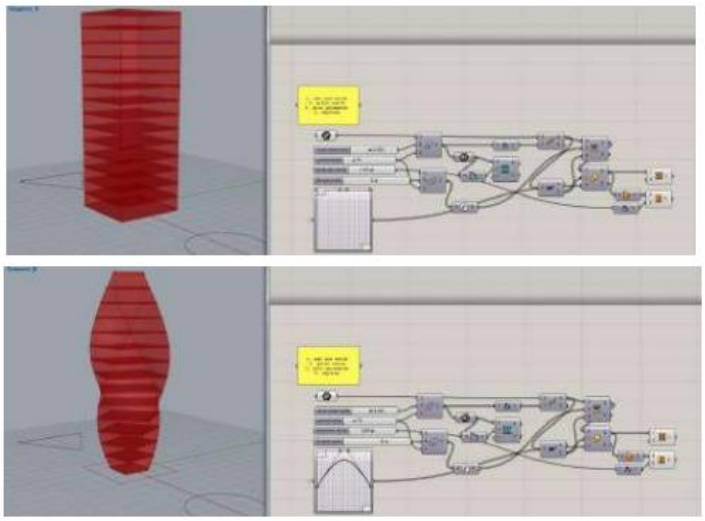


Figure 65: Several Student Form Studies (Putro & Pamungkas, 2019)

Putro and Pamungkas states that,

> *This study succeeded in introducing parametric design methods in enhancing the creativity of architecture students through parametric design software learning for form studies* (Putro & Pamungkas, 2019).

The earliest phase of design, primarily form studies, was the focus. Inter-floor stories, number of stories, floor depth, and building volume are all parameters that are used to generate parametric designs. The algorithm explanation in grasshopper created by students' form studies clarifies the role of parametric design as a fun technique to introduce new forms of form during the design development process. At the end of the process, a questionnaire survey was implemented and a positive reaction from students have been revealed; emphasizing the need of incorporating parametric design methodologies into the curriculum, one of which is through the creation of elective courses. Thus, the use of parametric design software such as Rhinoceros and

Grasshopper was mentioned as a way to boost student creativity (Putro & Pamungkas, 2019).

Case 17 is the architecture program at Chinese University of Hong Kong in China: The parametric design studio method targeted architectural design computational concepts at this program. It combined a studio-learning environment with in-depth digital media instruction. The goal was to gain and integrate parametric design skills in order to use it as the foundation for creating their architectural proposal's design. The pupils' expertise was linked to their desire to generate their own design concepts. It combined a studio-learning environment with in-depth digital media training to bridge the gap between skill development and knowledge reflection, as well as to investigate new ways of phrasing and integrating compounding in the design studio. The studio involved the students in the design process by asking them to question, construct, and define the form and function of the final designs utilizing a set of variables and a series of relationships. By evaluating the rules and parameters, the students investigated interaction approaches between their design intent, framing of the design challenge, subsequent generation, and reflection on their development.

The students and then began to develop and visualise their designs in three-dimensional forms that formed spatial manifestations of their findings and investigations, using the data from the first component and the abilities from the second. As an example, rather than relying just on compositional methods, the students used scripts to create their own generative qualities and a foundation for their design research (Figure 66).

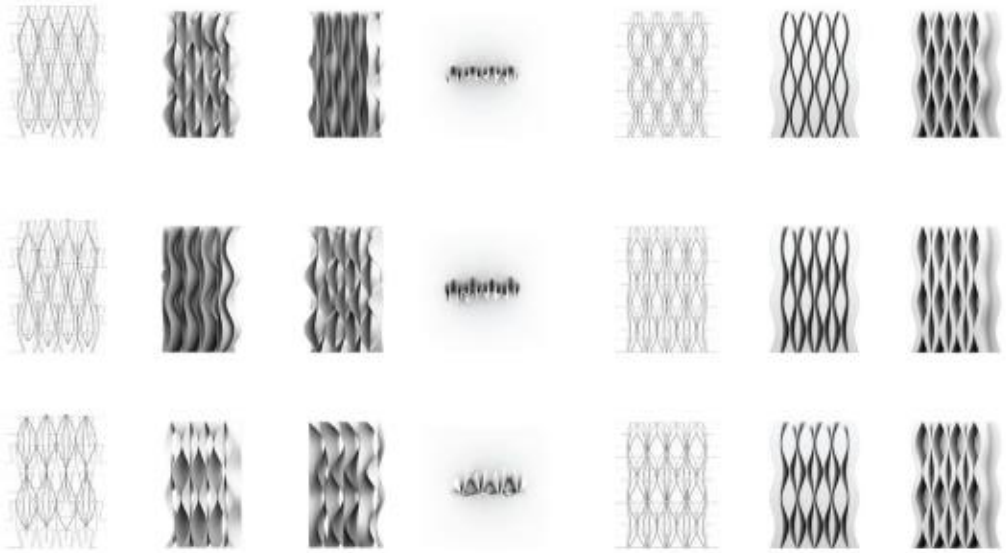


Figure 66: Variations produced by a script to change the facade tiles (Schnabel, 2012)

The students were able to design inside an environment based on the rules and generating descriptions by the usage of digital parametric instruments, which enhanced their design comprehension and learning. The studio made extensive use at all stages to explore the transformation of virtual design conceptions into physical objects via the use of computer-aided manufacturing (Figure 67).

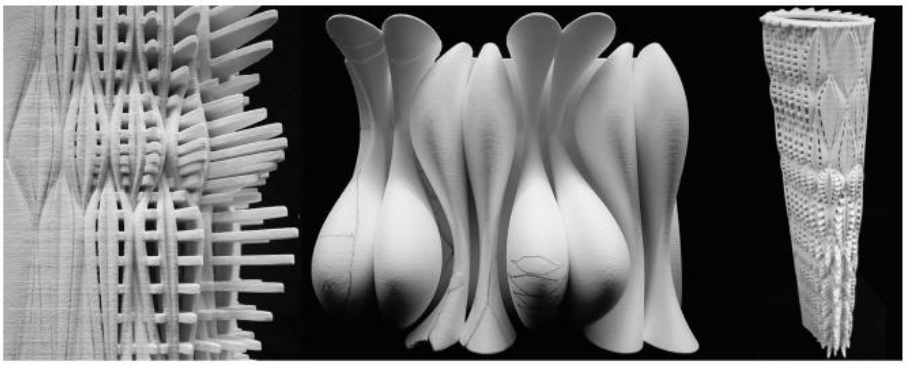


Figure 67: Details of the facade from the rapid-prototyping digital model by students (Schnabel, 2012)

Case 18 is the architecture program at National Technical University of Athens in Greece: There is a style of digital design thinking that may be used to educate students

in how to compose architectural space without the use of digital tools. It has been stated that the students find often hard to understand how to compose architectural space in a systematic and controlled way, using architectural elements such as surfaces, lines and volumes (Vamvakidis, 2016). Through three workshops, a specific geometry (a cube, a plane, and a contour curve) was used to produce a number of spatial and organisational transformations. Students were instructed to create four transformation stages in order to develop their basic geometry (for example, the cube) utilising digital design verbs such as cut, divide, trim, move, rotate, scale, stretch, offset, copy and paste (Vamvakidis, 2016) (Figure 68).

