PARAMETRIC DESIGN: THE DEVELOPMENT OF ALGORITHMS FOR FURNITURE AND INTERIOR DESIGN

By

MISS Klawkanlayaphon SAWATMONGKHONKUL

A Thesis Submitted in Partial Fulfillment of the Requirements
for Doctor of Philosophy DESIGN ARTS (INTERNATIONAL PROGRAM)
Silpakorn University
Academic Year 2023

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By	MISS Klawkanlayaphon SAWATMONGKHONKUL
Field of Study	DESIGN ARTS (INTERNATIONAL PROGRAM)
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Faculty of Decorative Arts, Silpakorn University in Partial Fulfillment of the Requirements for the Doctor of Philosophy

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MISS Klawkanlayaphon SAWATMONGKHONKUL : PARAMETRIC DESIGN: THE DEVELOPMENT OF ALGORITHMS FOR FURNITURE AND INTERIOR DESIGN Thesis advisor : Professor Dr. Eakachat Joneurairatana

This research explored the incorporation of parametric models into the algorithmic design process, specifically focusing on furniture and interior design. This research was conducted to explore and analyze the factors associated with using the parametric design method in interior design, with the main focus on the design and installation processes. Grasshopper parameterization modeling technology was applied to create, design, generate, and install. Adopting the parametric method was crucial because it offered a potent approach to efficiently generate designs by dynamically adjusting initial parameters and sequencing codes. This method allowed for the rapid creation of forms necessary for optimal design. The technology has been used widely in different fields, specifically engineering architecture, interior, product, and fashion design with several others, due to the advantages of computational and generative design methods. The core objective of this research is to provide a comprehensive set of guidelines and methodologies for individuals interested in employing parametric applications within furniture and interior design, facilitating a better understanding of this innovative design approach. This practical research divided method, thought, design, and manufacturing processes into five parts: data collection and analysis, design and development, experimentation, implementation, and delivery. Moreover, the experiment was used to explore the parametric design process with due consideration for the conditions, limitations, and design and installation processes. The intention was to determine the factors influencing the interior design, and it introduced a versatile parametric design approach that can be applied to various design tasks, highlighted the evolutionary trajectory of parametric design, and offered insights into its potential impact on future design practices.

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This research would not have been possible without the participation of individuals and Silpakorn University. Thank you all for your invaluable support and I express my sincere gratitude to all those who have contributed to the successful completion of this research endeavor.

Klawkanlayaphon SAWATMONGKHONKUL

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Background of the Research

1. Introduction

1.1 Background and Significance of the research

Parametric design is widely known in the fields of engineering, architecture, design and industry. The term parametric has its roots in mathematics, although its historical origin has been disputed. Parametric equations use one or more independent variables called parameters, which are also defined as continuous functions. In addition, this structured approach is used to express the relationships between the variables. Parametric design is often defined as an arithmetic concept for generating diverse design options while aiding decision- making in the entire process (Blosiu, 1999). A parametric equation is a set of quantities expressed in mathematics as an explicit function of several parameters.

Technology is evolving rapidly in the 21st century, leading to the development of tools for new challenges that require precision and speed in the design industry. This can be observed in the application of software such as Rhinoceros 3D, Maya and Autodesk Dynamo, which were developed based on parametric equations to create algorithmic modeling. The definition of parametric design revolves around the parameters that determine an entity (= a set of facts or fixed limitations that determine or restrict the occurrence or execution of something). Parametric design is a particular method in which features, such as building elements and engineering components, are shaped by algorithmic processes instead of being designed directly and manually.

Therefore, this research is about the application of parametric thinking in the design and development processes realized with the help of computer programs to process the results according to the planned conditions. The primary aim is to achieve results through the invention of algorithms that involve a sequential communication process in a computer language executed by appropriate programs. The design process is important from the beginning, including studying and experimenting with materials to obtain the results of the structural relationship that should be. This research also shows that testing or simulating work by creating equations to answer exciting forms or even the results in the production process of the work are accurate and can be used in real life. Exploring the potential benefits of parametric design in contemporary furniture and interior design practice is essential to realize its full potential and remain relevant in the evolving field of interior design.

1.2 Statement of the problem

In today's interior design industry, there is a growing interest in parametric design principles and technologies. While parametric design offers exciting opportunities for creating innovative and customized interior spaces, it also presents unique challenges and issues that must be solved. The task involves understanding and overcoming these challenges:

1. Parametric design tools and techniques can be complex and require specialized knowledge. It can be difficult for interior designers to acquire the necessary skills and knowledge to use parametric design effectively in projects.

2. In terms of cost and resources, implementing a parametric program can involve software and technology costs, and parametric work is currently still a challenge in the construction industry. For this reason, the expenses and costs in this section are estimated to be high.

3. Efficiency and time management. While parametric design can lead to highly customized interiors, it can also require more time and effort during

the design and construction phase. It can be a challenge to balance customization with the project's schedule and budget.

4. Integrating parametric design approaches with traditional interior design methods and processes remains a challenge, so a balance must be found if collaboration is to occur.

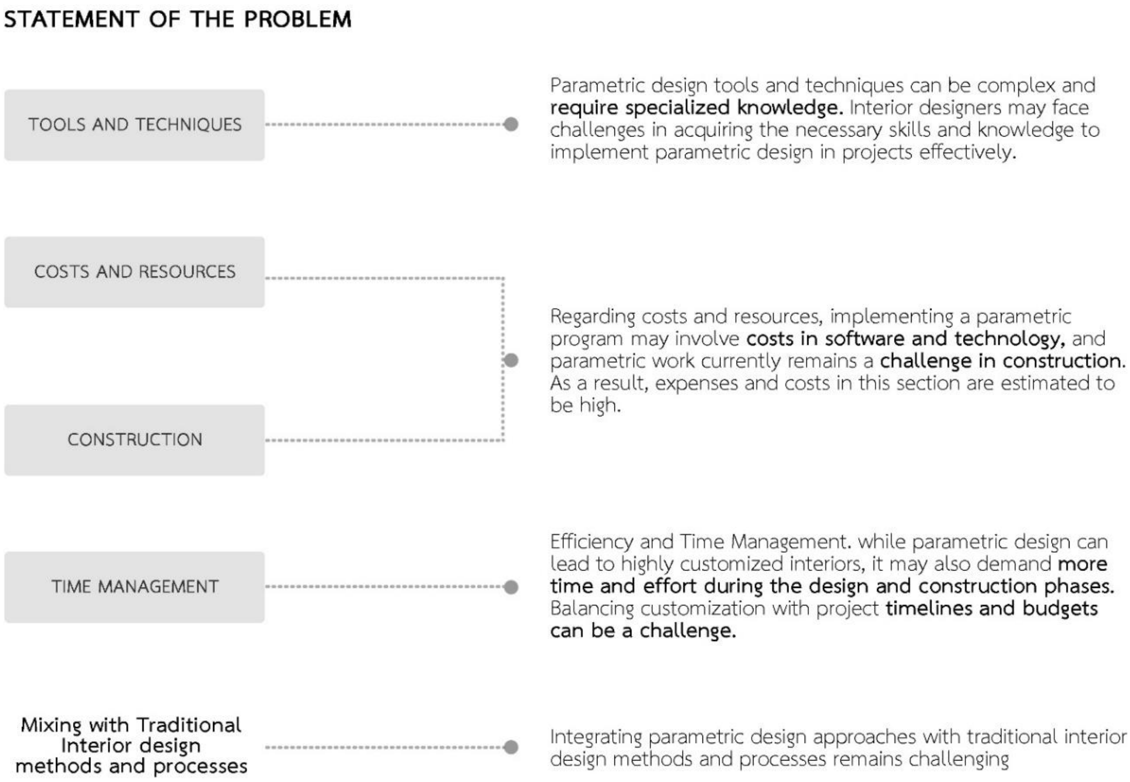

Figure 1 Statement of the problem

1.3 Hypothesis

Nowadays, technology plays an essential role in the calculation and reduction of errors. This makes design in today's time to introduce various technology programs that greatly influence the design field such as architecture, interior design, product design, fashion design and many others. Therefore, when art and design combine mathematics and science, it can help the design work to be accurate, fast and control the work piece effectively.

Designing a script to identify a program capable of addressing furniture design with materials that mitigate structural stresses while maintaining strength is a crucial aspect. This involves thorough examination and experimentation with organic compounds to develop furniture using the parametric design method.

1.4 Objective of the Research

The core objective of this research is to provide a comprehensive set of guidelines and methodologies for people interested in applying parametric applications in furniture and interior design to enable a better understanding of this innovative design approach. This research will transform methods, design processes and new ideas.

The objectives are committed to:

1. Gather the origins and history of parametrics and study parametric design and the construction of algorithms, investigate the principles of parametrics.

2. Create, design and develop algorithmic scripts, especially organic compounds to create patterns or new designs.

3. Create furniture designs based on parametric algorithms. and present furniture and interior design using parametrics, combining science, math and art.

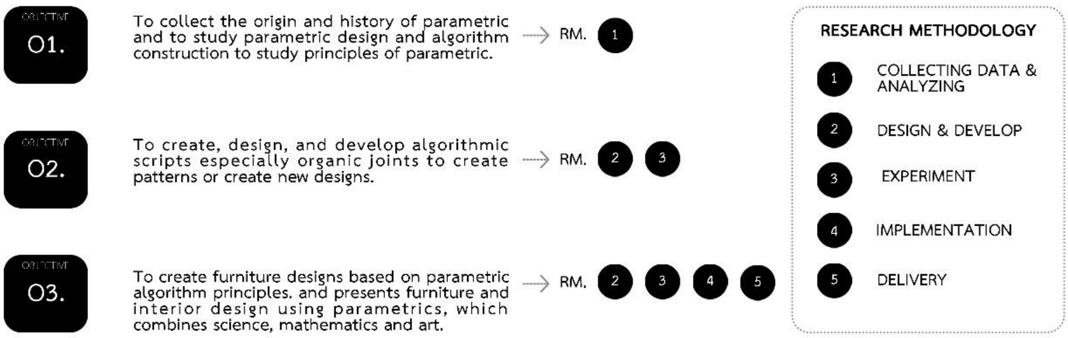

Figure 2 Relationship of objectives to research methods

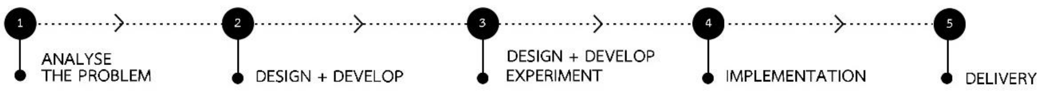

Figure 3 Diagram showing about the process of Research Methodology

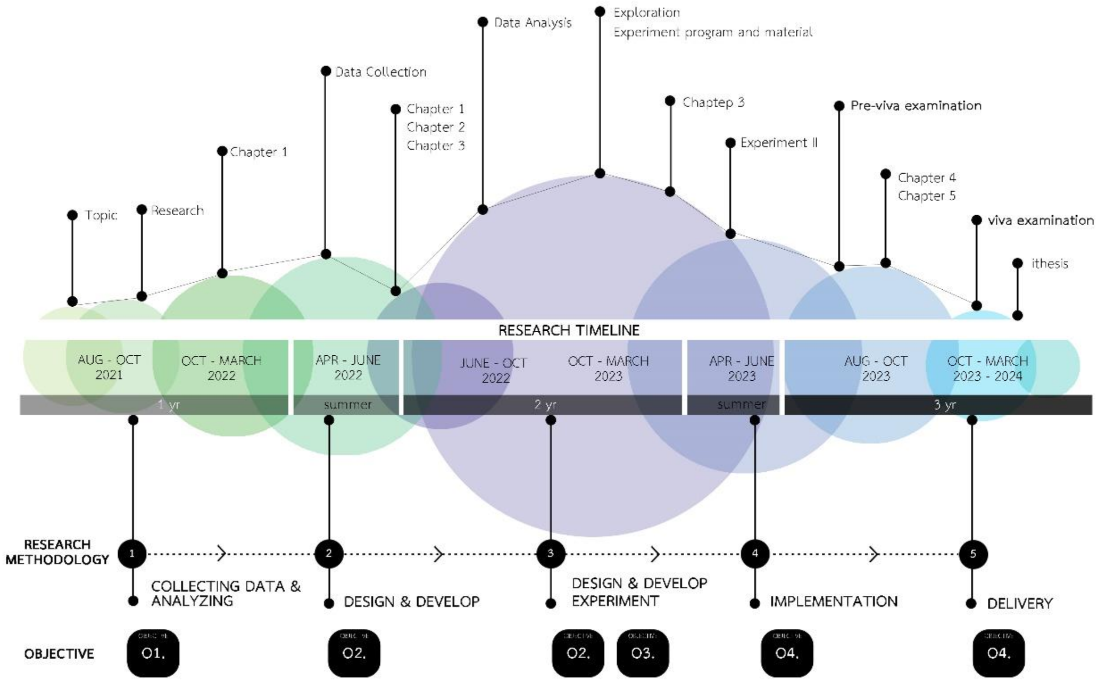

Figure 4 Time period and concept of art design development process

1.5 Scope of Research

1. Examining of the origin, evolution, and development of parametric design.

2. In-depth analysis of the parametric design process to gain a comprehensive understanding of the process and its applicability to furniture design and interior design.

3. Experimental investigation of equations, with particular emphasis on equations relating to natural forms, including the waffle structure, 2D-3D

Voronoi and Organic Joint, for their application in design and production processes.

4. Application examples of parametric design in various fields such as architecture, interior design and furniture design.

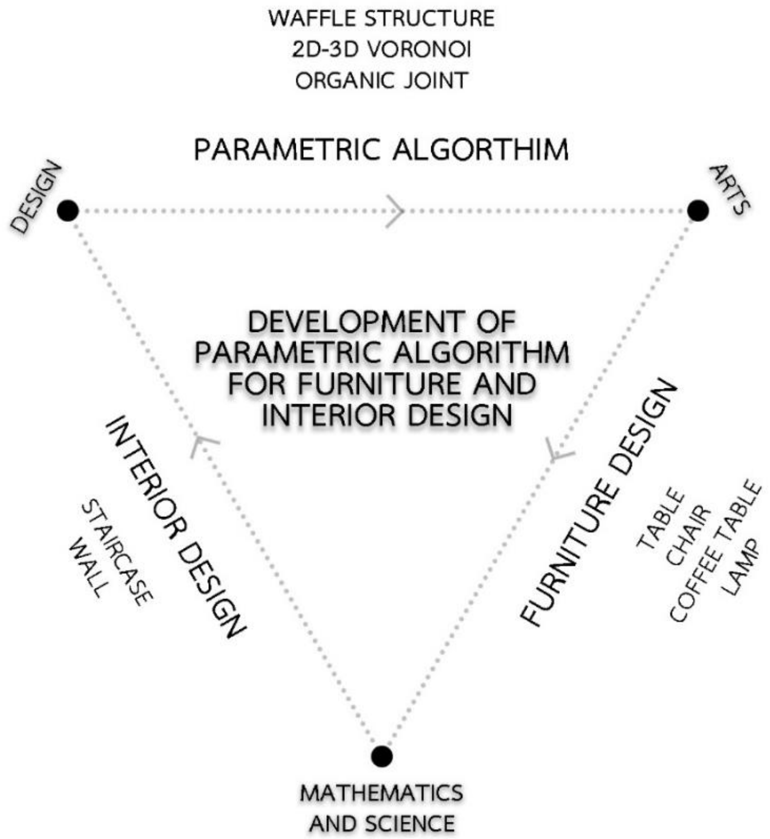

Figure 5 Scope of Research

1.6 Research Framework

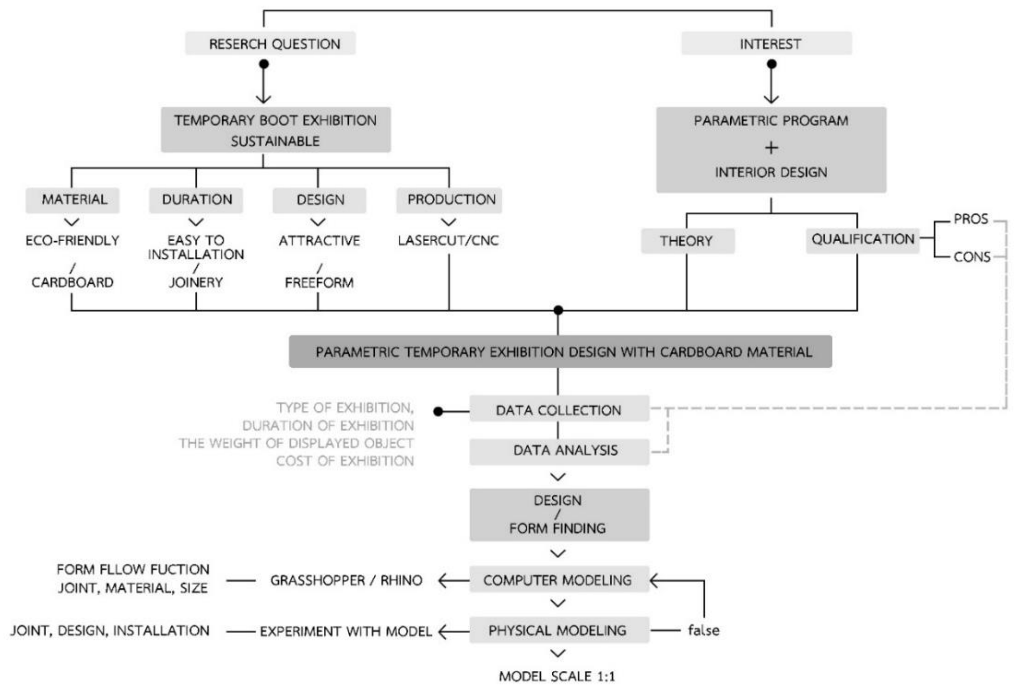

Figure 6 The Process of Research Framework including Problem Statement, Research Objectives, Research Questions, Research Methodology and Research Outcomes