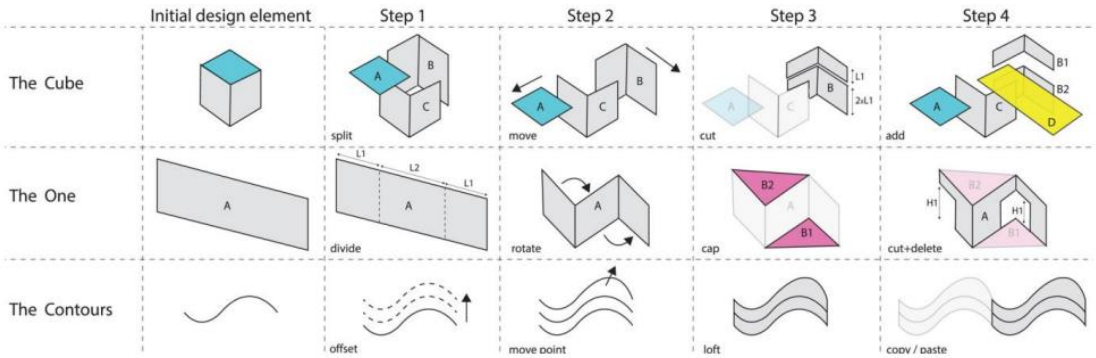


Figure 68: The three workshops, as well as potential transitions(Vamvakidis, 2016)

Students managed to tackle the studio's design approach and requirements quite well, even though this was the first term of their studies (Vamvakidis, 2016). A number of physical models were created, as previously stated. Physical models and 2D graphics were used to document all of the transformation phases (Figure 69).

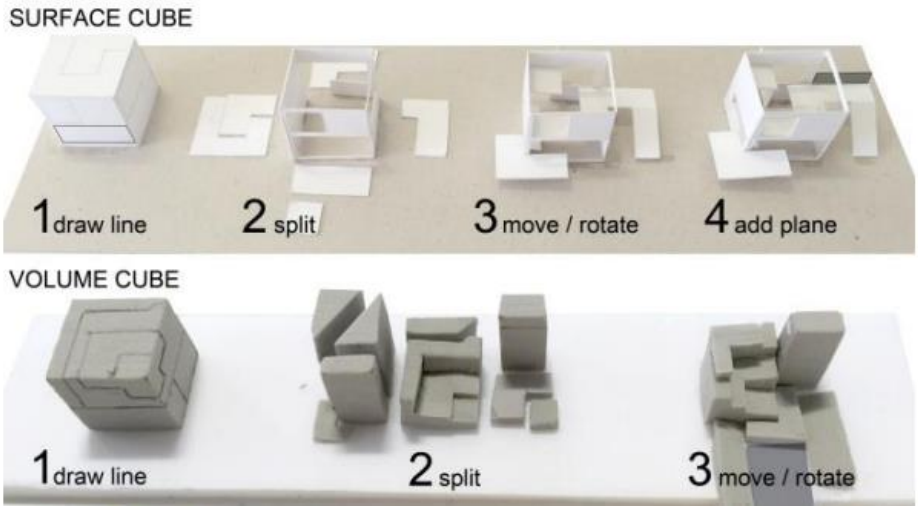


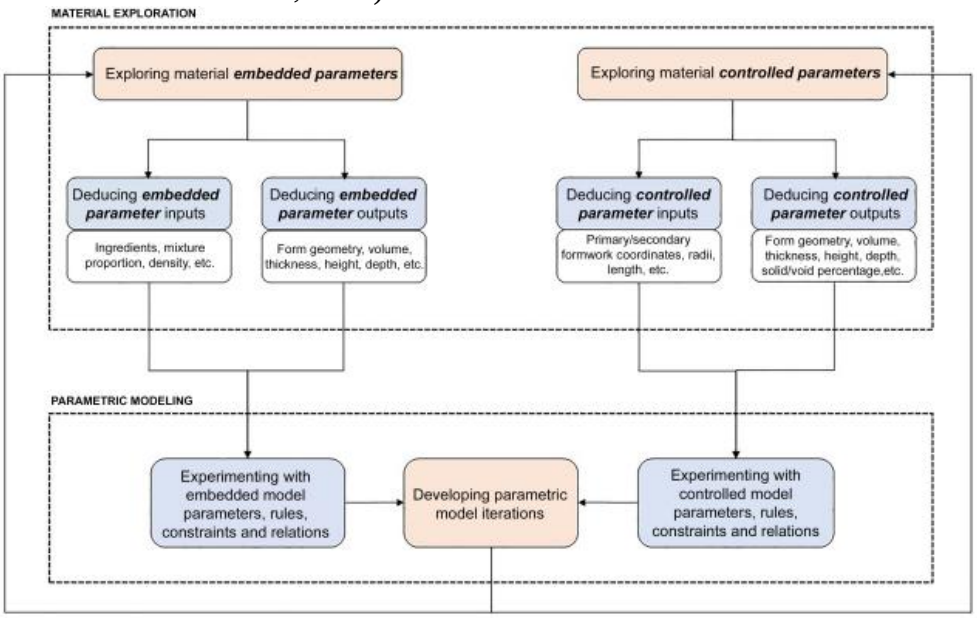
Figure 69: Students' modelling of the stages involved in transforming paper and foam cubes (Vamvakidis, 2016)

Students got the opportunity to learn how to compose space by creating their own design rules for the physical model transformations of the cube, paper plane, and curve. According to Vamvakidis, this procedure resembles how they would create design rules and parameters in a digital and/or parametric model. They may, for example, return to step 1 and change the basic shapes on the cube edges to see how the final physical model changes (Vamvakidis, 2016).

Case 19 is architecture program at The American University in Cairo in Egypt: There is an aim to develop a framework for incorporating parametric design and algorithmic thinking in architectural curricula through a material-informed holistic systems design method in design studio. It proposes a material-informed holistic systems design framework for parametric form finding. And also aim to identify affordances of material-based computation in terms of supporting the understanding of parametric design, informing the process of parametric form finding in an educational setup and augmenting student learning outcomes as relates to algorithmic thinking. Universities create a teaching method that incorporates material-based

computation into a computational design course (Digital Design Studio and Workshop) that focuses on the interaction of the physical and digital in a parametrically driven façade design exercise. The material-based parametric design framework proposed in case illustrates the holistic and adaptive cycle between the process of exploring the physical embedded and controlled parameters of materials on the one hand, and the process of developing parametric modelling iterations in the computational environment on the other, as shown in (Table 8).

Table 8: Parametric form-finding using a material-based parametric design framework (Abdelmohsen & Massoud, 2021)



It showed the process and outcomes of a design course with the primary goal of addressing the interaction between making and the physical interplay of materials on the one hand, and the process of parametric form-finding on the other, as well as how practical learning experience with materiality affects student learning and understanding of algorithmic thinking and parametric form-finding (Abdelmohsen & Massoud, 2021).

Case 20 is the School of architecture of Nancy in London: Curriculum of this program aims to broaden students' understanding of computer-aided design processes and digital technologies by including new generation parametric methodologies based on digital programming (Grasshopper). The parametric education in the program is spearheaded by the workshop on digital design and production, which runs concurrently with the lectures. Using parametric modeling and digital manufacturing techniques, the workshop offers a design process that enhances architectural form development and materiality. The students design an exhibition using a point (from nature) as a basic model (Gallas et al., 2015). They deduce the reference object's formal structure and portray it with sketches. The students offer an architectural design based on the recognized structure, which they then actualize using parametric modelling tools. The suggested solution adheres to the practical and material restrictions that were discussed at the start of the session. The sketches serve as a design tool for materializing the intended solution and defining its various modeling processes (Figure 70).

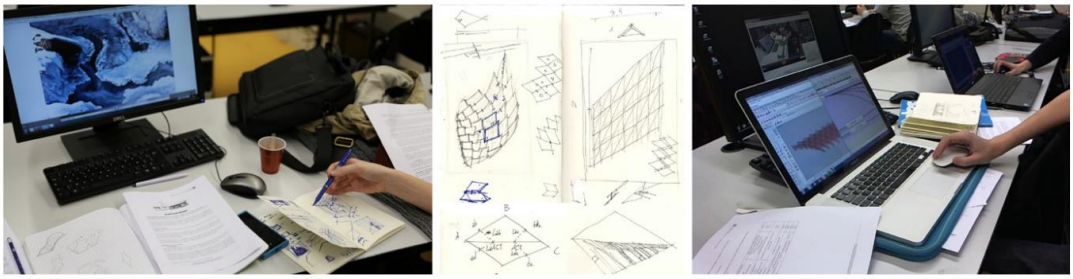


Figure 70: Sketches as a design and implementation tool by students (M.-A. Gallas et al., 2015)

In this method, workshop participants experiment with the created parametric model structure using a simple paper model and a more extended mockup (Gallas et al., 2015). They used the physical model to figure out how to connect the project's many parts.

The course continues by teaching students how to use the programming language included in the chosen modeling application to create and control sophisticated 3D forms. Students are taught how to use conventional commands in architectural software tools to create complicated geometrical forms. The example below demonstrates how parametric equations of well-known curves are combined to generate the project concept and parametric model feature (Figure 71).

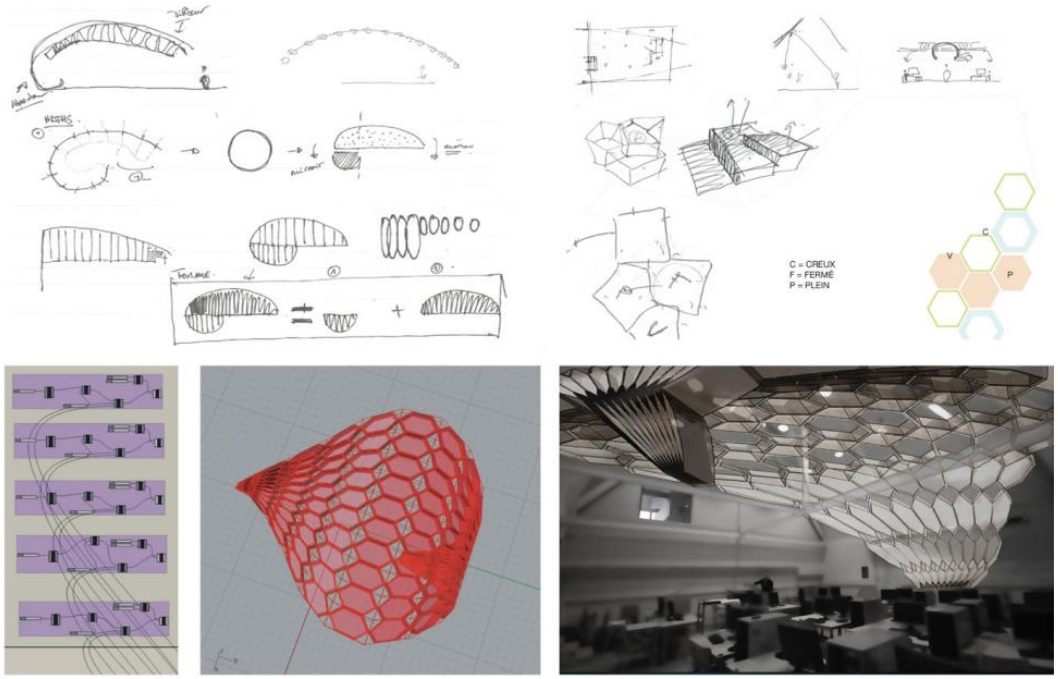


Figure 71: An example of a student's work in which the project form was created utilizing mathematical functions (M. Gallas et al., 2020)

The evaluation of the created projects and the design process reveals that including experimentation activities and devices results in a design-material interchange. This process of integration results in new design solutions as well as new materiality. This method satated as the part of a larger study aimed at improving the integration of digital design aid technologies in order to establish a digital continuity from concept to the real thing (Gallas et al., 2015).

Case 21 is the architecture program at University of Nicosia in Cyprus: Parametric design method has been applied during extracurricular workshops and competitions. The workshop's goal is to highlight the importance of intelligence in systems and to raise the issue of various conflicting parameters in digital design. The suggested workshop was developed using knowledge obtained from previous international contests. The method was directed by experimentation with both physical and digital models, which allowed for real-time visualization of forces to mould form-found designs and assess their structural efficiency. Gridshells are light, efficient structures that are formed to purely correspond to natural forces. Frei Otto and Shigeru Ban, two of the first grid shell designers, employed physical models of hanging nets to conceptualise their shapes. High-end digital design tools enable exact simulation of structural materiality as well as the investigation of a wide range of forms. The 9th graders successfully erected a full-scale lightweight prototype with a footprint of 11m x 5m in less than 6 hours (Figure 72).

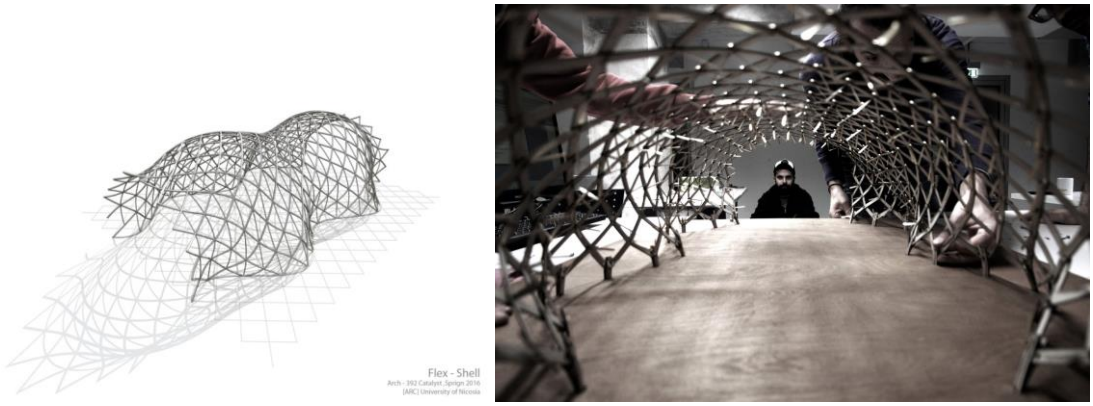


Figure 72: Model as a design and implementation tool by students (Michel, 2018)

The project team used parametric design tools to examine, comprehend, and digitally simulate a simple tensegrity module. The procedure involved digitising the physical properties of two different elements (rigid and tensile), made from wooden rods and

steel wires, as well as experimenting with different equilibrium locations of the digital apparatus by modifying many of its parameters. Another project team goal was to analyze, understand, and digitally simulate a basic tensegrity module utilizing parametric design tools. The procedure involved digitizing the physical properties of two different elements (rigid and tensile), wood rods and steel wires, as well as experimenting with different equilibrium locations of the digital apparatus by modifying many of its parameters. As a result, the experiment focused on the rods' initial position and the steel wires' initial dimensions. After achieving many stable structures, the team looked into the idea of combining a number of modules. Finally, the data obtained from the simulation (element sizes) was used to effectively construct a 1:1 physical module, demonstrating the digital model's validity and future potential (Figure 73).