1.7 Conceptual Research

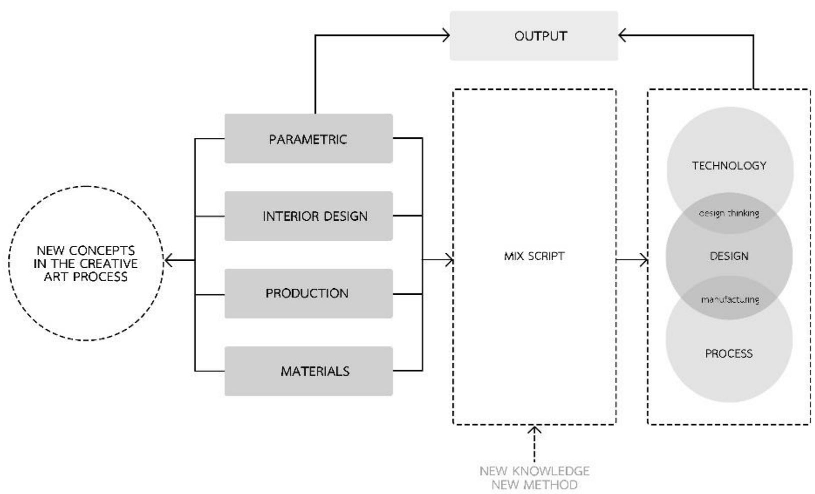

Figure 7 Concept Research

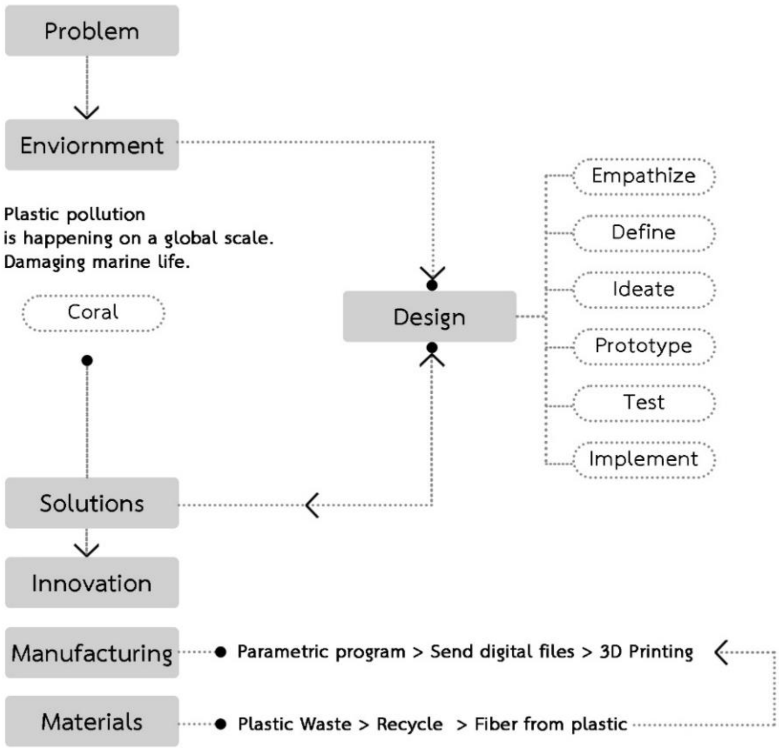

Figure 8 A framework of experimental principles for parametric equations, organic design, and coral concepts

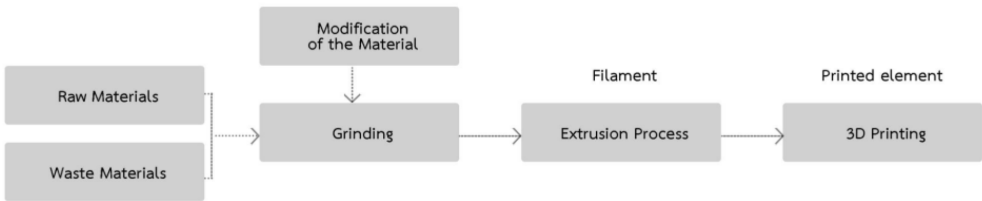

Figure 9 The conceptual process for utilizing waste materials in 3D printing

1.8 Research Methodology / Process

This is practical research with a combination of research objectives. The research investigates and uses parametric techniques to create designs considering conditions, constraints, and production and installation times to gather knowledge that will affect interior design. The second objective is to study and create design equations using parametric programs combined with the materials used to conduct trials and select the appropriate materials.

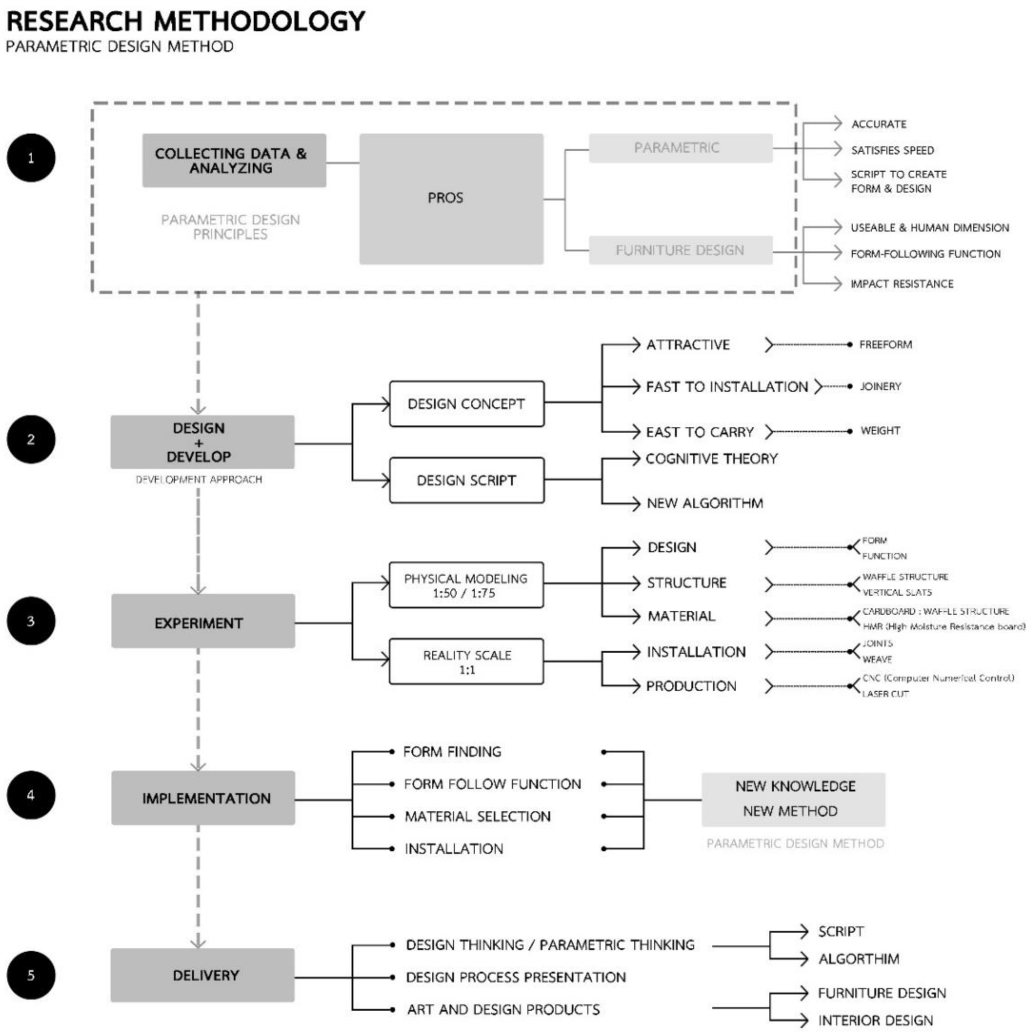

Figure 10 Research Methodology

1.9 Limitation of the Research

This research has limitations regarding tools and techniques, which may be complex and require specialized knowledge, including time and budget for construction or creation of works. At present, this technology is still considered an expensive tool. In the design process or software used, the experimentation process includes a complex production process that requires tools such as CNC, laser cutting, and 3D printing to make the production process possible.

1.10 Research Outcome

The knowledge gained from this research is effective in designing creative works of art that add value through the design process using technological tools. Design works from the design process, problem solving and production process for furniture and interior design using parametric technology techniques that present steps, processes and ideas for creating designs in parametric form. The results of this study will demonstrate an approach to design that allows technology to internationalize art and science in a new way and to share it with those interested in advancing the work in different ways.

<u>The expected benefits are as follows:</u>

1. The knowledge gained from this research is effective in the design of creative artworks and the use of sustainable or reusable materials that add value through the design process using technological tools. The parametric aspect leads to a deep understanding of material, manufacturing and application processes.

2. The design process using parametric technology tools including the production process, which will introduce the concept of saving resources, time and few errors in the installation process.

3. The results of this study will demonstrate a design approach through technology to internationalize art in a new way and share it with those interested in further developing the work based on this research.

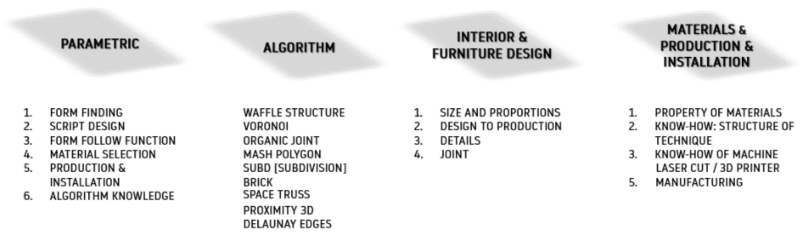

Figure 11 Research outcomes

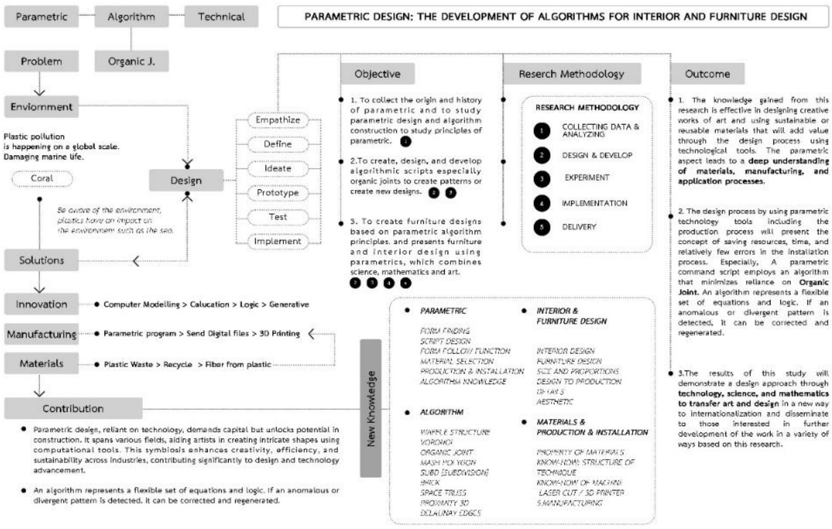

Figure 12 Concept summary diagram

1.11 Definition of Terms

1.11.1 Parametric – Relating to the parameters of something (= a set of facts or a fixed boundary that defines or limits how something can or must happen or be done). Design principles with different proportions controlled by algorithms or series equations.

1.11.2 Algorithm - a step-by-step set of instructions or rules for solving a particular problem or performing a particular task in a finite number of steps, often used in computer science and mathematics.

1.11.3 Generative design - a design approach in which algorithms and computer software are used to automatically generate and explore a variety of design solutions. It uses predefined parameters and rules to create innovative and optimized designs based on specific criteria or objectives, often leading to highly efficient and creative outcomes.

1.12 The relationship between research objective (RO), research question (RQ), research methodology (RM), research outcome (ROC)

Table 1 Relationship between Problem Statement, Research Objectives, Research Questions, Research Methodology and Research Outcomes.

TITLE	PARAMETRIC DESIGN: THE DEVELOPMENT OF ALGORITHMS FOR INTERIOR AND FURNITURE		
FRAMEWORKS OF TITLE	SUBJECT OF THE RESEARCH	PARAMETRIC DESIGN	
	SETTING:	ALGORITHMS	
	VARIABLE OF THE RESEARCH	INTERIOR AND FURNITURE	
PROBLEM STATEMENTS	PROBLEM STATEMENTS	PROBLEM STATEMENTS	PROBLEM STATEMENTS
Parametric design tools and techniques can be complex and require specialized knowledge.	Using the parametric programs in construction is associated with software and technical costs, and implementation remains a challenge.	Adapting the parametric design to a project's schedule and budget is a challenge that affects efficiency and time management.	Balancing between the parametric design and traditional methods in interior design is a challenge for collaboration.
RESEARCH OBJECTIVES	RESEARCH OBJECTIVES	RESEARCH OBJECTIVES	RESEARCH OBJECTIVES
To collect the origin and history of parametrics, study parametric design and construction of algorithms and study the principles of parametrics.	To create design and develop algorithmic scripts, especially organic compounds, to create patterns or new designs.	To present guidelines and conceptual frameworks for using parametrics in design work.	To create furniture designs based on parametric algorithms. and presents furniture and interior design using parametrics, which combines science, mathematics, and art.
RESEARCH QUESTIONS	RESEARCH QUESTIONS	RESEARCH QUESTIONS	RESEARCH QUESTIONS

- What were the early applications of parametric methods and how did they develop? - How has technology, especially computer technology, influenced the historical course of parametric design?	- How are the input parameters for the parametric study selected and validated? - What restrictions and limitations should be considered in the parametric analysis? - What are the pioneering projects that have contributed significantly to the development of parametric design?	- How are the results validated and compared with traditional research methods? - What impact do the results of parametric research have on the broader field or industry? - How has the adoption of parametric design evolved in different fields?	- How transferable are the results to real-life applications or practical scenarios? - Are there possibilities to refine or extend the parametric model for future studies? - what challenges or points of criticism were identified in its application?
RESEARCH METHODOLOGY	RESEARCH METHODOLOGY	RESEARCH METHODOLOGY	RESEARCH METHODOLOGY
- Qualitative Research - Historical Research - Literature Review	- Qualitative Research - Field Study	- Design Thinking - Design Process - Computational Thinking	- Computational Experiments - Experimental
RESEARCH OUTCOME	RESEARCH OUTCOME	RESEARCH OUTCOME	RESEARCH OUTCOME
The knowledge gained from this research is effective in designing creative works of art.	Design work from selecting sustainable or reusable materials through the design process using parametric technology tools.	The results of this study show a design approach through technology to transfer art into internationalization in a new way.	Parametric design offers a distinctive approach to customizing interiors and furniture, where elements can be carefully tailored to specific functional requirements and spatial constraints.

Chapter 2
Literature Review

2. Literature Review

In this chapter, the researcher reviewed the discussions on parametric design in the design fields. The literature review addresses three critical areas: The origin of parametric design, the parametric design process to better understand the entire process and how it can be effectively applied to furniture and interior design, and the application of parametric design: examples and insights. This research focuses on design development through the application of parametric algorithms in both interior architecture and furniture design. The literature review is divided into six parts, as follows;

2.1 History and Background

2.1.1 The analog parametric mechanism used by Antonio Gaudi.

2.1.2 Frei Otto's minimal surfaces derived from soap films.

2.1.3 Luigi Moretti

2.3 Theory

2.2.1 Definition of Parametric Design

2.2.2 Basic Principle of Parametric Design

2.2.3 Organic Joint (SUB-D)

2.2.3 Advantage

2.2.4 Disadvantage

2.3 Parametric in Design Fields

2.3.1 Architecture

2.3.2 Interior Design

2.3.3 Product Design

2.3.4 Fashion Design

2.4 Technique

2.4.1 Laser Cutting Machine

2.4.2 CNC: Computer Numerical Control

2.4.3 3D printing

2.5 Case studies

2.5.1 Interior Design

2.5.2 Furniture Design

2.5.3 Furniture Design

2.5.4 Product Design

2.5.5 Fashion Design: Iris Van Herpen's 3D-Printed Dresses

2.6 Summary

2.1 History and Background

Parametric design is a design method in which features (e.g. building elements and technical components) are shaped according to algorithmic processes, in contrast to direct design. In this method, parameters and rules figure out the relationship between design intent and design response. (Jabi, 2013) The term parametric refers to the input parameters that are fed into the algorithms. (Woodbury, 2010) While today the term refers to the use of computer algorithms in design, there are precedents in the work of architects. Antoni Gaudí used a mechanical model for architectural design (see analog model). He attached weights to a system of strings to determine the shapes of parts of buildings, such as arches (Frazer, 2016).

The term parametric is deeply rooted in mathematics, also in design and architecture. Furthermore, parameters and rules determine the relationship between design intent and response (Jabi, 2013). This definition emphasizes two important criteria: 1. A parametric equation expresses a set of quantities that represent multiple parameters. 2. The outcomes (quantities) were related to the parameters by explicit functions. This point was later discussed as some contemporary architects believed that compositional relationships represented parametric relationships. In parametric equations, quantities are explicitly expressed as functions of independent variables, known as parameters (Weisstein, 2003). The historical development of parametric understanding can be traced back to the nineteenth century, initially inspired by the crystal drawings of James Dana. Dana used the term parametric precisely in its original mathematical meaning, including parallelism, intersections and planes. Over time, this concept evolved, spanning epochs and reaching its peak in the twenty-first century through the influence of Gaudí, Moretti and Schumacher. The first representation of geometry using parametric equations was completed in the 19th century.

2.1.1 The analog parametric mechanism used by Antonio Gaudi

Antonio Gaudi ingeniously designed architecture using parametric and hyperbolic curves. Antonio Gaudi also used analog systems to design complex structures through parametric experiments. A significant example is the church of Colonia Guell, known for its analog model, which ingeniously features an inverted structure. Antoni Gaudi showed a brilliant application of analog parametric mechanisms by using a system of strings weighted with birdshot. This inventive mechanism facilitated the construction of interconnected arches and vaulted ceilings by pulling weights in an inverted tension-based model. The inverted structural model was used to efficiently distribute dead loads within a complex system. Gaudi placed a mirror at the base of the model to visualize the architectural forms as he manipulated the load distribution, adding a reflective touch.

The use of parametric equations can be seen in many architectural aspects of Gaudi's designs, particularly evident in the use of the hanging chain model (Burry, 2011). Antoni Gaudi further used a mechanical (analogical) model for architectural design by attaching strings with weights to determine the shapes for building features, such as arches (Frazer, 2016). Gaudi designed architecture with parametric catenaries and hyperbolic curves for the first time. This was the beginning of a transformative approach that still resonates in the architectural landscape today. The analogy method proposed by Gaudi incorporates the key features of a parametric computational model, including input parameters, equation and output:

The independent input parameters are the length of the string, the weight of the bird shot and the position of the anchor point. The vertices of the points on the strings represent the result of the model. The results are derived by explicit functions, in particular by concepts such as gravity or Newton's law of motion. Gaudi skilfully produced different model versions by modifying their parameters, resulting in structures defined by pure compression. Instead of manually calculating the results of the parametric equations, Gaudi automatically derived the shape of the catenary curves by the force of gravity acting on the strings. (Davis, 2013)

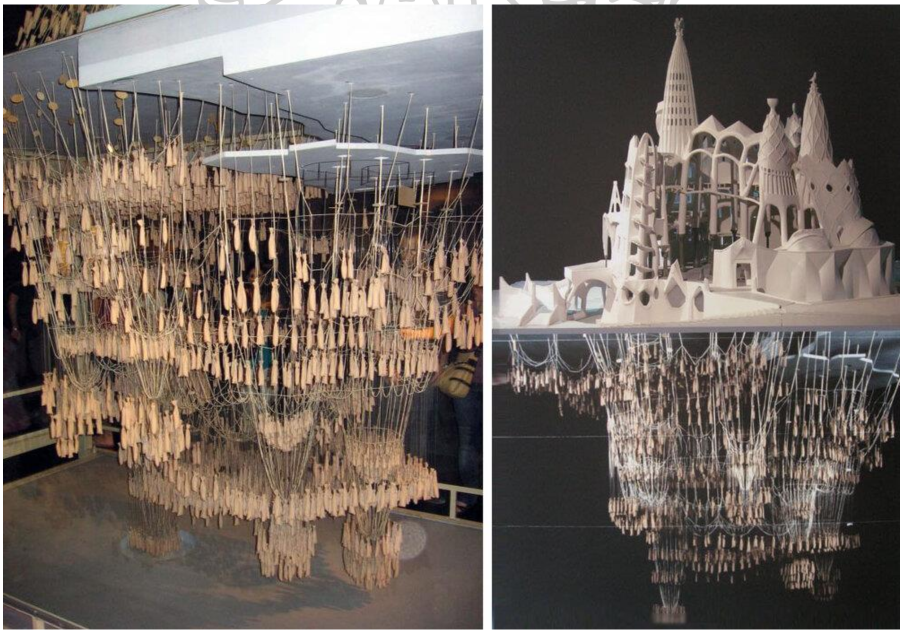

Figure 13 The analog parametric mechanism used by Antonio Gaudi to design the Church of Colonia Guell (Left) and a model showing the final design. (Right)

Source: https://www.researchgate.net/figure/An-upside-down-force-model-of-the-Colonia-Gueell_fig1_318103333

Figure 14 Church of Colonia Guell.