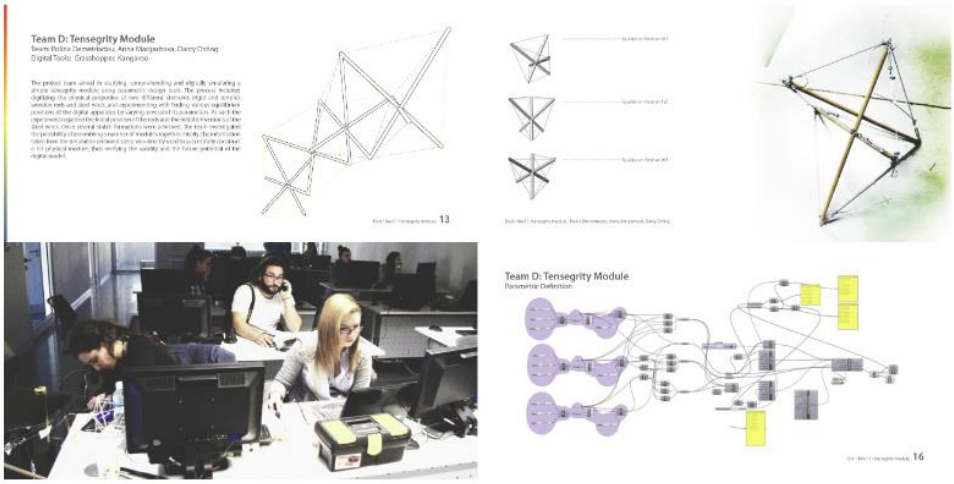


Figure 73: View from the workshop and different elements on various modules developed by students at the workshops. (2013, July 6) (URL 20)

In the workshop, a procedure has been characterized by which the multiplicity of a thing with specific attributes results in the creation of a whole. Replication, on the other hand, has been described as the procedure of replicating an object while changing

its properties in order to create a whole. As a result, one can explore alternative conceptual designs within a given family of results by modifying the features of the replicated objects. As a result, replication was able to produce adaptive systems that met specific design criteria. The knowledge that prompted replication has been accepted or logically approached for the workshop's aim and constrained schedule. However, all of the participants seemed to agree that producing, receiving, and filtering the feeded data is a new frontier for Parametric Design.

Case 22 is the architecture program at University of Liège in Belgium: Program integrates parametric modeling as a part of Computer-Aided Design courses. They proposed a design exercise where students used parametric modeling tools to generate original forms integrating structural and construction constraints (create an interaction between structure and form). It combines digital tools for modeling and fabrication tasks and physical tools for the parametric analysis process. The parametric design model was utilized as the primary tool for analyzing the intended object and defining the key parametric modeling cases. The parametric modeling activity is viewed by students as a reverse design process. The procedure began with an examination of a physical model (mock-up) of a pavilion with a complex structure shape. They identified the structural elements and attempted to envision how they may be developed. As a high-level abstraction activity, the sketching activity is used to depict modeling process steps (Gallas et al., 2015).

As a middle-level abstraction step, the students utilized it to convert the sketches into graphical algorithms that integrated geometrical and logical components. The equipment assists them in generating many modeling options and selecting the most appropriate. As a low-level abstraction activity, the last step of the modeling process

incorporates the transfer of the graphical algorithm using physical elements to a graphical algorithm uutilizing Grasshopper components. During the parametric modeling process students can utilize the model as a parametric design tool to help them build multiple degrees of abstraction (Figure 74).

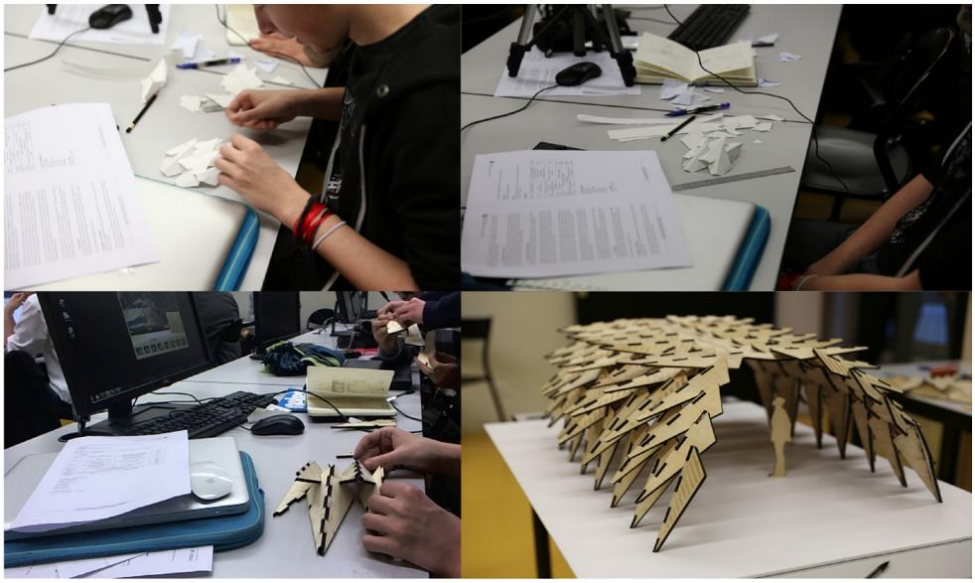


Figure 74: Experimenting with physical models and putting together mock-ups, by students (M.-A. Gallas et al., 2015)

Case 23 is the architecture program at University of Novi Sad in Serbia: A workshop titled "Materializing Parametric Design" was presented as part of the "Parametric Constructional Design" course at this case. Students who are already familiar with parametric design benefit from the workshop. Its purpose was to represent approaches for constructing real-world parametric structural models. Parametric design necessitates at least some automation in the manufacturing process. The pupils learned how to make lower-scaled models using the skills they acquired. Students will be able to prepare a model for laser cutting or 3D printing as a consequence of the session. In the process, all students knew how to create the models in a parametric design elective subject. This was the second semester of parametric design for a large number of

students. Students learnt how to fold the model in the workshop and then built the model from the printed pieces, as shown in (Figure 75) They learnt the fundamentals of architectural visualisation as well (Sarkozı, 2019).

Figure 75: Students created a model and paper model in the workshop (Sarkozı, 2019)

Sarkozı states that,

> *The presented teaching method introduces students to parametric design. Through class exercises, they learn the fundamentals of software programs and parametric design thinking. Students can use parametric design throughout the production of a different architectural job. Students are intrigued by this emerging discipline of architecture and the new possibilities that this expanding design tool offers. Students will be able to design a basic parametric schema and will have the skills to increase their parametric capabilities after completing the course* (Sarkozı, 2019).

Case 24 is the interior architecture/design programme at the Pratt Institute, School of Continuing & Professional Studies in New York Cıty, USA: It has been revealed that department of interior architecture/design study programme encourages students to change their focus from authoring individual design artefacts to creating and navigating rule-based design tools and connections. To accomplish this, the elective course looks at rule-based and parametric design principles and approaches in the

context of Grasshopper for Rhino, which is a generative modelling system. Accordingly objectives and goals of this approach is stated as:

• To gain an understanding of parametric modeling systems' overall structure.

• To become proficient in visual development environments.

• To became familiar with the process of incorporating design knowledge into a functional form.

• To use appropriate parametric tools to convey crucial formal features at each level of the design process.

Accordingly, design software developments, design methods, and the manifestation of architectural form have all been influenced by parametric modelling tools and thinking. And thus the principles of parametric and rule-based modelling for practical application in interior architecture/design, architecture, product development, and beyond are taught in this course. Course entails two physical output projects polishing the skills taught, using digital design and fabrication processes in conjunction with Pratt's production facilities of 3D printing and digital cutting, through a sequence of lectures, workshops, and interactive development. Furthermore, software is used in another course in order to create virtual 3D models of parts and assemblies (parametric CAD software). Learning the interface, communicating design intent, creating parts and assemblies using solid features, making 2D drawings from Solidworks models, 2D and 3D sketch tools, associative connections and parametric restrictions, and basic rendering are just a few of the topics covered. It has been pointed out that there is no necessity to have any prior expertise with Solidworks or other CAD modelling software.

Alonsgside the above mentioned implementations, the history, philosophy, and use of Parametric Design for architectural creation are covered in this course as well. The emphasis of the course is on the fundamental principles and processes for developing performance-based parametric modules. The focus is on lateral design methodologies that can modulate and adapt to a variety of restrictions, hierarchies, and performance requirements. Having the goal of offering students with a conceptual and technical framework for better understanding the use of Parametric Design to the many design problems that they will face as architects is the other strenth of the method applied (Yüce Gün & Coersmeier, 2008).

Case 25 is the interior architecture/design programme at the University of West Attica in Greece: This case has covered parametric design as a 3-credit course in which introduction to the concept of algorithmic design is made in department of interior architecture/design. It focuses on design methodologies with parametric models and optical code. Especially the development of computer mechanisms for creative production processes of space and objects are discussed. The goal and objectives of the implementation are as follows:

- Algorithmic design of curved lines and surfaces
- Grid transformations on flat and curved surfaces.
- Algorithmic transformations on the plane and in 3D space.

The relationship between algorithmic design and modern methods of digital fabrication.

Examining the relationship between generated form and the management of the structure of the designed object through code. And another development of criteria for

controlling the evolution of form and the definition of the desired solutions. It is stated that the students were able:

- To analyze the form of a place or item using algorithmic reasoning, and describe it using parametric models.
- To create using parametric design approaches and logics.
- To incorporate design criteria as a parameter in such techniques.
- To use current digital methods, connect the design and fabrication processes.

3.3 Result and Interpretation of the Explored Cases

These methods in universities are taught to students in a creative thinking training studio, where they are taught to examine the complicated structure of the design from multiple points of view, and they are trained in preparation for the closing of gaps that exist in varied environments. Students who are attempting to learn the distinctive, varied structure of the design process benefit from this educational process, which develops their sensitivity and perceptual abilities. These methods, in the context of the students' need to demonstrate fluency in thought and form, may be unusual, original ideas, the ability to establish previously unknown correlations between relationships, the ability to easily switch from one idea to another, the ability to manage complex relationships, and the ability to synthesize and analyze.

The approach and benefits of elective seminars could be summariez as; modeling for implementations; using digital design; physical structure and form; and the capacity to generate forms. It was used at a rate of 38% design studios; much-desired mobility as well as design options, helped to build their analytical thinking and to investigate parametric tools and how they can be used to generate numerous formal expressions, students were given access to digital parametric tools and to use it as the foundation

for creating their architectural proposal's design. It is used at a rate of 7% of theoretical courses; the approach is based on their theoretical and practical knowledge, their capacity for problem-solving, and the benefits of their proficiency in parametric design thinking. It is used at a rate of 3% of software-based courses; the approach is based on their program on a variety of design concepts and the benefits of their use of algorithmic thinking and computer software skills. It is used at a rate of 24% of extracurricular activities; the approach is based on noted theoretical and cultural components of the parametric approach, physical and digital models, and investigation of a wide range of forms, techniques of the sketches into graphical algorithms that integrated geometrical and logical component constructing parametric structural models. As the benefits of the ability to like digital skill set, ability to fold the model, 3D printing, converted the sketches into graphical algorithms that integrated geometrical and logical components constructing parametric structural models.

It is used at a rate of 19% in parametric design courses; the approach is based on the benefits of the ability to the environment based on the rules and generates descriptions of the usage of digital, understanding the use of parametric design to the many design problems computer-aided design processes and digital technologies (Table 5).

Exploration results have been put forwas that, parametric design techniques have limitedly integrated in interior architecture/design programs compared to how substantially it has been studied in architectural programs. The use of digital techniques, search for form, particularly in design studio courses, modeling and reuse in parametric design courses, variations in generating alternatives in extracurricular activities and design studio courses, and algorithmic thinking are the most popular approaches in the applied methods. The ability to recycle in modeling environmental

challenges, as well as the development of algorithmic thinking and finding forms in design studios and electives, employing deductive induction elements, are examples of similar methodologies used in the universities under study. As distinct methodologies, it has been noted that in some universities they diverge in aspects like physically building models without the aid of a computer software (Table 9).

In addition, several aspects of the skills are valued related to the spaces of the location as such that there is a possibility of utilizing it as the foundation for developing architectural concepts and naturally occurring geometric structures transformed into parametric objects/buildings.

Table 9: Tabulating and synthesizing multiple cases of techniques and benefits of linking and implementing institutions' with courses (by author)

CURRICULAR / EXTRACURRICULAR	CASE STUDIES	IMPLEMENTATION	BENEFITS
DESIGN STUDIO	• **University of Sydney**	To an integrated digital media component that addressed parametric modeling	Ability to each stage and variable on the design and track how it affected the project
	• **Gdańsk University of Technology**	To include Grasshopper 3D software and the Weaverbird mesh modeling library and algorithmic design	Ability to new abilities
	• **Sultan Qaboos University**	To include parametric thinking in the early stages	Ability to apply to knowledge
	• **University Of Darmstadt**	To an integrated climatic elements, physical durability tested, parametric thinking	Ability to easy production of alternatives of the design, Natural geometric structures
	• **German Jordanian University**	To investigate parametric tools and how they can be used to generate numerous formal expressions	Ability to students were given access to digital parametric tools
	• **Kansas State University**	To purpose analytical with a grasp of what parametric design	Ability to modified, and evolved parametric design thinking skills
	• **Rangsit University**	To include process of creating the desired form using parametric design	Ability to new forms or solutions
	• **University Of Yogyakarta**	To include parametric design methods of students by learning parametric design software for form studies	Ability to software such as Rhinoceros and Grasshopper as a way to student creativity
SOFTWARE-BASED COURSES	• **Cracow University**	To an integrated Rhinoceros 5 + Grasshopper program on a variety of design concepts	Ability to computer software and algorithmic and parametric design
THEORETICAL COURSE	• **The University of Pécs in Hungary**	To purpose parametric design methods of students by learning parametric design software for form studies	Ability to consider solutions and strengthen their parametric design thinking skills
PARAMETRIC DESIGN COURSES	• **University of Lisbon**	To include Geometric and Generative Modeling, use of Rhinoceros software	Ability to shape by studying model development and helped to build their analytical thinking
	• **Birzeit University**	To employing digital parametric tools and techniques in architectural design and manufacturing	helped to build their analytical thinking
	• **School of the architecture of Nancy**	To understanding of computer-aided design processes and digital technologies	Ability to form development, and This process of integration results in new design solutions
	• **The Chinese University of Hong Kong**	To use it as the foundation for creating their architectural proposal's design	Ability to environment based on the rules and generate descriptions to the usage of digital
	• **Pratt Institute**	To modeling for practical application, using digital design, algorithmic design and digital fabrication	Ability to understanding the use of Parametric Design to the many design problems
	• **University of West Attica**	using digital design, algorithmic design and digital fabrication	Ability to digital technologies and parametric thinking
ELECTIVE SEMINARS	• **Université de Montréal**	To include modelling for practical application, using digital design, and physical structure and form	Ability to form generation
EXTRACURRICULAR ACTIVITIES	• **Virginia Tech's School of Architecture**	To include three-dimensional computer models for 'two-dimensional' fabrication using the laser cutter	Ability to digital skill set
	• **University of Calabria**	To noted theoretical and cultural components of the parametric approach	Ability to digital technologies
	• **Pilot University of Colombia**	To use of digital tools, geometric definition to develop a flexible modular system	Ability to developments in sustainable architecture lead to functional refinement
	• **National Technical University of Athens**	To include digital design thinking that may be used to educate students to compose architectural space	Ability to physical models and 2D graphics were used to document all of the transformation phases
	• **The American University**	To include parametric design and algorithmic thinking and a material-informed, parametric form finding	Ability to process of developing parametric modelling iterations in the computational environment
	• **University of Nicosia**	To include physical and digital models, investigation of a wide range of forms	Ability to producing, and filtering the feed data
	• **University of Liège**	To include parametric modeling as a part of Computer-Aided Design courses	Ability to converted the sketches into graphical algorithms that integrated geometrical and logical component
	• **University of Novi Sad**	To include constructing parametric structural models	Ability to fold the model, 3D printing