Source: https://www.viator.com/en-MY/Barcelona-attractions/Colonia-Guell-and-Gaudi-Crypt/d562-a15660

2.1.1.1 Casa Batlló

Figure 15 Casa Batlló.

Source:https://en.wikipedia.org/wiki/Casa_Batll%C3%B3#/media/File:Casa_Batllo_Overview_Barcelona_Spain_cut.jpg

Figure 16 Noble floor of Casa Batlló.

Source:https://en.wikipedia.org/wiki/Casa_Batll%C3%B3#/media/File:CasaBatll%C3%B3_NobleFloor_saloon_side.jpg

2.1.1.2 Casa Milà (La Pedrera) (Barcelona, Spain - 1906-1912)

Figure 17 Façade close-up of Casa Milà.

Source: https://www.barcelona.de/en/barcelona-casa-mila-pedrera.html

2.1.1.3 Sagrada Família

Figure 18 The Basílica i Temple Expiatori de la Sagrada Família, by Antonio Gaudi

Source: https://www.archdaily.com/438992/ad-classics-la-sagrada-familia-antoni-gaudi

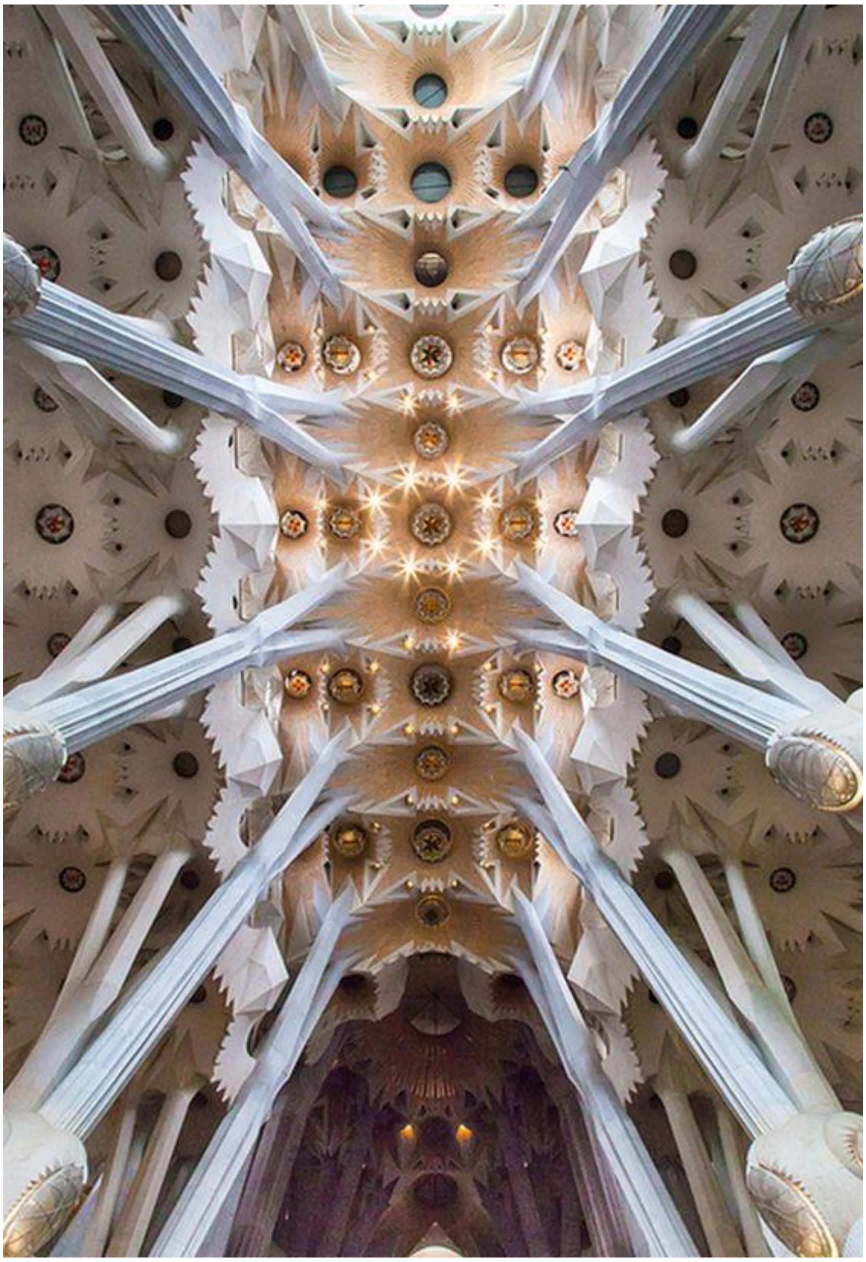

Figure 19 Celling design in la Sagrada Família.

Source: https://www.archdaily.com/438992/ad-classics-la-sagrada-familia-antoni-gaudi/5253fa09e8e44eff02000687-ad-classics-la-sagrada-familia-antoni-gaudi-photo

2.1.2 Minimal surfaces derived from soap films by Frei Otto

One of the most important parametric processes is "form-finding"," which consists of comparing a script with a model to find a desired shape or certain constraints. Ultimately, this leads to the final form of a designed object based on these constraints and variables. Another example is Frei Otto, who extended analog computational methods to include minimal surfaces from soap films and paths found through wool dipped in liquid. Frei Otto conducted soap bubble experiments using floating soap films and dipped strings to create perfect circles, resulting in minimal surfaces. This form-finding method is also known as design experimentation. These methods have been revisited by contemporary practices that utilize parametric and algorithmic designs, while the legacy left by Otto has recently undergone further investigation (PETEINARELIS & YIANNOUDES).

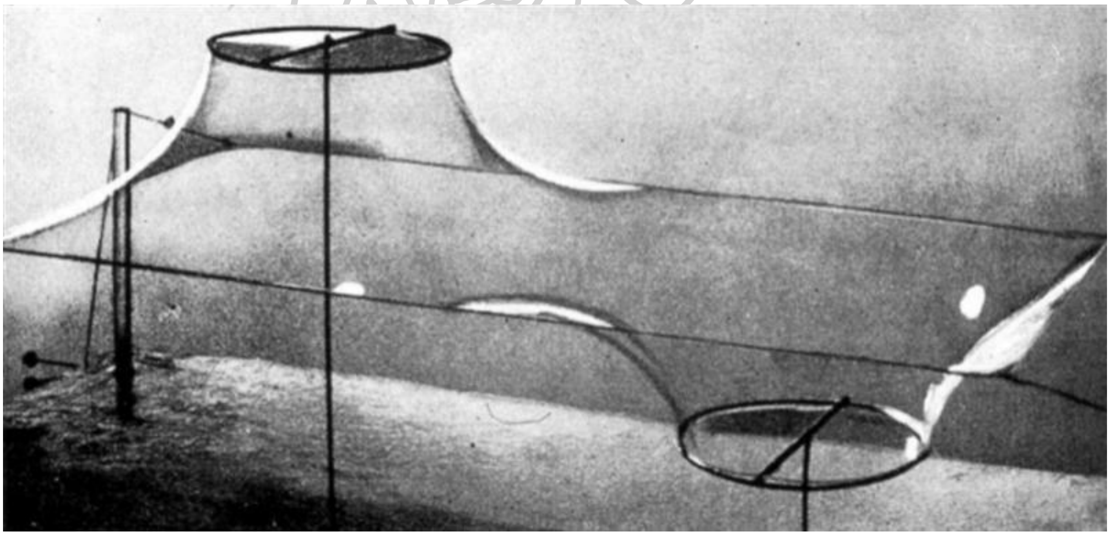

Figure 20 minimal surfaces derived from soap films by Frei Otto.

Source: https://www.researchgate.net/figure/Frei-Otto-Experimenting-with-Soap-Bubbles_fig2_318103333

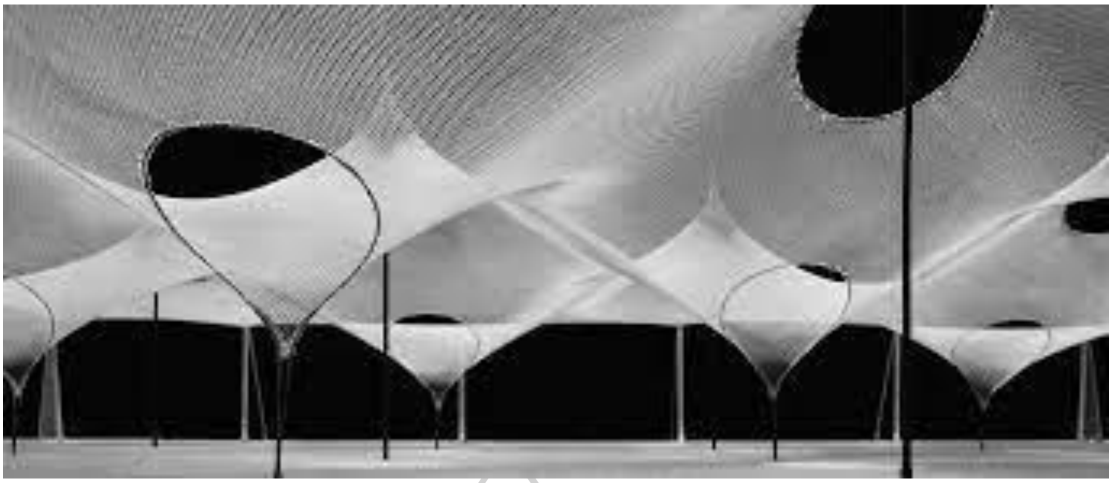

Figure 21 Minimal surfaces derived from soap films by Frei Otto.

Source: https://zkm.de/en/presskit/2016/exhibition-frei-otto-thinking-in-models

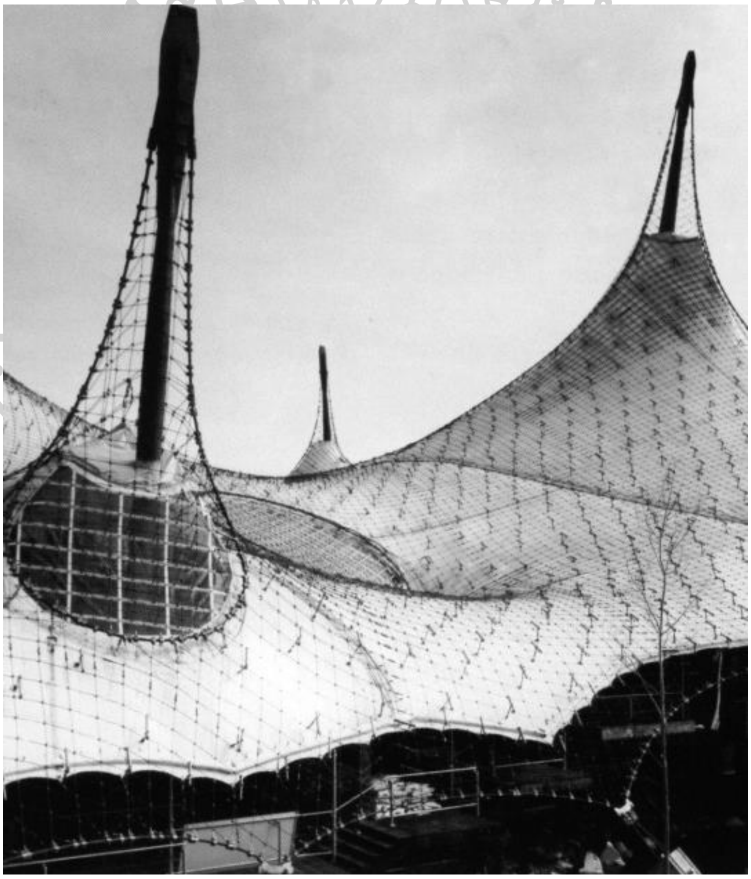

Figure 22 The German Pavilion at the Expo 1967 in Montreal.

Source: https://www.metalocus.es/en/news/frei-otto-german-pavilion-expo-1967#

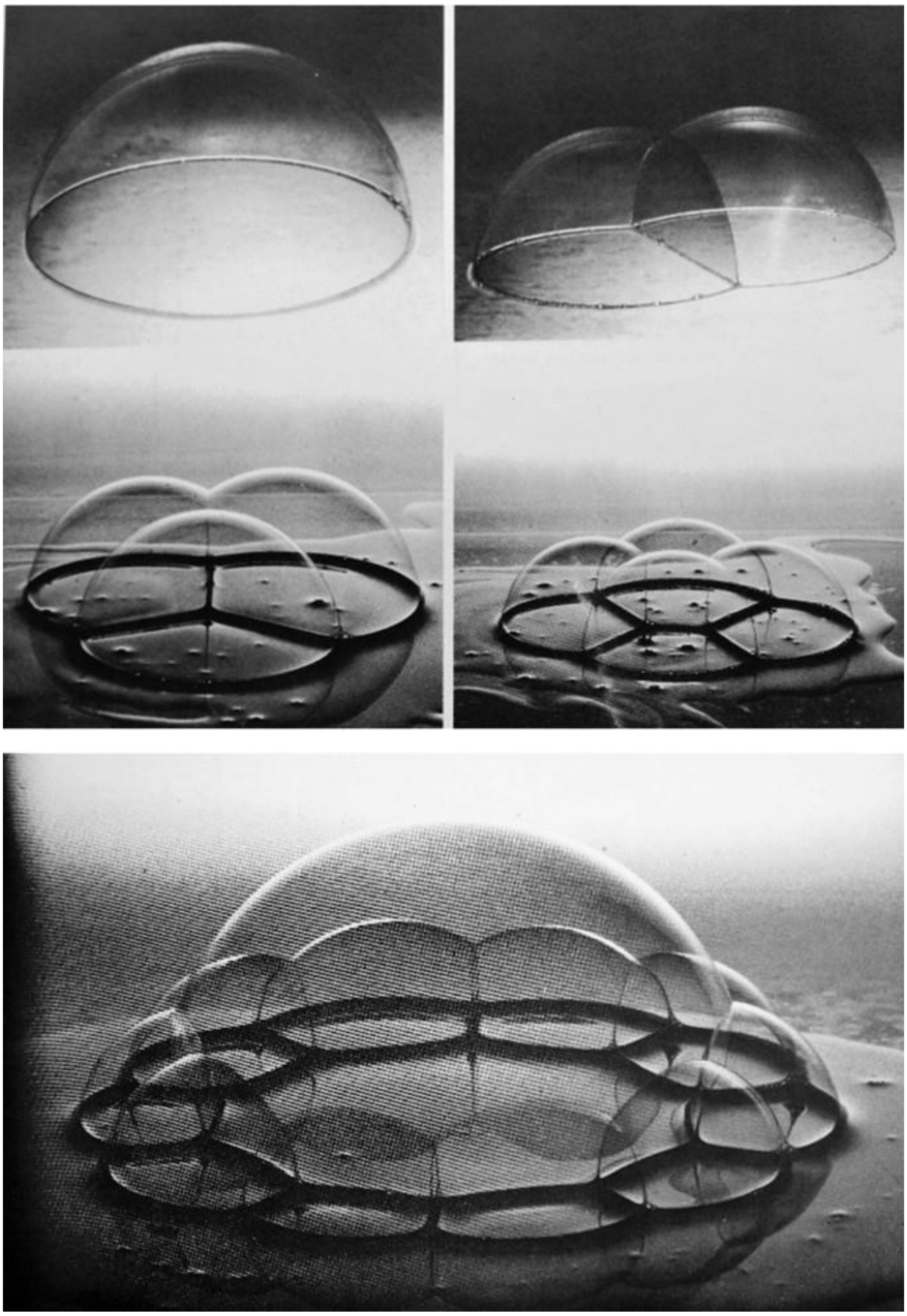

Figure 23 Frei Otto's Experiments with Physical Self-Forming Processes from Soap Solutions.

Source:

https://www.google.com/url?sa=i&url=https%3A%2F%2Flink.springer.com%2Fchapter%2F10.1007%2F978-3-031-33144-2_3&psig=AOvVaw3YPZuCJp7AFqS7u9_E7hcc&ust=1713464781249000&source=images&cd=vfe&opi=89978449&ved=0CBIQjRxqFwoTCMDZue7vyYUDFQAAAAAdAAAAABAE

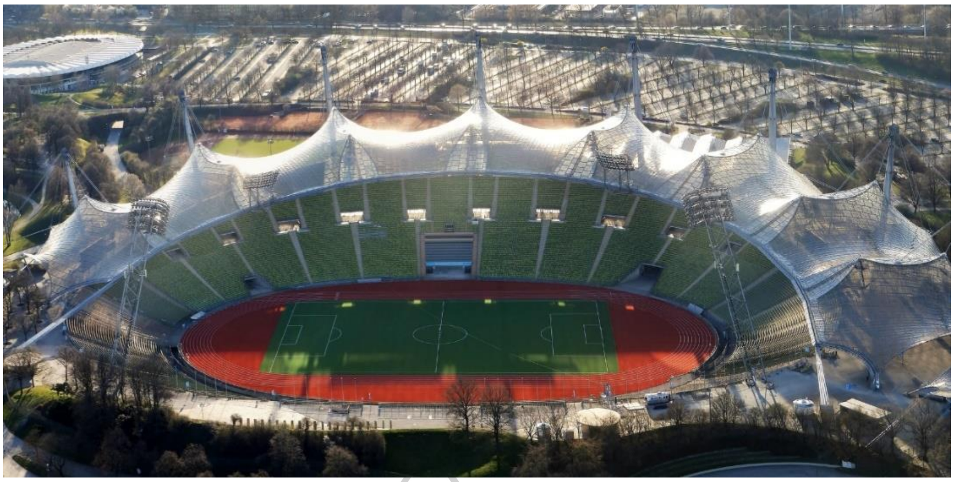

Figure 24 Munich Olympic Stadium Canopy in Munich, Germany, 1972.

Source:

https://www.archdaily.com/109136/ad-classics-munich-olympic-stadium-frei-otto-gunther-behnisch

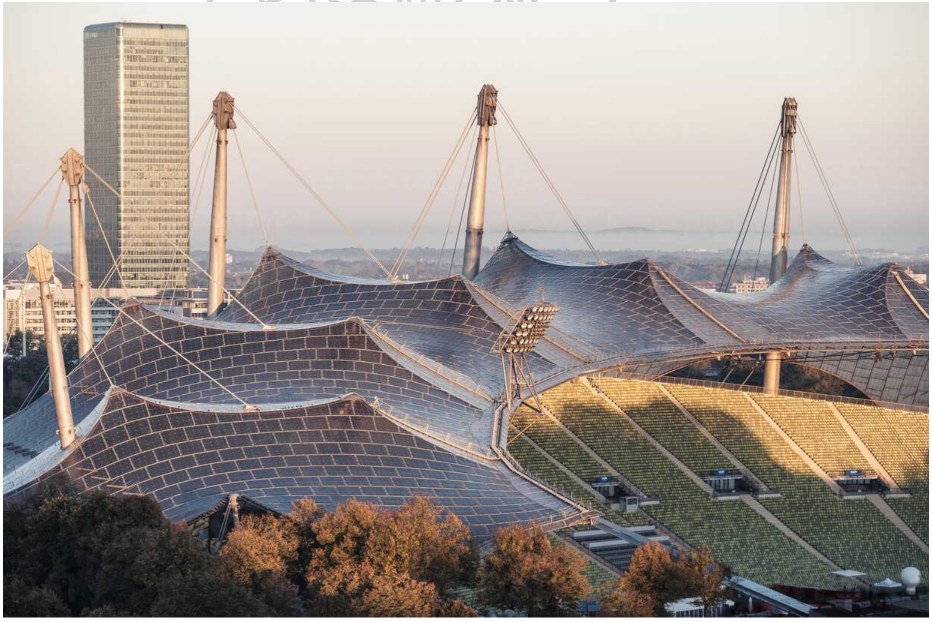

Figure 25 Munich Olympic Stadium Canopy in Munich, Germany, 1972.

Source: https://images.westend61.de/0001162266pw/germany-munich-olympic-park-olympic-stadium-tent-roof-construction-in-the-morning-light-WFF00042.jpg

2.1.3 Luigi Moretti introduced parametric concepts to architecture and art.

In 1940, Luigi Moretti, an Italian architect, introduced parametric concepts to architecture and art. Moretti's work and writings were dedicated to the systematic study of architecture and gained great recognition, especially in Italy. Luigi Moretti defined parametric as describing the relationships between dimensions influenced by various parameters (Moretti et al., 2002). The application of a parametric design was illustrated by the design of a stadium by Moretti, which was exhibited at the twelfth Milan Triennial (Triennale di Milano) in 1960. Luigi Moretti (1971) used this example to show how the shape of the stadium could be derived from nineteen different parameters, including factors such as viewing angle and the economic cost of concrete. In the five years following the exhibition, between 1960 and 1965, Moretti designed the Watergate Complex, believed to be the first major construction job to make significant use of computers (Livingston, 2002).

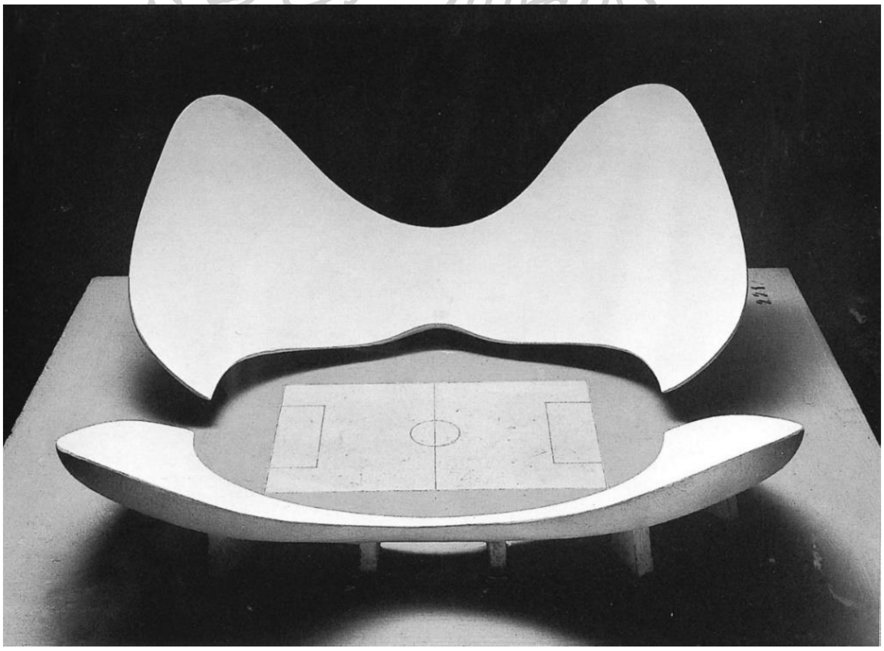

Figure 26 The stadium model by Luigi Moretti.

Source: https://encrypted-tbn0.gstatic.com/images?q=tbn:ANd9GcQaFxxFU6yhdqU5PAeWO7tsj8j4KWAthZOGsm8ImL99PDNDVg4H9dBXRNPWR19o2RTcV34&usqp=CAU

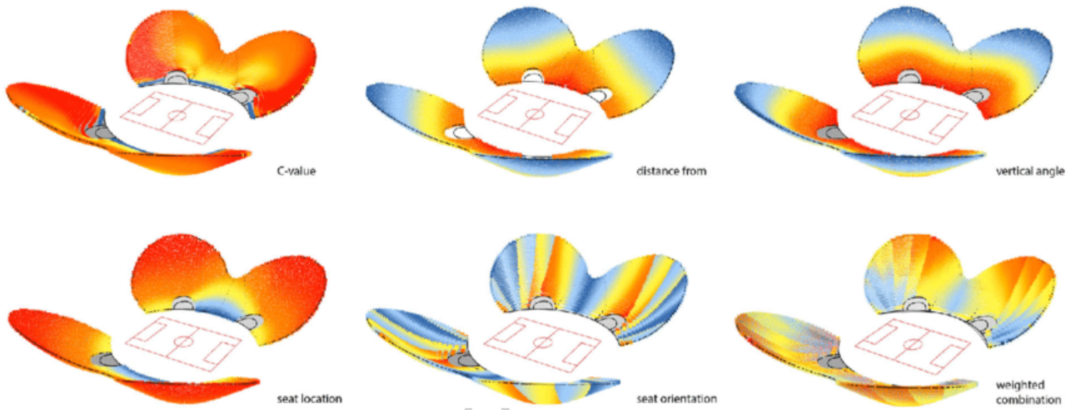

Figure 27 Analysis of Moretti's Stadium with the f-factor approach: C-value, distance from the opposite corner, vertical angle, seat location, seat orientation and a weighted combination of the previous values.

Source: https://www.researchgate.net/figure/Analysis-of-Morettis-Stadium-with-the-f-factor-approach-C-value-distance-from-the_fig8_337298716

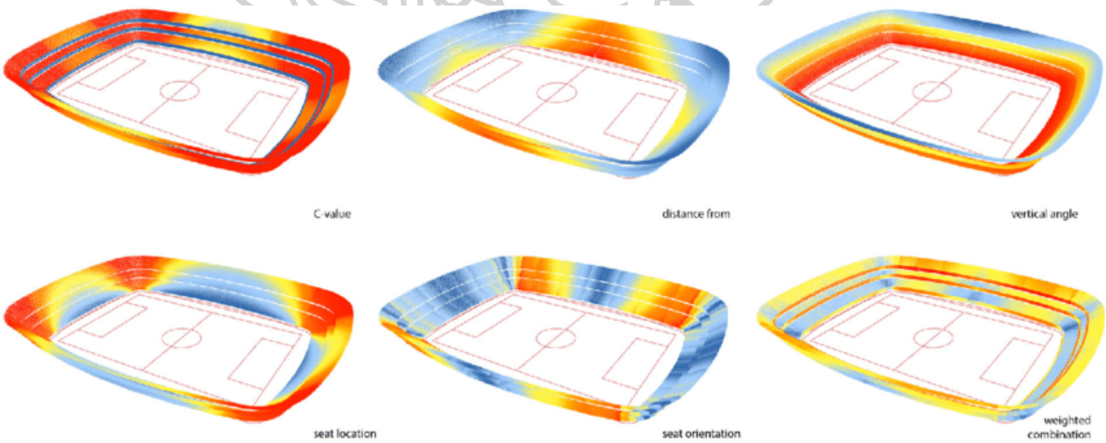

Figure 28 Fi-factor analysis on a typical bowl.

Source: https://www.researchgate.net/figure/Fi-factor-analysis-on-a-typical-bowl-C-value-distance-from-the-opposite-corner_fig5_337298716

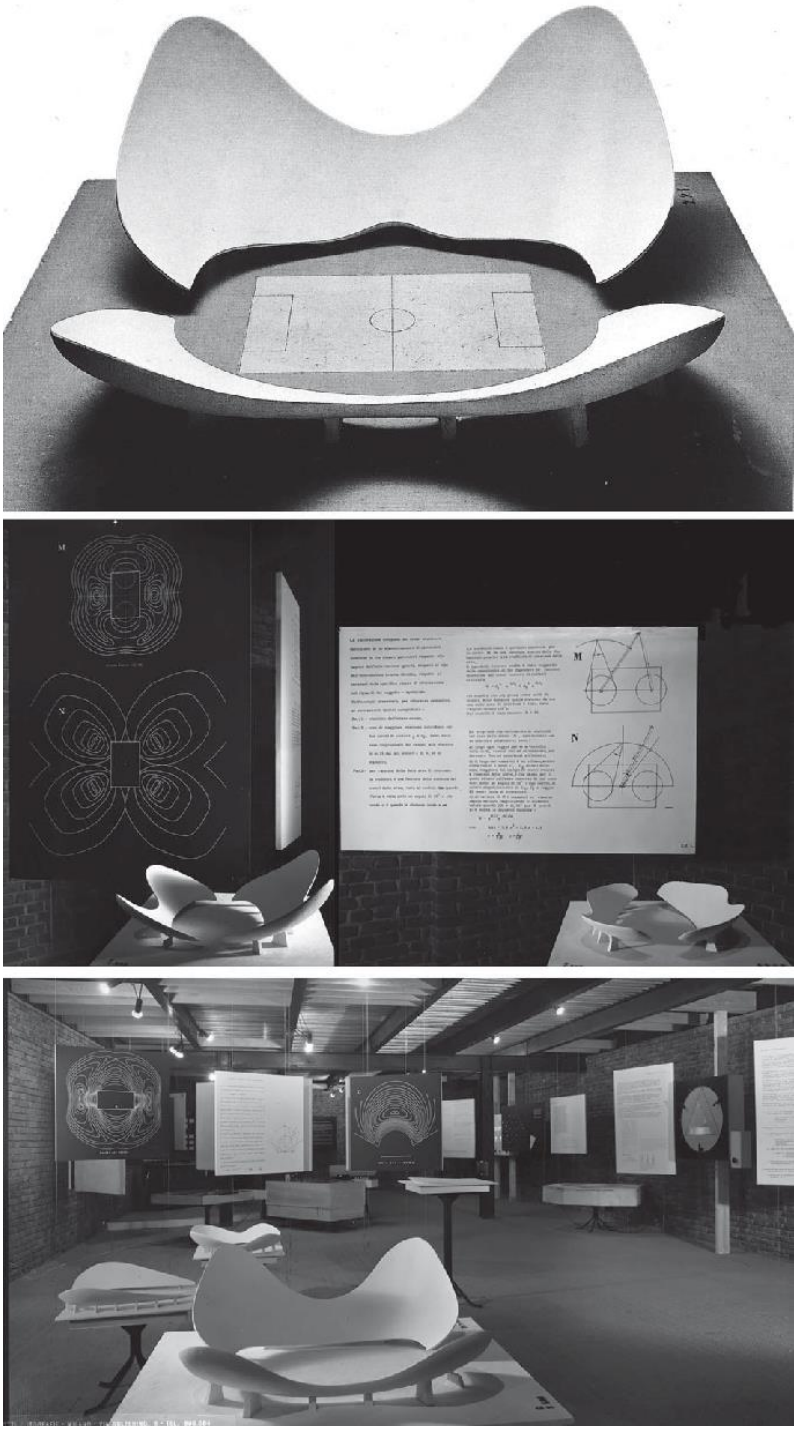

Figure 29 A model of stadium N by Luigi Moretti. Exhibited at the 1960 Parametric Architecture exhibition at the Twelfth Milan Triennial.

Source: https://www.researchgate.net/figure/Luigi-Morettis-models-and-exposition-on-parametric-architecture-during-the-Triennale-di_fig4_337298716

By the year 2000, the availability of computer technology had already had a profound impact on architects and designers. This technological tool allowed them to analyze and simulate mathematical and natural complexities, which was used in practice to create building structures and furniture designs. Parametric programming became popular among designers through understanding and algorithmic thinking, which proved invaluable in solving design problems. A significant turning point occurred in the 1980s when architects and designers began to use computer software originally developed for the aerospace industry to create patterns of movement and, in particular, animated forms (Parametric Design; A Brief History, Stephen Phillips, 2010). It is a term for a class of tools that create or modify design geometry based on non-geometric requirements or constraints on product performance.

This iterative design process consists of a program that generates outputs that conform to certain constraints and a designer that fine-tunes the feasible region by adjusting input values, ranges, and distribution. The process can run in a test environment or involve artificial intelligence, such as a generative adversarial network. The designer also learns to refine the program (usually consists of algorithms) with each iteration as their design goals become better defined over time (Meintjes, 2017). The application of parametric design to industrial goods is to take certain elements that influence product modeling as parameters. The computer software establishes a logical relationship (algorithm) to construct a digital model, effectively yielding a prototype for the product design (Sun & Huang, 2019). It is important to recognize that the digitized computational method differs significantly from the methods used by Antonio Gaudi and Frei Otto. Their methodologies were based on physical laws to calculate parametric equations, a difference from the digitized processes facilitated by today's computer technology.