The development of worldwide information for parametric design application as a roadmap for architecture schools who are teaching this technique has been provided that particularly in developing countries is a beneficial method. Accordingly, the current study recommends the following considerations in order to close the gap in interior architecture/design education as a result of an in-depth study of various ways of integrating parametric design methods into interior architecture/design and architecture education via exploring multiple cases worldwide. The recommendations of the parametric design method to interior architecture/design education are listed as a result of these evaluations:

- The perception of basic geometry and the definition of form behind the exceptionally complex-shaped fantasy of a design produced using a parametric design technique plays a critical role in the educational process. In this regard, parametric design has been found as a useful approach/tool in order to expose new design concepts in architectural and interior architecture/design education.
- Another important point that emerged is that the parametric design approach is used in a diverse array of courses such as design studios, software-based, and computer-based practical courses, extracurricular activities (workshops, competitions, etc.) that is being used for various aims: form-finding, modularity, modification, induction. Accordingly, this method either could be integrated to the existing course groups or could be integrated as an elective course.
- Nowdays, sustainable/ecological architecture design is a hot topic with an aim to create structures which are self-sufficient in energy, that do not harm the environment, and that are built with greater consideration for the environment by using renewable energy sources rather than energy sources. Accordingly,

the integration of digital technologies and parametric design is explored as a useful tool in order to accomplish this goal.

- It is also recommended that the parametric design approach chould be included in the interior architecture/design education curricula either in particularly in the first year design education or in the upper year studios, furniture courses, lighting courses or to understand and test the subjects like acoustics. It is a significant issue in the course of sustainability in interior architecture/design as well as an intriguing technique in creating space within space particularly in larger, higher spaces with a large span.
- Air conditioning, this space creation/design, and other factors are treated as parameters in the parametric design method raises another significant issue in academic settings where this approach is studied. It also highlights the value of the courses, and it is advised that all interior architecture/design departments could incorporate these programs into their curricula and benefit from this useful tool to handle this significant topic by the help of creating them as parameters.
- Moreover, it is recommended that it is required to promote faculty members' access to the relevant tools and expertise in this sector in order to expand the usage of the parametric design approach in interior architecture/design education and to raise its quality.

Chapter 4

CONCLUSION

Result of this research shows/indicates that parametric design methodologies can be included in interior architecture/design education without completely replacing traditional teaching methods. In interior architecture/design, architecture, and architectural education, the usage of parametric design methods is increasing. In parametric design, designers use preset parameters to define a form. Sufficient reasoning is required to construct a sophisticated geometrical framework that is integrated into a complex model that is flexible enough to do alterations. They can also assist designers in creating better products by offering more context for how their ideas will be used, allowing them to make more informed design decisions.

Furthermore, to effectively extend the process beyond production, parametric design, a new design methodology, enables interior architects and students to have a more active role throughout the entire design and development process. So it is believed that parametric design, a novel design style, will fundamentally alter how students learn and endow them with cutting-edge information and useful abilities. But it is also important to remember that this approach shouldn't replace more conventional forms of instruction. The goal of this method is to develop a systematic approach and a parametric design framework as a new design methodology. Parametric Design Thinking is also discussed, and it is thought that combining various strategies and principles under the protection of a systematic procedure will enable tools to be applied

not only in theory but also primarily in education, which will aid in understanding the design activity of data analysis, method, management, technology, and parameters. The main question was; “To which extend parametric design method could be integrated into interior architecture/design education without replacing the traditional education methods?”.

Accordingly alongside its use and implementation in the professional market; 25 cases were examined to see if parametric design techniques could be integrated into interior architecture/design education without replacing the traditional education methods. There are 23 case studies with in the architecture program but just 2 in the interior architecture/design program. Study have revealed that compared to the architecture programs the number of interior architecture/design programs are fewer and hence it has been noticed that this creates a research and implementation gap.

Study not only analyse/ difference of course groups such as design studios, applied courses (i.e theory with a project or a workshop, etc.), and theoretical courses, but also analyse/review parametric forms of design as a development tool in extracurricular activities to explore existence and differents approaches of parametric design as a part of the architecture and interior architecture/design curriculum.

Study conclude that the modeling for implementations, employing digital design, physical structure and form, the methodology and advantages of optional seminars, and the ability to develop shapes are some of the topics covered in the exisiting implemetations. Aslo, it has been achieved that the students were given access to digital parametric tools and encouraged to use them as the basis for designing their architectural proposal. It was used at a rate of 38% design studios; much-needed

mobility as well as design options, helped to develop their analytical thinking, and investigated parametric tools and how they can be used to generate numerous formal expressions. The technique is based on their theoretical and practical knowledge, their aptitude for problem-solving, and the advantages of their skills in parametric design thinking. Moreover, this study explored that it is also employed in theoretical courses. Furthermore, as a technique it is based on their curriculum on a variety of design concepts and the advantages of their usage of algorithmic thinking and computer software abilities; it is employed at a rate of 3% in software-based courses. Its use in extracurricular activities has been revealed and it has been exposed that the approach is based on the acknowledged theoretical and cultural elements of the parametric approach, physical and digital models, and investigation of a wide range of forms, techniques of the sketches into graphical algorithms that integrated geometrical and logical component constructing parametric structural models. Furthermore, benefits of the capacity to create parametric structural models include the ability to fold the model, use 3D printing, and convert sketches into graphical algorithms that incorporate geometrical and logical elements. Findings explored that parametric design method/approach would be a useful tool with its multiple benefits once it is integrated into interior architecture/design education. However no shortcomings were found as a result of the exploration of 25 cases.

Accordingly, based on the developed framework, this research may serve as a point of convergence and a foundational step toward the development of a useful parametric design a model for interior architecture/design and instruction.

The parametric design method could be included in interior architecture/design education without displacing the established educational approaches that use software programs, modularity, induction, and deduction to enhance the perception of basic geometry and form definition. Future academics interested in studying parametric design-related topics in interior architecture/design and architecture education may find this thesis to be helpful. By applying the analysis carried out in this research, the study anticipates that students and academics of interior architecture/design will benefit from parametric design methodologies. In the next stage, this study aims to go beyond the recommendations and to develop a model of integrating parametric design approach into interior architecture/design education.

REFERENCES

Abdelmohsen, S., & Massoud, P. (2021). A material-based computation framework for parametric design education. *Open House International*, 46(3), 459–475. https://doi.org/10.1108/OHI-02-2021-0043

Ağırbaş, A. (2020). *A Teaching Methodology for Parametric Design: A Case Study with Parametric Bench.* 720–725. https://doi.org/10.5151/sigradi2020-99

Aia, E. C., & Vt, V. T. (2011). *Parameters of a Digital Design Foundation.*

Alalouch, C. (2018). A pedagogical approach to integrate parametric thinking in early design studios. *Archnet-IJAR*, 12(2), 162–181. https://doi.org/10.26687/archnet-ijar.v12i2.1584

AL-Ratrout, S., & Zureikat, R. (2014). *PEDAGOGIC APPROACH IN THE AGE OF PARAMETRIC ARCHITECTURE Experimental Method for Teaching Architectural Design Studio to 3 rd Year Level Students.* Architectural Design, 79(4), 14-23. https://doi.org/10.1002/ad.912

Bakırhan, B. (2019). *Mimarlık temel eğitiminde hesaplamalı ve yaratıcı düşünce yetisinin kazandırılmasında parametrik tasarımın rolü* (Master's thesis, Konya Teknik Üniversitesi).

Barrios Hernandez, C. R. (2006). Thinking parametric design: Introducing parametric Gaudi. Design Studies, 27(3),309-324. https://doi.org/10.1016/j.destud.2005.11.006

Basu, T., & Ghosh, M. (2017). Visual perception of space and parametric design: A brief discussion. *GSTF Journal of Engineering Technology*, *4*(2), 1-11.

Basulto, D. (2009, August 26). National Library in Astana, Kazakhstan / BIG. https://www.archdaily.com/33238/national-library-in-astana-kazakhstan-big

Brakke, A. P., & Velasco, R. (2008). Eco-envelopes : An Environmental Approach to Parametric Design. *SIGraDi 2008 - [Proceedings of the 12th Iberoamerican Congress of Digital Graphics]*.

Canestrino, G., Miraglia, S., Perri, G., & Lucente, R. (2021). Parametric strategies in an architectural design workshop. Blucher Design Proceedings. https://doi.org/10.5151/sigradi2021-115

Chokhachian, A. (2014). Studies on Architecture Design Procedure, A Framework for Parametric Design Thinking. *Architecture, February*.

Curletto, G. (2014). Parametric modeform-finding finding and application to the design of modular canopies. WIT Transactions on The Built Environment. https://doi.org/10.2495/mar140181

Davis, D. 2013, Modelled on Software Engineering: Flexible Parametric Models in the Practice ofArchitecture, Ph.D. Thesis, RMIT University *Design Studies*, 27(3), 309–324. https://doi.org/10.1016/J.DESTUD.2005.11.006

Dino, I. G. (2012). Creative design exploration by parametric generative systems in architecture. *Metu Journal of the Faculty of Architecture*, 29(1), 207–224. https://doi.org/10.4305/METU.JFA.2012.1.12

Gallas, M., Jacquot, K., Jancart, S., Delvaux, F., Gallas, M., Jacquot, K., Jancart, S., Delvaux, F., & Modeling, P. (2020). *Parametric Modeling : An Advanced Design Process for Architectural Education To cite this version : HAL Id : hal-02890293 Parametric Modeling : An Advanced Design Process for.*

Gallas, M.-A., Jacquot, K., Jancart, S., & Delvaux, F. (2015). Parametric Modeling: An Advanced Design Process for Architectural Education. *ECAADe*, 2(December 2017), 149–157.

Gane, V. (2004). Parametric Design - a Paradigm Shift? Master, Massachusetts Institute of Technology. http://dspace.mit.edu/handle/1721.1/7582

Gane, V. (2004). Parametric design: a paradigm shift? (Doctoral dissertation, Massachusetts Institute of Technology).

Gehry partners. (1997). ArchDaily. https://www.archdaily.com/422470/ad-classics-the-guggenheim-museum-bilbao-frank-gehry

Gelernter, M. (1995). Sources of Architectural Form. UK: Manchester University Press.

Headley, D. (2013). *Integration of Parametric Thinking Within.* 167–176.

Hermann, C. (2004). Branko Kolarevic, ed.—Architecture in the digital age: Design and manufacturing. *Nexus Network Journal*, *6*(2), 131-134. https://doi.org/10.1007/s00004-004-0025-4

Hernandez, C. R. B. (2006a). Thinking parametric design: introducing parametric Gaudi.

Hernandez, C. R. B. (2006b). Thinking parametric design: Introducing parametric Gaudi. *Design Studies*, 27(3), 309–324. https://doi.org/10.1016/j.destud.2005.11.006

Iordanova, I. (2007). Teaching digital design exploration: Form follows…. *International Journal of Architectural Computing*, *5*(4), 685-702. https://doi.org/10.1260/147807707783600807

Jabi, W. (2013). Parametric design for architecture. Laurence King Publishing.

Kalogiannakis, M., & Papadakis, S. (2020). Handbook of research on tools for teaching computational thinking in P-12 education. IGI Global.

Karle, D. & Kelly, B. M. (2011). Parametric Thinking. University of Nebraska – Lincoln

Kowaltowski, D. C., Bianchi, G., & De Paiva, V. T. (2009). Methods that may stimulate creativity and their use in architectural design education. *International Journal of Technology and Design Education*, *20*(4), 453-476. https://doi.org/10.1007/s10798-009-9102-z

Lee, J. H., Gu, N., Ostwald, M. J., & Jupp, J. (2013). Understanding cognitive activities in parametric design. *Communications in Computer and Information Science*, 38-49. https://doi.org/10.1007/978-3-642-38974-0_4

Lawson, B., 2011. Como arquitetos e designers pensam. São Paulo: Oficina de Textos.

Maria, N., Tinoco, B. D. M., & Ribeiro, D. (2015). *Reflections on the introduction of parametric thinking into design education.*

Matcha, H. (2007). Parametric Possibilities: Designing with Parametric Modelling. *Predicting the Future - 25th ECAADe Conference Proceedings*, 849–856. http://www.architektur.tu-darmstadt.de/techno/

Matcha, H., & Ljubas, A. (2010). Parametric Origami: adaptable temporary buildings. *28th ECAADe Conference Proceedings*, Figure 1, 326–334.

Miller, N. (2011). The Hangzhou Tennis Center: A case study in integrated parametric design. *ACADIA Regional - Parametricism*, 141–148.

Monteiro, V., Lisboa, U. De, Design, P., & Design, C. (2010). *Design collaboration towards parametric design process constructibility.* 1(Picon 2004), 305–314.

Nakapan, W., & Onsuwan, S. (2018). *Investigating the Arch RSU Parametric Design Studio Investigating the Arch RSU Parametric Design Studio.* May.