2.1.4 Zaha Hadid

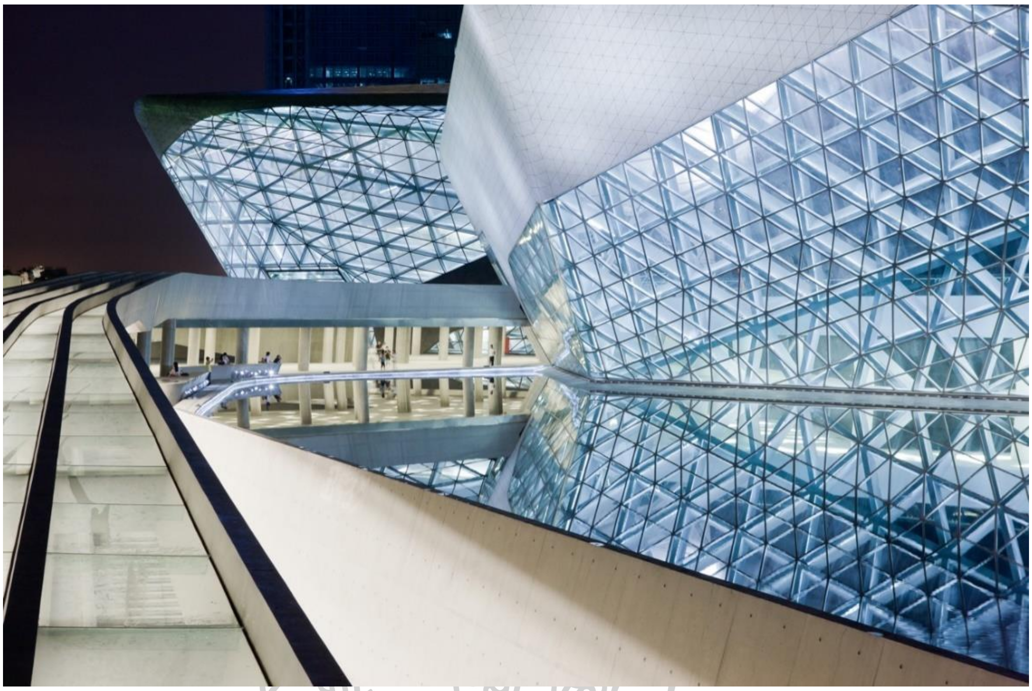

Figure 30 Guangzhou Opera House

Source: Zaha Hadid Architects

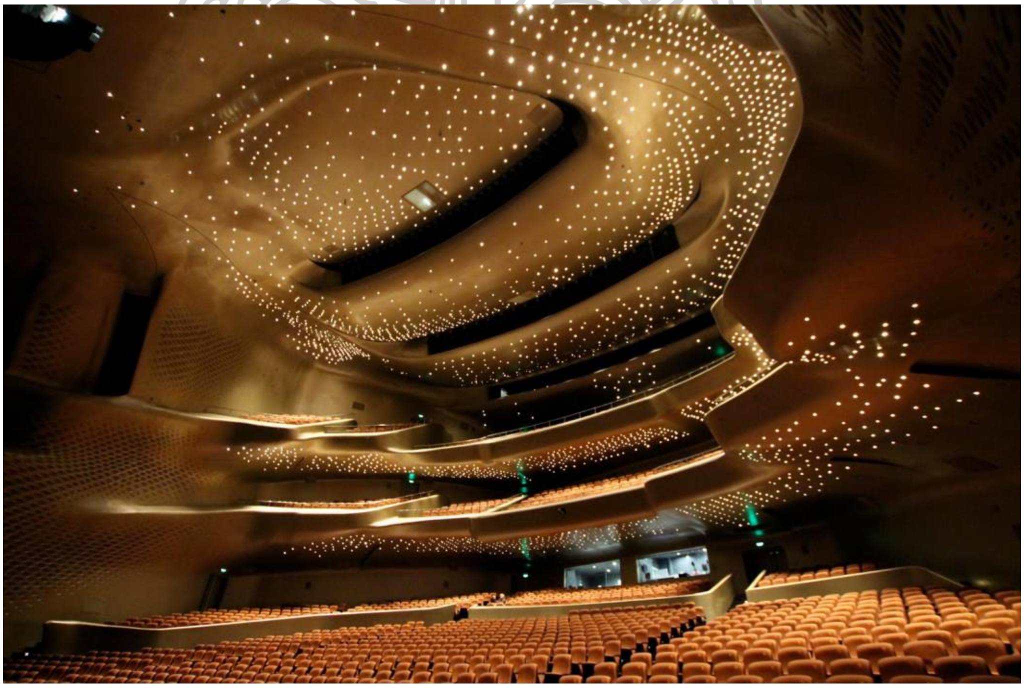

Figure 31 Guangzhou Opera House

Source: Zaha Hadid Architects

2.1.4.1 London Aquatics Centre

Figure 32 **London Aquatics Centre, 2012**

Source: Zaha Hadid Architects

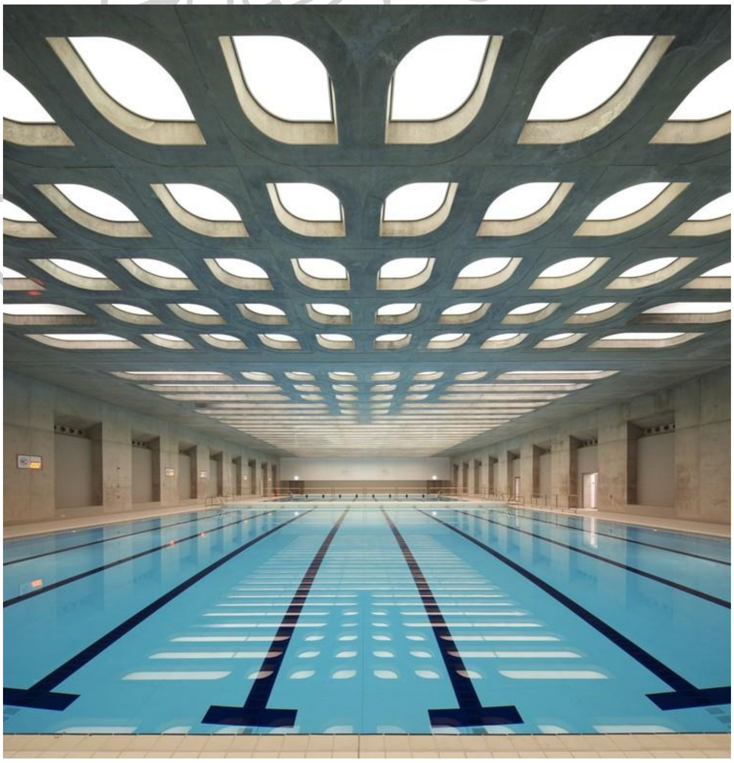

Figure 33 Interior design of **London Aquatics Centre**

Source: Zaha Hadid Architects, photo taken by Helene Binet

2.3 Theory

2.2.1 Definition of Parametric Design

The program command works with mathematical precision to optimize parameter types that can be solved with one or more parameters, such as the Grasshopper plugin in Rhinoceros 3D. This tool shows how mathematical correctness and optimization intertwine to solve multi-parameter scenarios. Grasshopper is a plugin for Rhinoceros3D and provides a visual programming language interface that allows users to create and modify geometries through simulation. In addition, algorithmic design is not the use of computers to design architectural objects. Algorithms allow designers to overcome the limitations of traditional CAD software and 3D modelers to achieve a level of complexity and control that exceeds manual human capabilities (Tedeschi & Wirz, 2014). The results of this research led to conceptual design principles through parametric programs. These scripts and equations provide opportunities for further exploration, especially for those seeking a deeper understanding. They are also a guide for the presentation of designs and artworks that utilize these techniques. The outcome of this knowledge can be applied in the future, presenting a conceptual design that leverages scripting to create shapes using parametric programming. This allows freedom and flexibility to deconstruct and precisely represent the problem with code (Burry, 2011).

2.2.2 Basic of Principle

It is a term for a class of tools that create or modify design geometry based on non-geometric requirements or constraints on product performance. It is an iterative design process in which a program generates a certain number of results that satisfy certain constraints, and a designer fine-tunes the feasible range by selecting certain results or changing input values, ranges and distribution. The designer does not have to be a human, but can be a test program in a test environment or an artificial intelligence, for example a generative adversarial network. The designer learns with each iteration to refine the program (usually with algorithms) as its design goals become better defined over time (Meintjes, 2017).

The main objective of this research is to use a parametric method to assist in the creation and development of furniture patterns, simplifying the design and product development processes in this industry. With the increasing adoption and growing confidence in integrating computer programming, commonly called scripting, its role in the design process has grown in importance (Burry, 2011). Since 2008, parametric design software has introduced transformative capabilities, with numerous firms, including 3dsMax, 3DMaya, Revit and Grasshopper based on Rhinoceros 3D contributing to its development. It is a type of mathematical optimization in which the optimization problem is solved as a function of one or multiple parameters (Gal Tomas, 1995). However, among these options, Grasshopper is the most commonly used software in this field. Grasshopper 3d (originally Explicit History) is a plug-in for Rhinoceros 3D that provides users with a visual programming language interface to create and edit geometry.

This graphical algorithm serves as a parametric modeling tool in conjunction with Rhinoceros. This particular functionality allows users to preview changes to the geometry directly in the Rhinoceros viewport so that the resulting model updates are immediately visible. The parametric design method offers rapid adaptability, application and alterations. It efficiently calculates equal or offset distances between components based on equations. The combined advantage of modeling in Rhinoceros and Grasshopper software is the ability to allow for rapid design changes to achieve accurate and fast results. This dynamic duo effectively creates 3D furniture models with different styles that can be easily customized for different design applications. In the furniture industry, using a parametric method is helpful as it reduces work time and the possibility of errors.

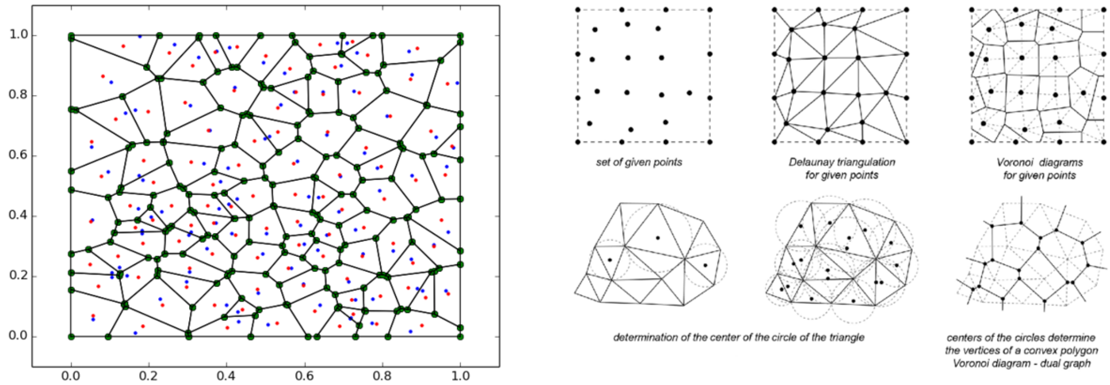

Figure 34 Examples of natural Voronoi cells diagram

Source: https://stackoverflow.com/questions/28665491/getting-a-bounded-polygon-coordinates-from-voronoi-cells

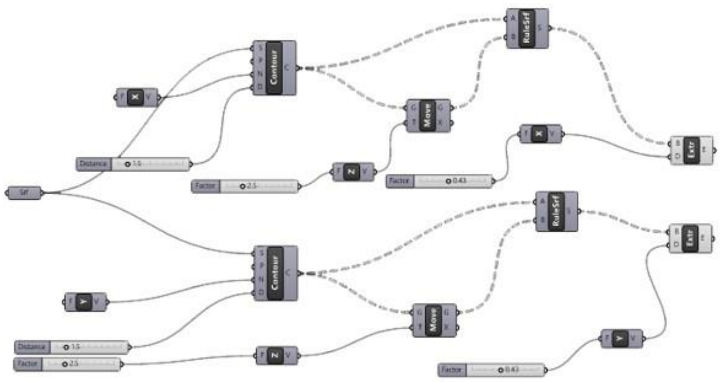

Figure 35 Parametric Algorithm.

2.2.3 Organic Joint (SUB-D)

In Rhino, the term "organic joint" typically refers to a method or technique used to create connections or joints between different components of a 3D model in a more fluid, natural or "organic" way. This methodology often incorporates the use of curves or forms that mimic natural shapes and structures.

In contrast, "Sub-D" stands for Subdivision Surface, a modeling technique used to create smooth and curved surfaces in 3D modeling software such as Rhino. Sub-D surfaces are created by subdividing and smoothing polygonal meshes, resulting in a more pliable and smooth representation of intricate shapes.

In the field of furniture design or any other 3D modeling project, the integration of organic joints and the application of Sub-D techniques can enhance the achievement of esthetically pleasing and realistic outcomes, particularly when replicating natural forms or intricate structures.

2.2.4 Summary

In the field of creative projects, parametric design is characterized by its incomparable flexibility. It allows you to easily modify parameters and make iterative design improvements without having to start from scratch. This adaptability proves particularly beneficial for projects that require constant refinement. The capabilities of parametric design also extend to managing intricate designs and handling numerous variables, making it well-suited for tackling the inherent complexity of modern creative endeavors. The ability to apply changes globally further streamlines the design process, increasing efficiency and precision. Additionally, parametric tools empower designers with the ability to explore and optimize designs based on various criteria such as material usage, cost considerations or structural performance. This capability contributes to the development of designs that are not only esthetically pleasing but also demonstrate functional efficiency.

2.4 Technique

2.4.1 Laser Cutting Machine

Laser cutting is a highly accurate technique applicable across various tasks including engraving, cutting, and stenciling, and it finds utility across a broad spectrum of materials such as wood, metal, and glass. The operation of a laser machine necessitates the creation of Computer-Aided Design (CAD) files in 2D format, meticulously considering material specifications and thickness limitations. Furthermore, a comprehensive study of parameter adjustments such as laser power, speed, and frequency are imperative to enhance cutting efficiency; however, this mandates thorough experimentation and testing to ascertain optimal settings prior to actual cutting. Safety precautions are paramount due to the utilization of high-power lasers and the inherent risk associated with cutting materials through laser evaporation. Establishing a dedicated workspace with proper ventilation to dissipate fumes and mitigate air pollution is essential. Additionally, adherence to stringent personal protective equipment (PPE) protocols and adherence to machine-specific safety guidelines is imperative.

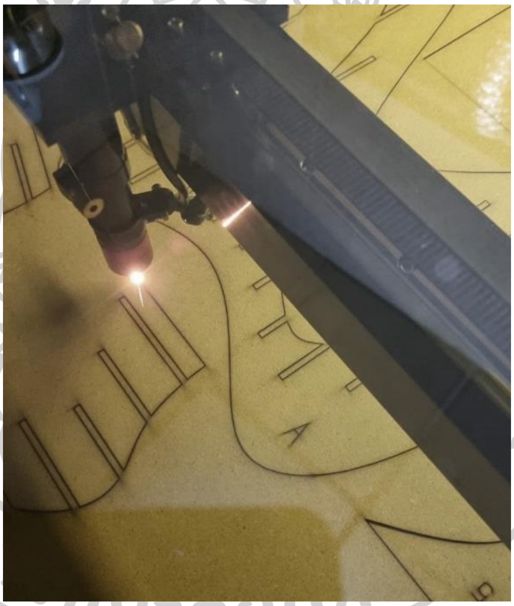

Figure 36 laser cutting machine

Figure 37 laser cutting machine

2.4.2 CNC: Computer Numerical Control

CNC (Computer Numerical Control) techniques involve the automation of machine tools using computers that precisely control their movements. These techniques are extensively applied across various fields, from automotive engineering to woodworking and metal fabrication, facilitating the production of complex components and prototypes with precision and speed. The CNC process initiates with the creation of a digital file using software. A 2D or 3D Computer-Aided Design (CAD) file serves as a blueprint for the desired form. Upon completion of the design process, this digital file is transmitted to a CNC cutting machine. It comprises a set of alphanumeric instructions that specify tool paths and parameters for controlling the CNC machine, which in turn controls the positioning mechanism of the workpiece and ensures precise motion control.

Currently, CNC techniques have gained popularity in interior design circles, prized for their precision and speed in installation processes. Custom furniture design, for example, can be efficiently designed and executed via CNC machines, allowing for quick assembly with significantly less dust at the construction site compared to traditional processes that involve on-site lumber cutting and assembly. Additionally, CNC machines have the capability to carve complex patterns and textures into various materials, enhancing the visual interest of walls or partitions. Key considerations when utilizing a CNC cutting machine include the selection of tools, cutting speed, feed rate, and material properties. Regarding safety, it is crucial to operate within a specifically designed room that is well-ventilated and secure.

Overall, CNC cutting machines are invaluable tools that enable designers to rapidly prototype their designs, pushing the boundaries of creativity with enhanced precision in the manufacturing process.

2.4.3 3D printing

The use of 3D printers represents a revolutionary technology that creates three-dimensional objects from digital files, and it has gained significant popularity across various industries. Fields such as product design, medical devices, automotive, architecture, interior design, art, and fashion all benefit from the numerous advantages of 3D printing. This technology enables designers, engineers, and scientists to rapidly produce prototypes and facilitates iterative design processes, allowing for swift adjustments based on real-world testing. The ability to create complex shapes introduces new challenges and pushes the limits of production processes.

In the realms of architecture and interior design, professionals can create components that are not only aesthetically unique but also functionally specific, such as bespoke furniture hinges and joints. As the popularity of 3D printers continues to grow, these devices prove to be versatile tools that meet the demands of many professional fields, enhancing both creativity and functionality.

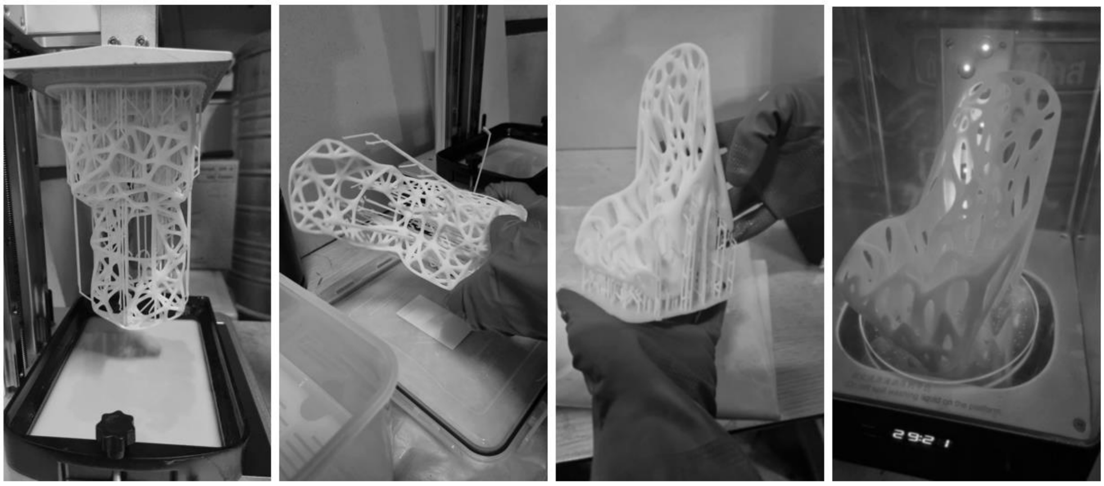

Figure 38 3D printers

2.5 Case studies

2.5.1 Interior Design: The Heydar Aliyev Center

The Heydar Aliyev Center in Baku, Azerbaijan, was designed by Zaha Hadid Architects. The Heydar Aliyev Center in Baku, Azerbaijan, was designed by Zaha Hadid

Architects following a competition in 2007. Using parametric tools, the architects meticulously studied the surface geometry to create a coherent relationship that allows the building to blend seamlessly with the surrounding landscape. This emphasis on continuity and dynamic geometric forms demonstrates the potential that parametric design offers in architectural practice. It also considers practical construction challenges such as fabrication, handling, transportation and assembly. The design process considers various dynamic factors, including movement due to deflection, external loads, temperature fluctuations, seismic activity and wind-induced forces. This comprehensive approach ensures that the architectural work embodies esthetic and conceptual brilliance and blends seamlessly with real-world structural requirements.