Oxman, R. (1997). Design by re-representation: A model of visual reasoning in design. Design Studies, 18(4), 329-347. https://doi.org/10.1016/s0142-694x(97)00005-7

Oxman, R. (2017). Thinking difference: Theories and models of parametric design thinking. Design Studies, 52, 4-39. https://doi.org/10.1016/j.destud.2017.06.001

Peters, B., & Peters, T. (2013). Inside Smartgeometry. https://doi.org/10.1002/9781118653074

Putro, H. T., & Pamungkas, L. S. (2019). Parametric Design in the phase of schematic design case study: Student creativity on form studies. *Proceedings of the 18th International Conference on Sustainable Environment and Architecture (SENVAR 2018)*. https://doi.org/10.2991/senvar-18.2019.14

Salim, F. D., & Burry, J. (2010). Software openness: Evaluating parameters of parametric modeling tools to support creativity and multidisciplinary design integration. *Computational Science and Its Applications – ICCSA 2010*, 483-497. https://doi.org/10.1007/978-3-642-12179-1_40

Sarkozı, R. (2019). *Parametrıc Archıtectural Desıgn In The Context Of Graph Theory And Coordınate System Transformatıons.*

Schnabel, M. A. (2007). Parametric Designing in Architecture. *Computer-Aided Architectural Design Futures (CAADFutures) 2007*, 237–250. https://doi.org/10.1007/978-1-4020-6528-6_1

Schnabel, M. A. (2007). Parametric Designing in Architecture. Computer-Aided Architectural Design Futures (CAADFutures) 2007, 237–250. https://doi.org/10.1007/978-1-4020-6528-6_18

Schumacher, P. (2009). Parametric Patterns. AD Architectural Design. 79 (6).

Schumacher, P. (2009). Parametricism: A new global style for architecture and urban design.

Sharp, J. A. (1992). Data flow computing: Theory and practice. Ablex Pub.

Turrin, M., Von Buelow, P., & Stouffs, R. (2011). Design explorations of performance driven geometry in architectural design using parametric modeling and genetic algorithms. *Advanced Engineering Informatics*, *25*(4), 656-675. https://doi.org/10.1016/j.aei.2011.07.009

Vamvakidis, G. S. (2016). Controlled transformations: A method to introduce first-year architecture students to digital and parametric design thinking. *Blucher Design Proceedings*. https://doi.org/10.5151/despro-sigradi2016-364

Woodbury, R. (2010). *Elements of parametric design*.

World, S. (2022, February 17). Büro Ziyu Zhuang's chamber church is an ethereal abstraction of sacred archetypes. STIRworld - architecture, design and art magazine.https://www.stirworld.com/see-features-buro-ziyu-zhuang-s-chamber-church-is-an-ethereal-abstraction-of-sacred-archetypes

Yuan, C. Z., & Yi, Z. (2012). To discuss the application of parametric technology in architectural design. Applied Mechanics and Materials, 174-177, 1734-1738.

Yüce Gün, O., & Coersmeier, J. (2008). *Progressions in Defining the Digital Ground for Component Making.* 57–64. http://papers.cumincad.org/data/works/att/cdc2008_057.content.pdf

Zarei, Y. (2012). The Challenges of Parametric Design in Architecture Today: Mapping the Design Practice. MSc Thesis. https://parametric-architecture.com/wp-content/uploads/2018/11/The-Challenges-of-Parametric-Design-in-Architecture-Today.pdf

URL 1: https://www.archdaily.com/115949/guangzhou-opera-house-zaha-hadid-architectspera-house-zaha-hadid-architects.

URL 2: ParaStorm LAB. (2018, November 16). Grasshopper 014 - Parametric Bench Design Concept. YouTube. https://www.youtube.com/watch?v=-L4qtfzH_kI

URL 3: AD classics: La Sagrada Familia / Antoni gaudi. (2013, October 16). ArchDaily.https://www.archdaily.com/438992/ad-classics-la-sagrada-familia-antoni-gaudi

URL 4: Object 12-1: An architectural attire designed by Matija cop. (2018, August 17). ParametricArchitecture. https://parametric-architecture.com/object-12-1-an-architectural-attire-designed-by-matija-cop/

URL 5: parametric. (2020, July 7). Hangzhou tennis center. Parametric House. https://parametrichouse.com/hangzhou-tennis-center/

URL 6: Nordpark railway stations – Zaha Hadid architects. (2007). Zaha Hadid Architects. https://www.zaha-hadid.com/architecture/nordpark-railway-stations/

URL 7: World, S. (2022, February 17). Büro Ziyu Zhuang's chamber church is an ethereal abstraction of sacred archetypes. STIRworld - architecture, design and art magazine.

URL 8: Louvre Abu Dhabi — Ateliers Jean Nouvel. (n.d.). Ateliers Jean Nouvel. https://www.jeannouvel.com/en/projects/louvre-abou-dhabi-3/

URL 9: National library in Astana, Kazakhstan / BIG. (2009, August 25). ArchDaily. https://www.archdaily.com/33238/national-library-in-astana-kazakhstan-big

URL 10: National Museum of Qatar shop interiors / Koichi Takada architects. (2019, May 3). ArchDaily. https://www.archdaily.com/916244/national-museum-of-qatar-shop-interiors-koichi-takada-architects

URL 11: Digital Object Identifier System. https://doi.org/10.1002/ad.912

URL 12: Madrid civil courts of justice – Zaha Hadid architects. (2007.). Zaha Hadid Architects. https://www.zaha-hadid.com/architecture/madrid-civil-courts-of-justice/

URL 13: Yinchuan Museum of contemporary art (MOCA) / waa. (2015, August 6). ArchDaily. https://www.archdaily.com/771375/moca-yinchuan-waa

URL 14: National Museum of Qatar — Ateliers Jean Nouvel. (n.d.). Ateliers Jean Nouvel. https://www.jeannouvel.com/en/projects/musee-national-du-qatar/

URL 15: Architectural details: Jean Nouvel's National Museum of Qatar - Architizer journal. (2020, June 17). Journal. https://architizer.com/blog/practice/details/national-museum-of-qatar/

URL 16: National Museum of Qatar / Atelier Jean Nouvel. (2019, March 29). ArchDaily. https://www.archdaily.com/913989/national-museum-of-qatar-atelier-jean-nouvel

URL 17: Italy pavilion – Milan expo 2015 / Nemesi. (2015, May 14). ArchDaily. https://www.archdaily.com/630901/italy-pavilion-milan-expo-2015-nemesi

URL 18: The building. (2016). The Broad. https://www.thebroad.org/about/building

URL 19: Gate of zero, a magnificent poetry of Seckin Pirim in the Maldives. (2018, August 17). ParametricArchitecture. https://parametric-architecture.com/gate-of-zero-a-magnificent-poetry-of-seckin-pirim-in-the-maldives/

URL 20: (2015, December 4). Odysseas Georgiou - Structural Design + Computation. https://www.odysseasgeorgiou.com

URL 21: On Parametricism (2012). Patrik Schumacher. https://www.patrikschumacher.com/Texts/On%20Parametricism_.html

URL 22: https://prattug-parametricdesign.tumblr.com/about

URL 23: https://www.dezeen.com/courses/parametric-design-foundations-pratt-institute/

URL 24: https://www.enrole.com/prattscps/jsp/index.jsp?categoryId=4A02320