Figure 39 **Heydar Aliyev Center**

Source: Zaha Hadid Architects, photo taken by Iwan Baan

Figure 40 Heydar Aliyev Center, Zaha Hadid Architects

Source: photo taken by Alex Cheban

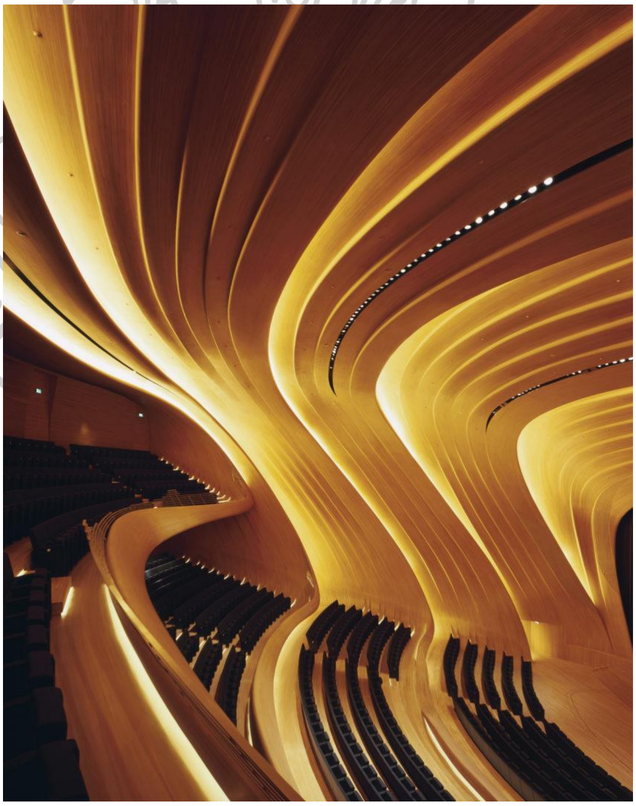

Figure 41 Heydar Aliyev Center

Source: Zaha Hadid Architects, photo taken by Helene Binet

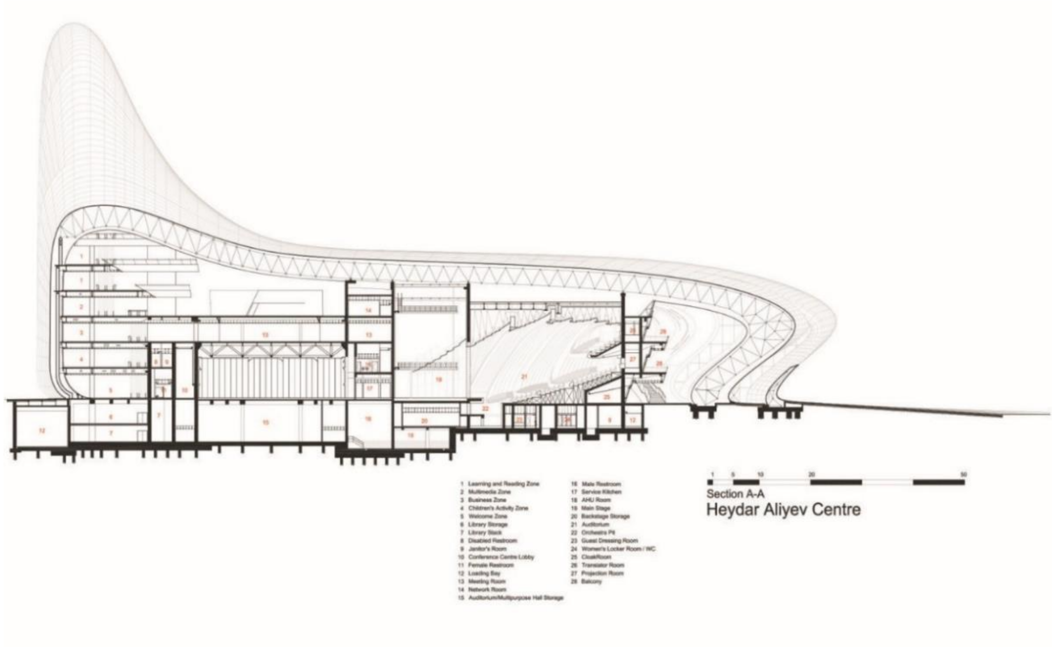

Figure 42 Heydar Aliyev Center Section

Source: Zaha Hadid Architects

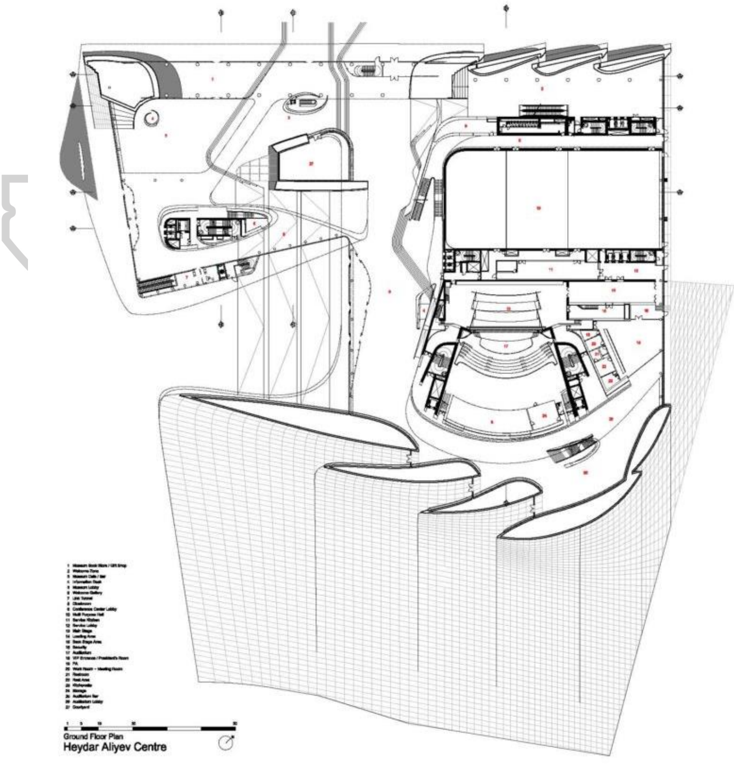

Figure 43 Ground floor plan of Heydar Aliyev Center

Source: Zaha Hadid Architects

2.5.2 Furniture Design: Generico chair

Example of parametric furniture design. Marco Hemmerling, Ulrich Nether and Philipp Meise designed the Generico chair. Their design approach involved the use of computer algorithms and FEM software analysis to turn this vision into reality. A special feature of the Generico chair is its flexible backrest, which is designed to support the weight while allowing for a significant reduction in volume when needed. What makes this design special is the strategic incorporation of advanced algorithms into the computational process, allowing the software to use its expertise to realize specific design goals. Beyond the volume reduction, the Generico chair has an ergonomic shape that prioritizes seating comfort. The generative form-finding process takes into account structural efficiency, material properties, ergonomic requirements and production processes. Parametric concepts were used from the beginning of the entire design through to the production process. As an indication of the ever-evolving technological landscape, 3D printing is a viable approach to producing chairs with this topological equation.

Figure 44 Parametric furniture design, Generico chair
Source: Generico chair by Marco Hemmerling, Ulrich Nether, Philipp Meise, 2014

2.5.4 Product Design

Parametric design has gained considerable popularity in product design due to its ability to enable designers to create models that meet specific needs, thereby optimizing the end product. By adjusting fundamental parameters, designers can alter the size or other features of a model, which then automatically updates to reflect changes based on new specifications or real-time adjustments by the designer. Additionally, the use of parametric concepts in product design allows for the optimization of properties to enhance product performance. For instance, the Adidas Futurecraft 4D shoe employs parametric design alongside digital light synthesis technology to produce a sole that is not only lightweight and comfortable but also optimized for stability.

Figure 45 Parametric footwear design, ADIDAS ALPHAEDGE 4D
Source: ADIDAS, ALPHAEDGE 4D, 2018

2.5.5 Fashion Design: Iris Van Herpen's 3D-Printed Dresses

Parametric concepts in fashion design are often combined with advanced manufacturing methods such as 3D printing, laser cutting, and digital knitting. These technologies can directly interpret parametric designs to produce dynamic or repetitive textiles and structures that would otherwise pose challenges in practical fabrication. Parametric advantages include being able to display results quickly and adjust to the wearer's body, or even incorporate textile innovations such as Designers can incorporate sensors and other electronic devices into parametric designs. This has led to the development of smart clot,hing that can change color, movement, form, shape or functionality.

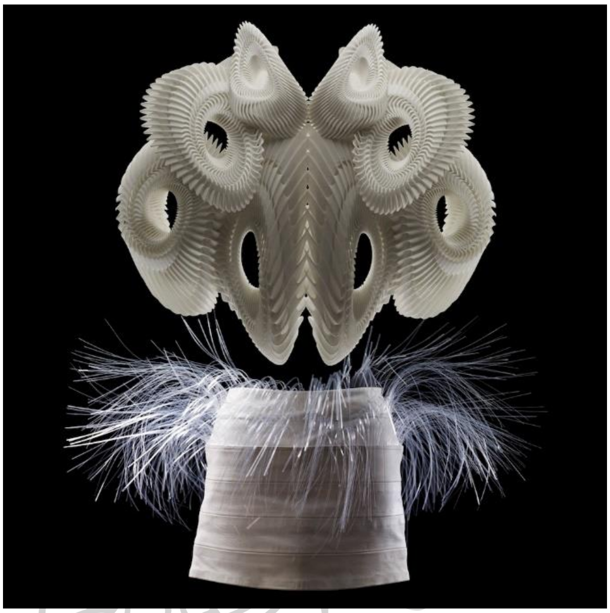

Figure 46 Iris van Herpen: Crystallization, July 2010

Source: Iris van Herpen & Groninger Museum. Photo by Bart Oomes, No 6 Studios.

Figure 47 Iris Van Herpen's Meta Morphism Collection Brings 3d Digital Printing and The Natural World Together with Flair and Bravura

Source: Iris van Herpen

2.6 Summary

Parametric design is widely known in engineering, architecture, design circles, and industries. Architectural design aspects and their dimensions can be considered as parameters, such as location, orientation, shape and solar radiation (Eltaweel & Yuehong, 2017). Furthermore, it also has a positive influence on the development of production technology. Due to the constant creative challenge of parametric programming, designers can create unique and different designs that affect the production process, which requires different tools and technologies to make the work visible, such as the use of CNC machines to assist the workpiece instead of humans, or some designs with complex shapes used in the manufacturing process. Parametric technology is a highly effective way to develop series of products. It can quickly generate various design schemes by creating series of primary parameters and dynamically editable logic programs (Sun & Huang, 2019). Parametric design is constantly evolving and is used in a wide range of design fields. Therefore, this research article focuses on the study of parametric design principles in interior design, especially the design process to the production and installation process, to create a new design method that can be applied to other design works.

In summary, parametric design is design principles with varying proportions controlled by an algorithm or series of equations. It is a design approach where a set of rules, parameters and algorithms are defined to create designs that can adapt, and change based on inputs and variables. In other words, it is a way to create designs that are flexible, adaptable and responsive to evolving conditions.

A visual representation of the parametric creation process, which begins with the creation of a simulation model through computer programming and allows for the manipulation and adjustment of equations. These adjustments account for various factors, including material properties, size variations and connection specifics. The next step is to translate these equations into physical models. These models were created based on the form-finding equations generated through inventive experimentation within the program. The practical implementation of these models is done through 3D printing or laser cutting to complete proof of connection, proper design and installation. The insights gained extends to the selection of suitable materials for furniture construction and the simplification of the production process, including precise installation calculations. This research takes an in-depth exploration of this complex investigation and shows the path from creative idea to tangible production, which is facilitated by the possibilities of a parametric program. The design begins by modifying the digital shape using commands in the parametric program to take into account the size of the furniture, the materials, the structures and the articulation requirements. Once the shape has been modified in 3D modeling, the next step is to create a true-to-life model considering the materials, manufacturing methodologies, and installation techniques.

Chapter 3
Research Methodology

3. Research Methodology

This is practice-bases research with a combination of research objectives. This research investigates and utilizes parametric techniques to create designs considering conditions, limitations, and production and installation times to gather knowledge that will impact interior design. The second objective is to investigate and create design equations using parametric programs combined with the materials used to conduct trials and select the appropriate materials.

All guidelines fall under the framework of a design process that is divided into five steps: Part 1 is collecting data and analyzing parametric design principles. Part 2 is designing and developing equations to simulate shapes using computer models. The third part is an experiment in which a physical model is produced. If the proof is successful, it will be further developed to a size that can be used by humans. The fourth part is the application. In this research, the design process of form-finding, form-following function, material selection and installation process are introduced. Finally, new concepts in geometric design, parametric programming concepts, and a script or equation are provided for further use by those interested. It is also a way to present designs and art products in a new way. Ultimately, the result of this knowledge is a new design approach with a script for creating shapes using parametric programs that can be used in the future and applied to interior design, which must consider the relationship of human use, human behavior and functions, which are also essential factors. The researcher has started to investigate and analyze the feasibility of parametric design, develop it further through research, and to lead the efficiency of parametric and the feasibility of design structure with practical experiments through computer models and physical models to a deeper understanding of this research. With this process and these steps, it is possible to understand the parametric design in depth and apply it to various designs, but it must also consider the use of each design. The process of surveying and collecting data for analysis provides more clarity and clarity in the design process. The design and development part is another important step because the parametric program simulates a three-dimensional model, and the designer can adjust or modify the equations and parameters to achieve the functional proportions or esthetics. The next step is experimentation, which is very important for the assembly or production process, as it involves experimenting with materials and tools that really need to be suitable for the design and production work.

Another valuable result is the script format and algorithm that can be used to create blueprints that are suitable for the design predicted by the designer, blueprints that can be used, selection of materials that are suitable for the design, and installation on the construction site that allows the builder to use the blueprint. Therefore, it is obvious that the parametric design process must consider every step and every challenge to achieve appropriate results in both the thinking, design and manufacturing process.

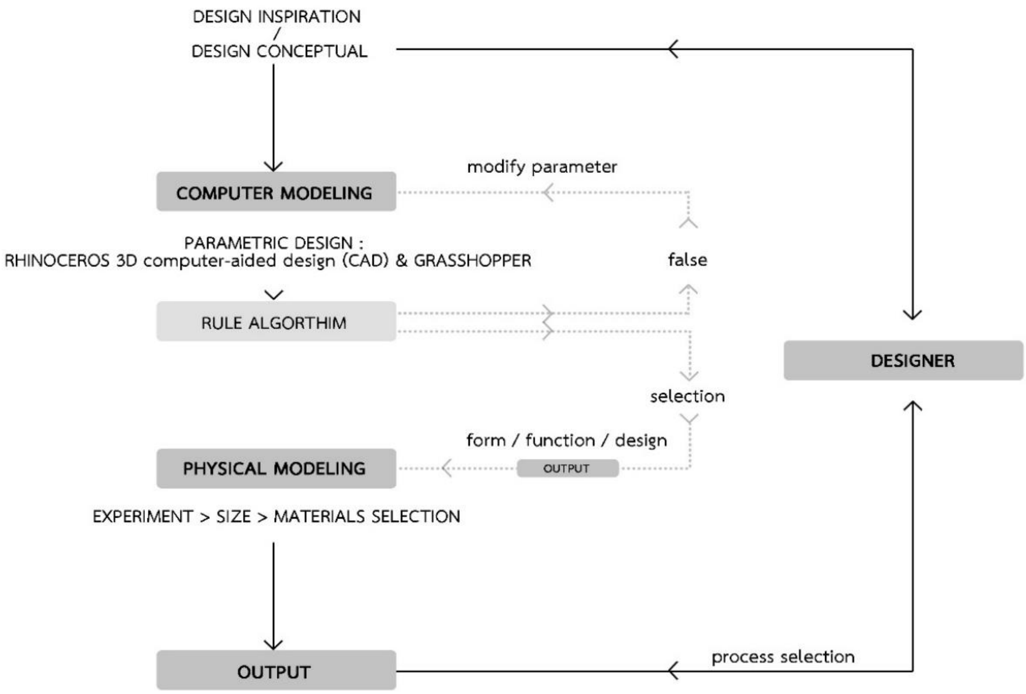

Figure 48 Parametric Design Process

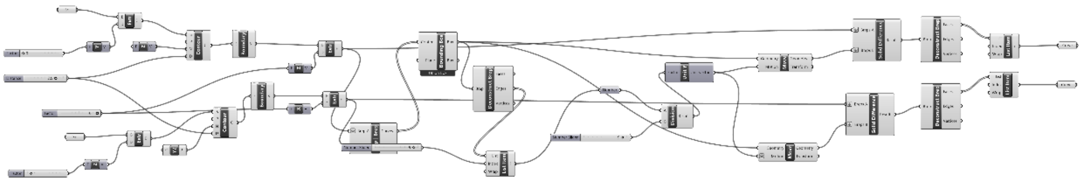

Figure 49 Parametric equation

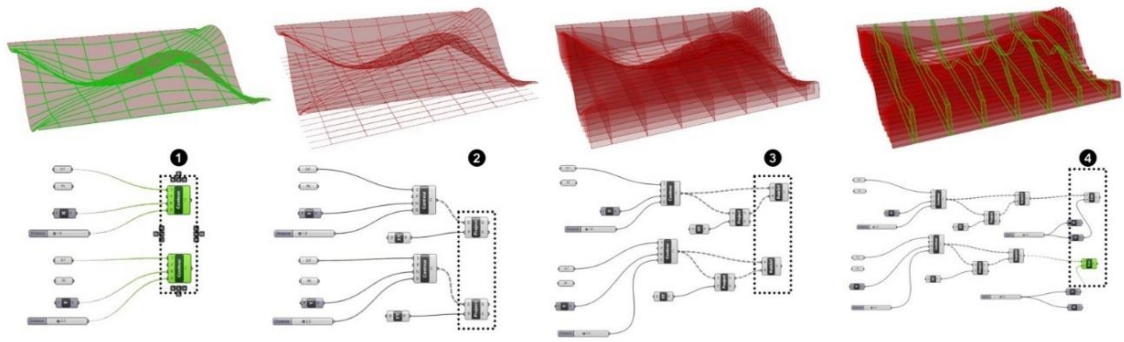

Figure 50 Visual programming language and graphical algorithm editor simulating relation among parameters

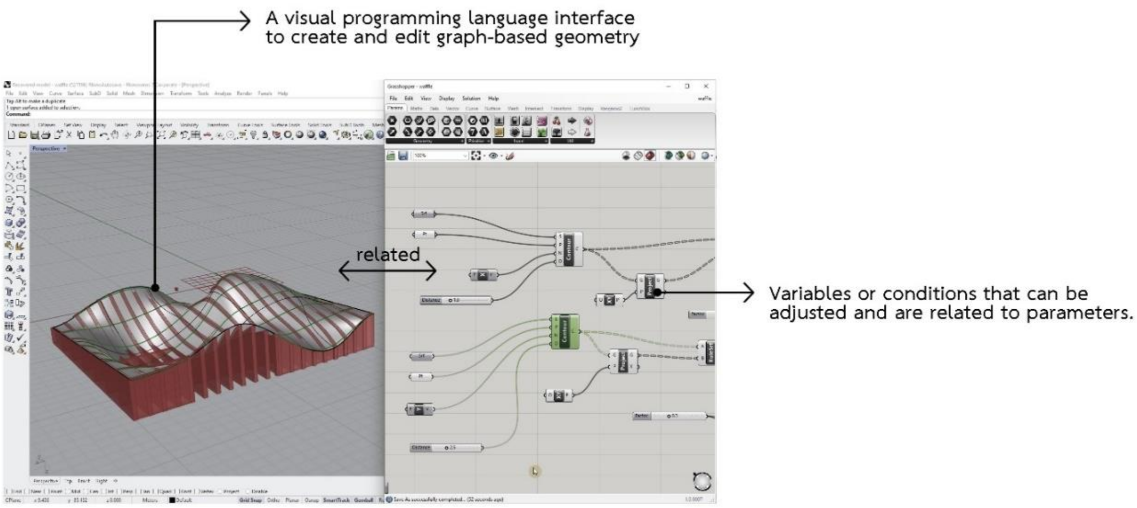

Figure 51 The processing screen and script during designing with parametric programs

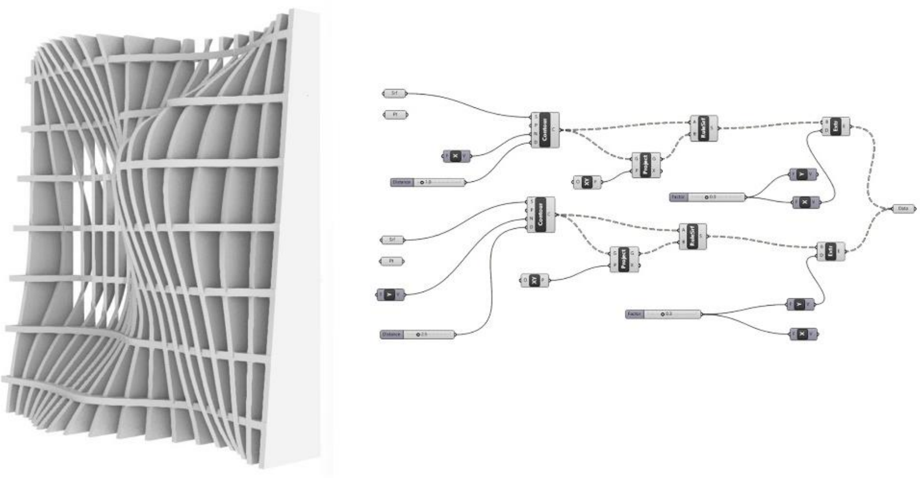

Figure 52 The processing screen and script during designing with parametric programs

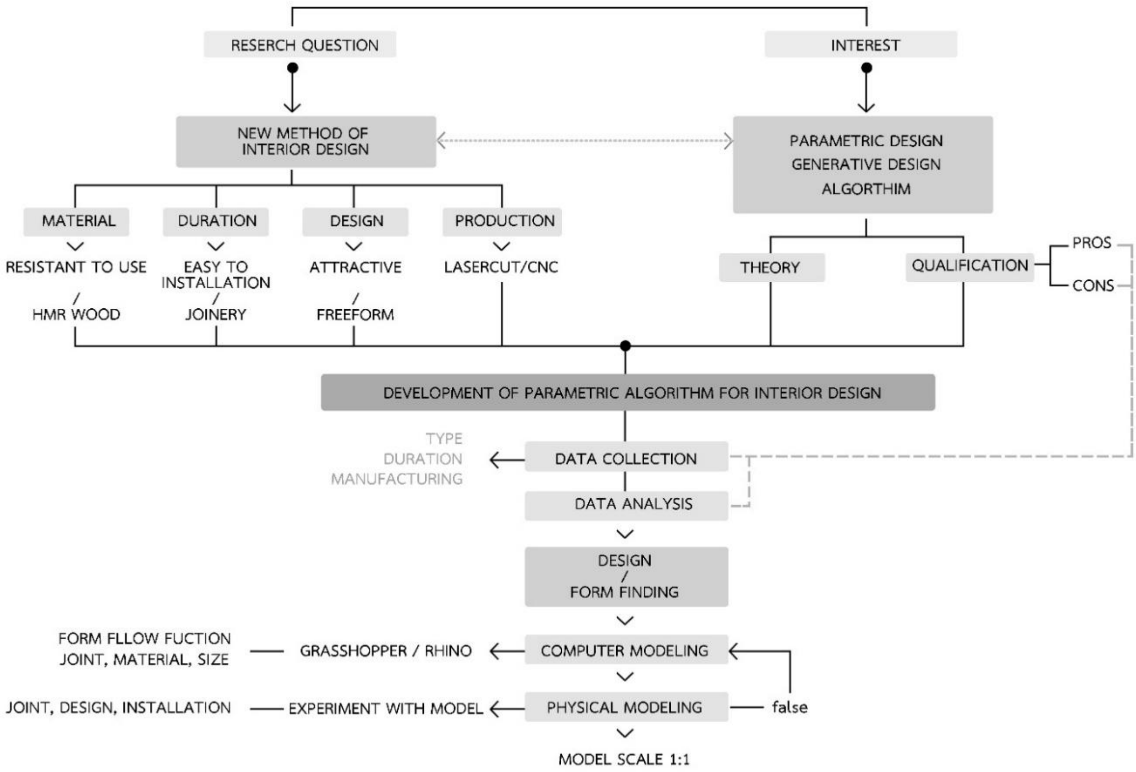

Figure 53 The Process of Research Framework including Problem Statement, Research Objectives, Research Questions, Research Methodology and Research Outcomes

3.1. Qualitative Research

This research is action research that collects information about parametric design and experiments with modeling through a parametric program to have the proper structure and proportions of the interior design, including the materials selected.

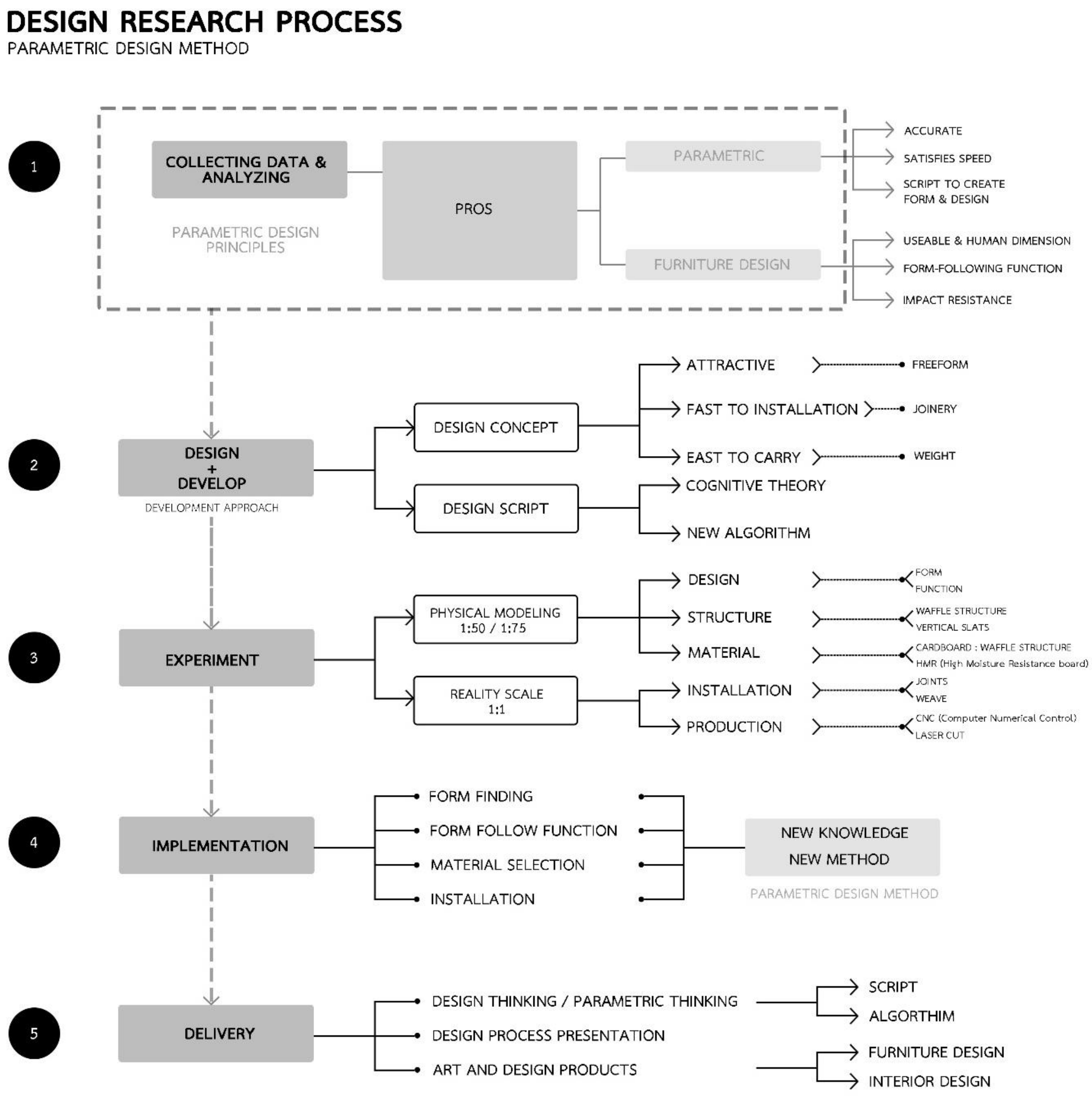

Figure 54 Design Research Process

All guidelines fall within the framework of a design process that is divided into five steps: Part 1 is the collection of data and the analysis of parametric design principles. Part 2 is design and development guidelines that create equations to simulate shapes using computer models. The third part is an experiment in which a physical model is produced. If the proof is successful, it is further developed into a size that can be used by humans. The fourth part is the application. In this research, the design process of form-finding, form-following function, material selection and installation process are introduced. Finally, new concepts in geometric design, parametric programming concepts, and a script or equation are provided for further use by those interested. It is also a way to present designs and art products with designs in a new way. Ultimately, the result of this knowledge is a new design approach with a script for creating shapes using parametric programs that can be used in the future and can be applied to interior design, which must consider the relationship of human use, human behavior, and functions, which are also essential factors.

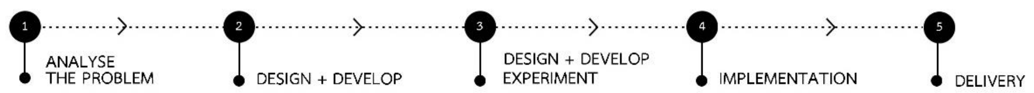

Figure 55 Diagram showing about the process of Research Methodology

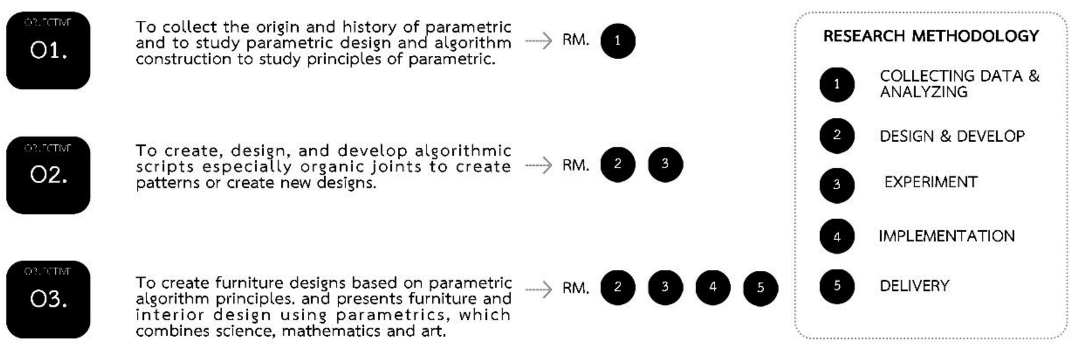

Figure 56 Relationship of objectives to research methods

3.2 Data Collection and Analysis

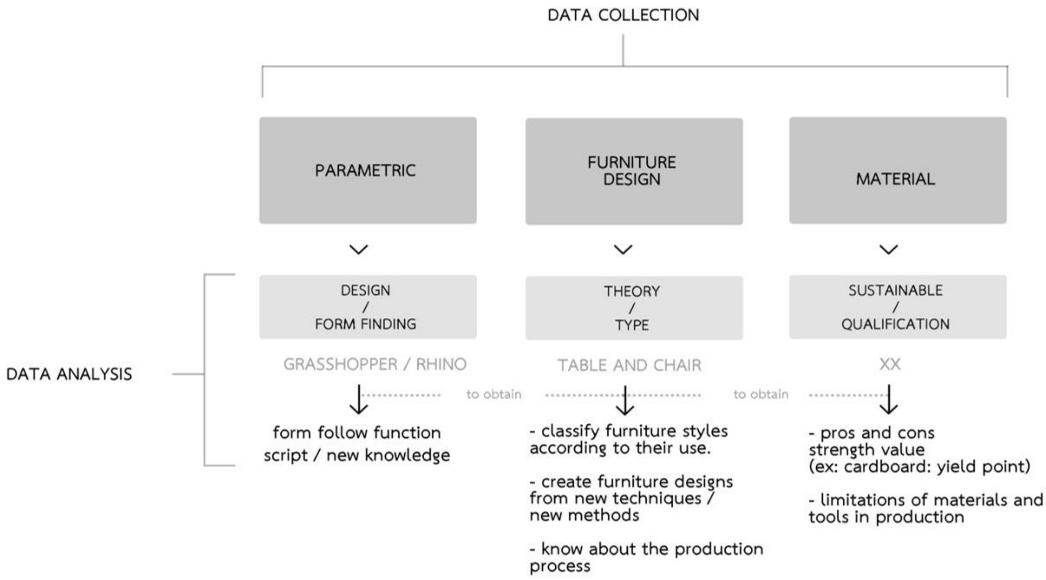

Figure 57 Data Collection and Analysis process

3.3 Conceptual design

From the invention of the concept of art design development process in this practical research, Therefore, it has come in a sequence of steps as follows:

1) Objectives in this research is the research area.

2) Design methods through the search for solutions or directions in design, such as materials conducive to the use and qualified tools used in the research. (Parametric program)

3) The design process is divided into three phases: study and design planning, programmed computer experiments and practical experiments through realistic simulations. Another step is the combination with various environmentally friendly materials.

4) All the results of the design development process are developed into a practical artwork. So, this is another concept of art and design research.

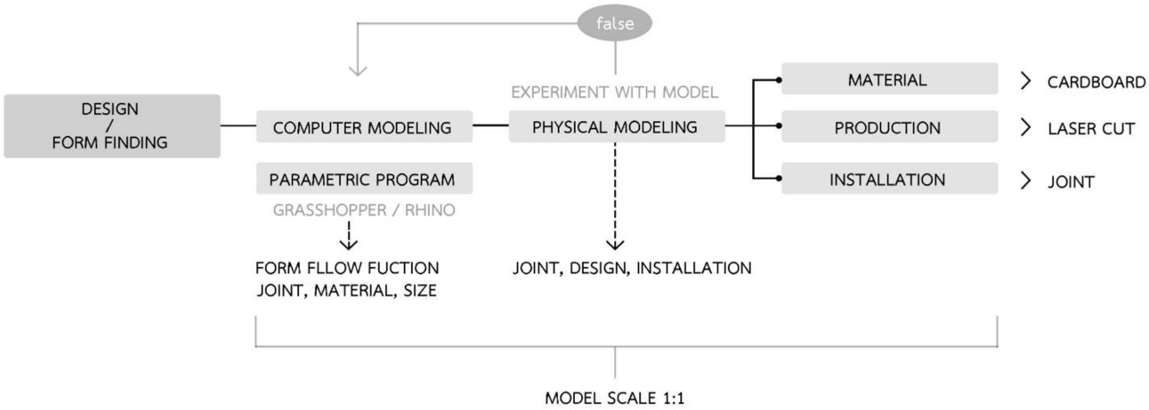

Figure 58 Conceptual framework-parametric program execution principles and process of the physical model

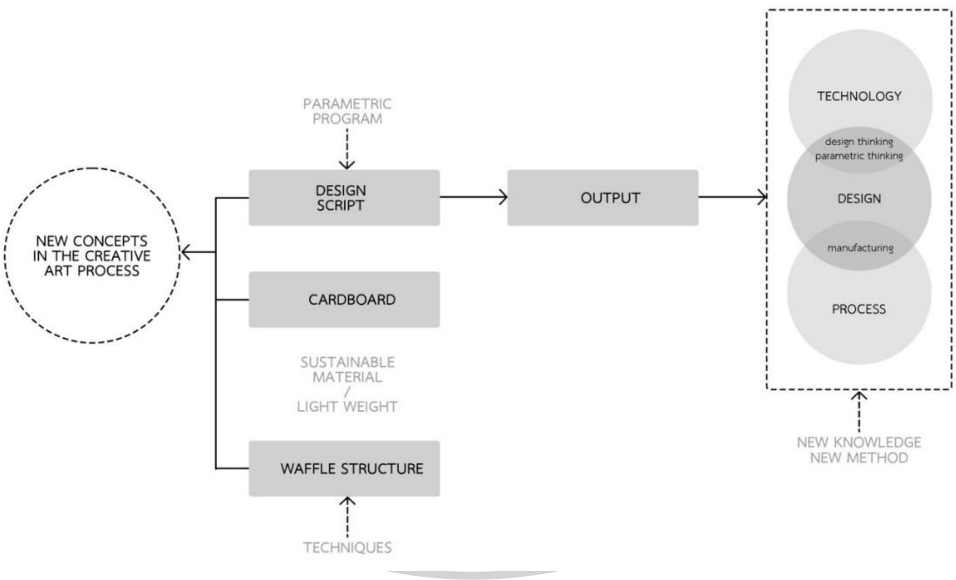

Figure 59 Diagram of Conceptual Analysis Conclusion

3.4 Design Process

3.4.1 Design Process in the 1st Step: Data Collection and Analysis

The data collection process will entail the examination of scripts or equation formats and machine limitations pertinent to the production process. Accordingly, the initiation of the data collection procedure will involve the study and evaluation of equations utilizing programs such as Rhinoceros Grasshopper. This approach aims to foster a comprehensive comprehension of the envisioned designs crafted by designers, alongside the gathering of relevant data about machines like laser cutting machines, 3D printers, and CNC machines. Subsequently, the synthesized information can be further refined and expanded upon to explore potential applications.

3.4.2 Design Process in the 2nd Step: Computational Experiments

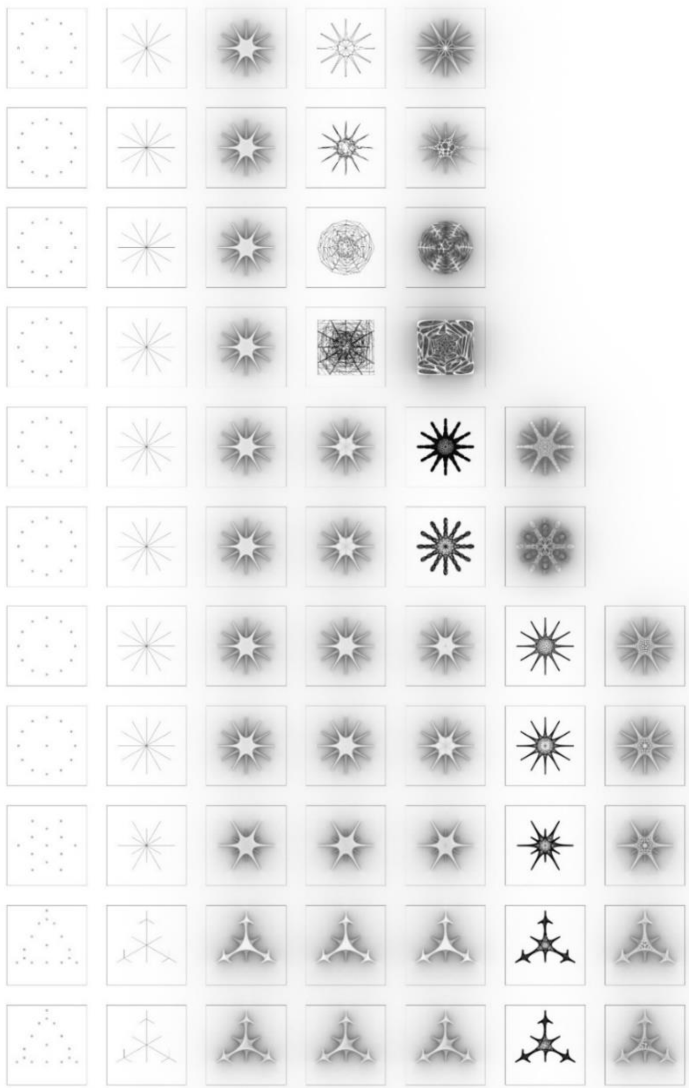

Figure 60 Computer simulation models to see the process and overall picture of the workpiece

Through the process of experimenting with computer simulation models, a discernible pattern emerges wherein the designer meticulously crafts and configures equations to realize a desired shape. For instance, as illustrated in Figure 60, the designer identifies the force transfer points within the table construction and proceeds to articulate the desired shape by scripting and formulating parametric equations. Subsequently, the computer is tasked with calculating the requisite surface area under natural conditions, effectively serving as a computational tool for the designer.

Once the shape derived from the scripted equations is obtained, it transitions into the production phase. This transition underscores the utilization of the parametric design methodology, wherein the computer assumes the role of an assistant, aiding in the realization of the designer's concepts. Consequently, the designer's focus remains on ideation, relying solely on digital files and production processes, which can be seamlessly transmitted to a 3D printer, as depicted in Figures 61 and 62.

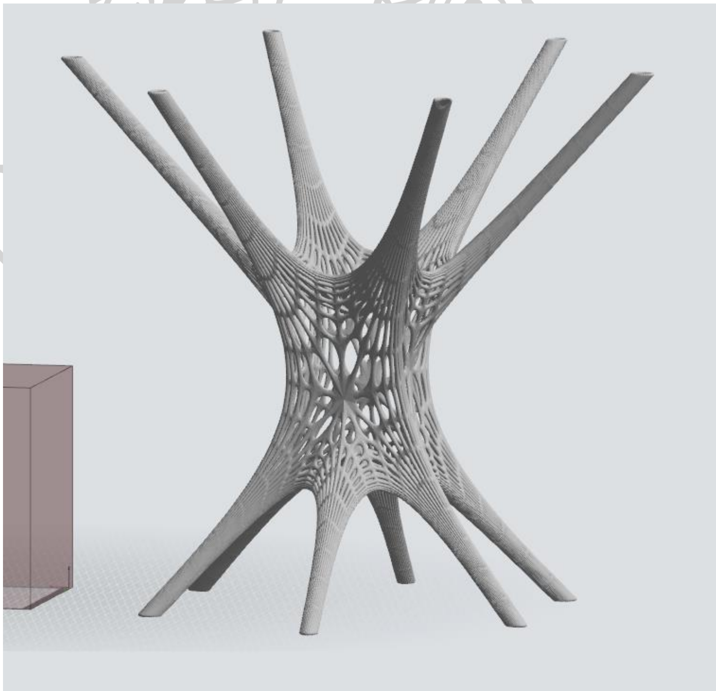

Figure 61 Simulation models and digital files to prepare for the 3D printing process

Figure 62 Simulation models and digital files to prepare for the 3D printing process

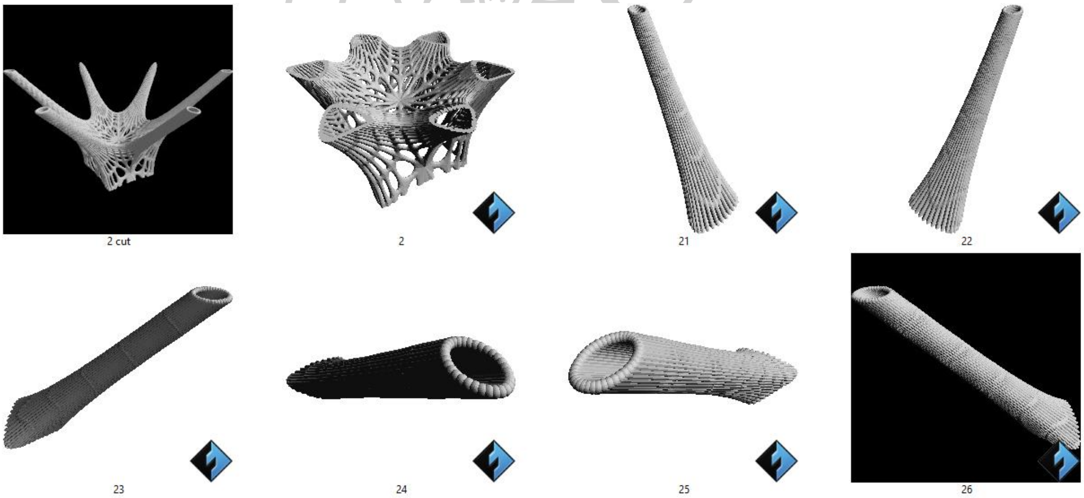

Figure 63 Model for dismantling parts for 3D printing

3.4.3 Design Process in the 3rd Step: Prototype

The prototype testing process, particularly within the domain of laser cutting machines and 3D printers, encompasses a variety of testing methodologies, essential for designers to cultivate a comprehensive understanding of the machinery they will operate. This knowledge is crucial in shaping and forming the workpiece effectively. Consequently, prototype experimentation involves employing laser cutting techniques on materials such as paper, wood, and cardboard, as well as methods for assembling numbered parts into predefined shapes. The primary benefit derived from this experimentation lies in the expedited production of workpieces facilitated by laser cutting machines operating from 2D digital files.

Furthermore, the principles underlying this process can be extrapolated to CNC machines, particularly in applications within interior design that utilize panel formats and interconnected wall panels. Another facet of experimentation involves the utilization of 3D printers to prototype designs, utilizing various materials ranging from synthetic fibers to resin models. Materials such as polyethylene terephthalate (PET), a plastic commonly utilized in the production of drinking water bottles, to 3D printer resin, are explored. Each material variant offers distinct advantages and drawbacks, tailored to specific usage requirements. Consequently, the selection of the appropriate 3D printer, considering both design specifications and material characteristics, assumes paramount importance in the production process.

Figure 64 Laser Cutting Experimental Model

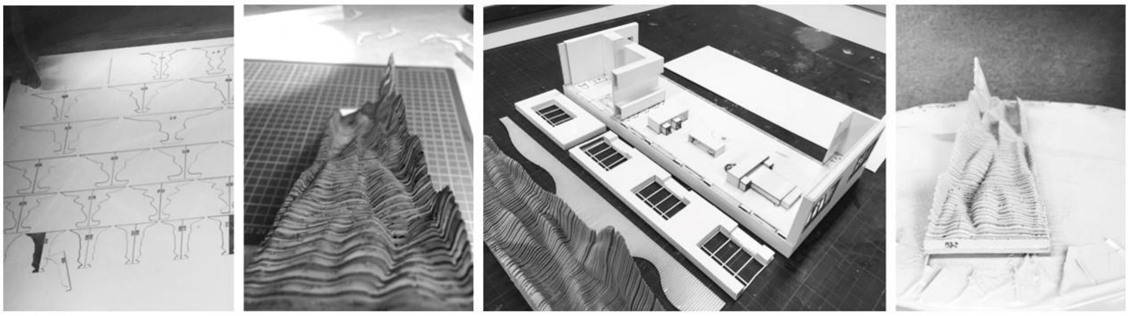

Figure 65 Laser Cutting Experimental Model

Figure 66 Experimental 3D Printing Model

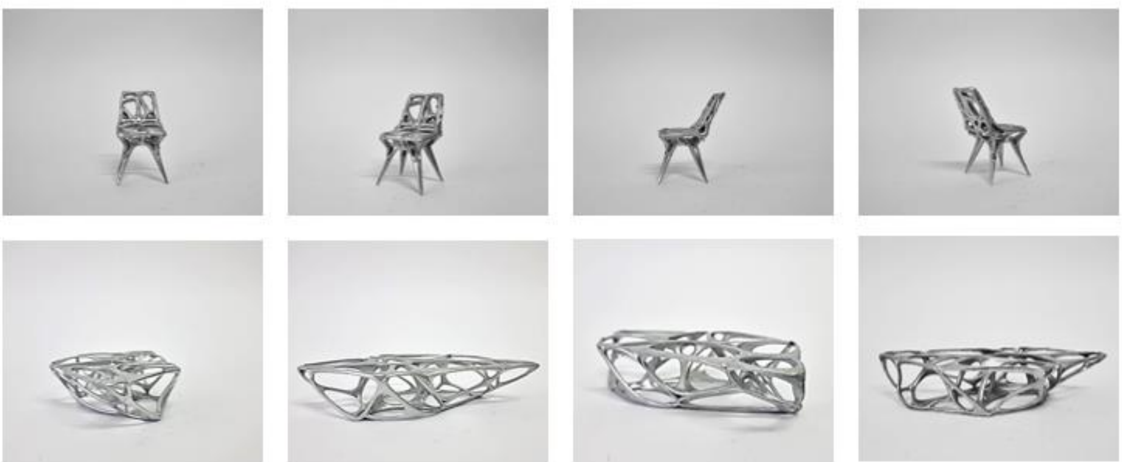

Figure 65 Experimental 3D Printing Model

3.4.4 Design Process in the 4th Step: Physical Model Experiment

Due to the limited size of 3D printers, the production process necessitates that furniture pieces be separated and subsequently assembled to ensure optimal performance and strength. Ideally, all parts should be printed in one location to minimize joints and maximize structural integrity. However, when tools are limited, designers must carefully select the division of parts by considering the size of the printer and the points at which the design will receive and transfer force.

Figure 67 3D printing process

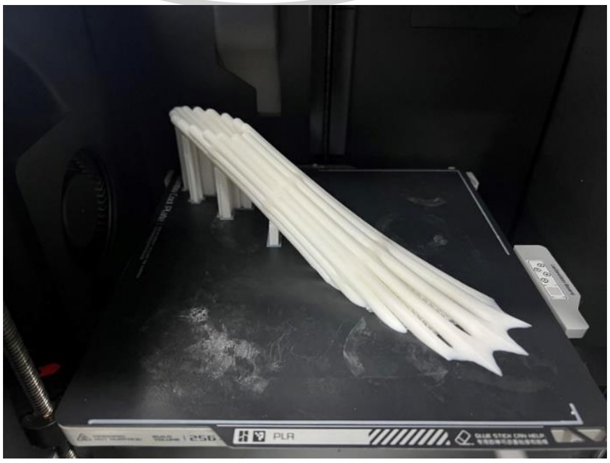

Figure 68 3D printing process

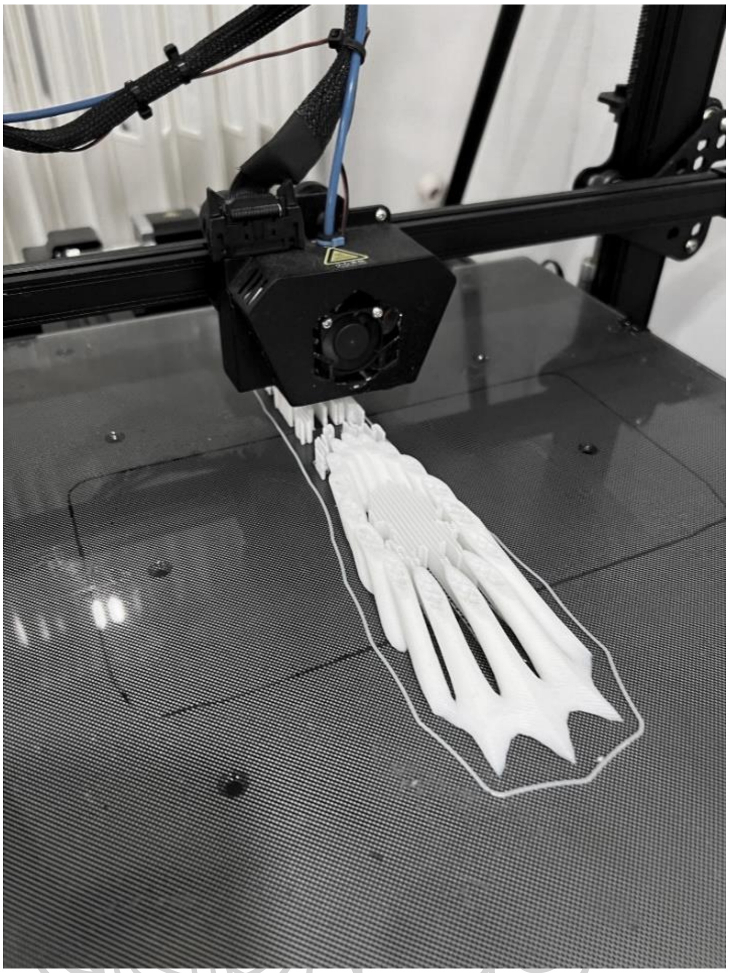

Figure 69 3D printing process

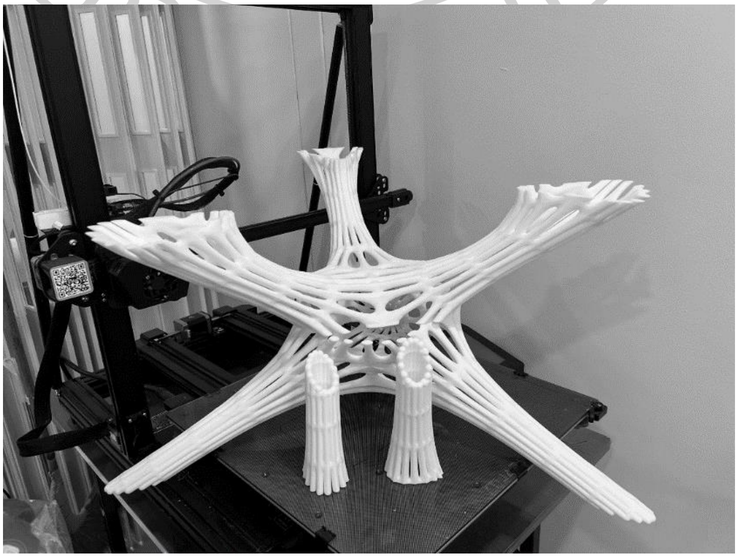

Figure 70 3D printing process

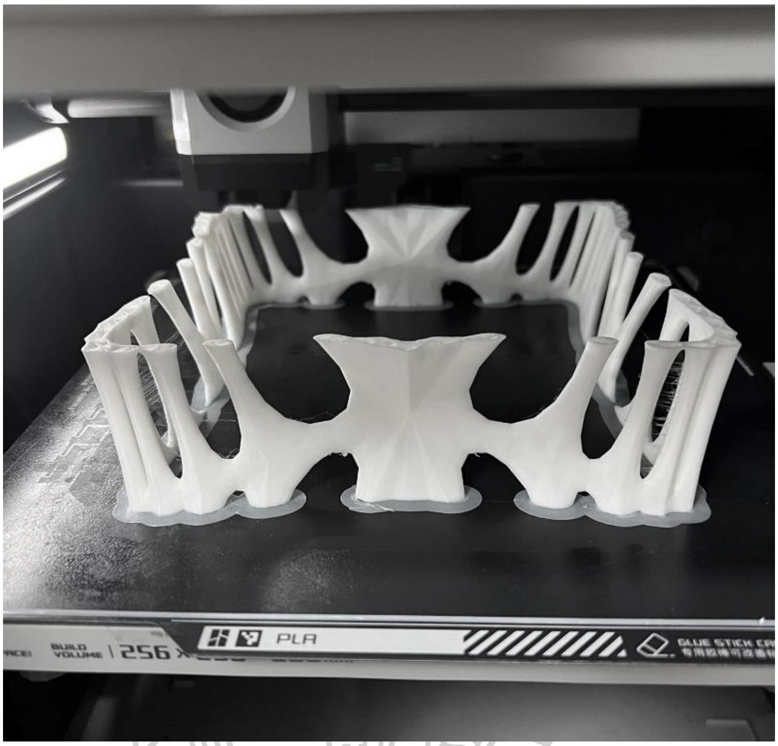

Figure 71 3D printing process

3.4.5 Design Process in the 5th Step: Delivery

Figure 72 Parametric table

3.5 Design Experiment

3.5.1 Experiment 1: Waffle structure

To apply the feasibility of using scrap materials for parametric design styles in interior design, such as in a showroom or exhibition.

Today's lifestyle has changed compared to the past, as the demand for consumption is increasing and the world's population is growing, resulting in more wasteful consumption or production. which leads to new products entering the market in large quantities. Therefore, if the limited number of resources is not taken into account when manufacturing a product, this also harms the environment. The use of environmentally friendly materials that can be recycled and are compostable was considered, but the scope of the study was based on temporary exhibitions that required lightweight materials to be easily set up in different locations. So, the primary material to be researched is cardboard because the cardboard material can meet the requirements of temporary exhibitions. Cardboard is excellent choice for building temporary structures for both exhibition areas.

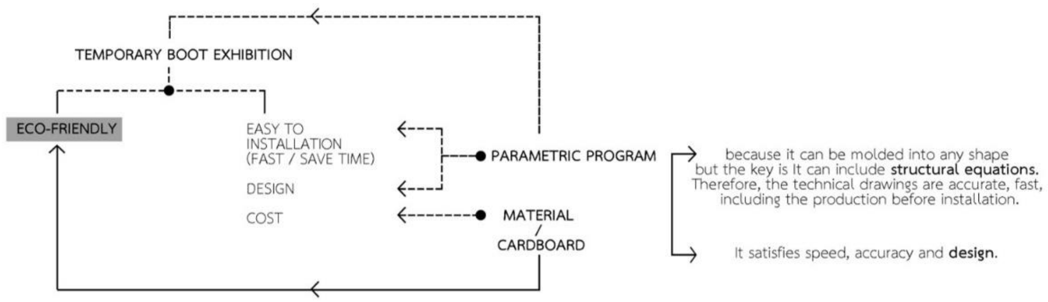

Figure 73 Conceptual framework for experimenting with waffle structures in applications such as booths or temporary exhibitions

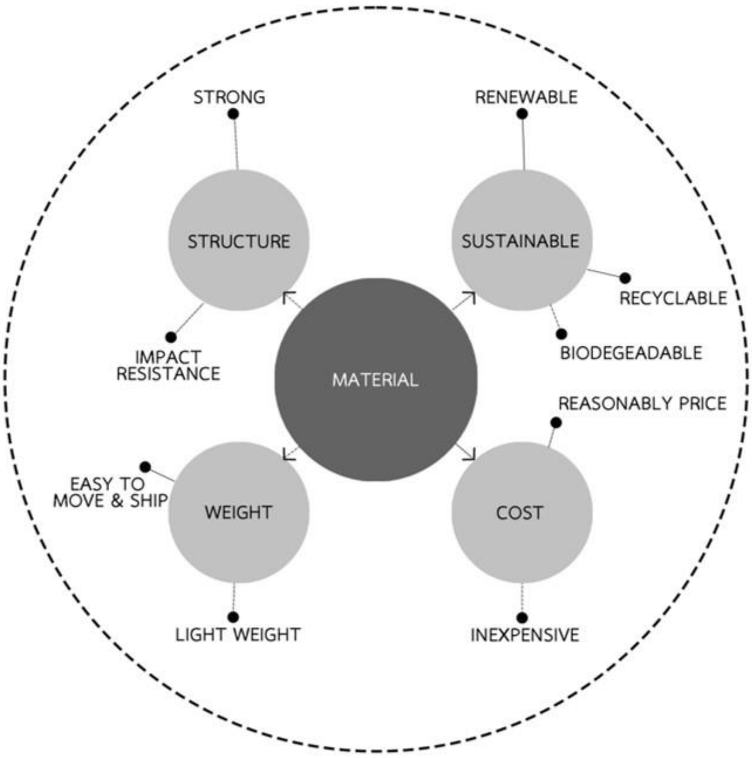

Figure 74 Diagram for explaining the relationships and benefits of materials

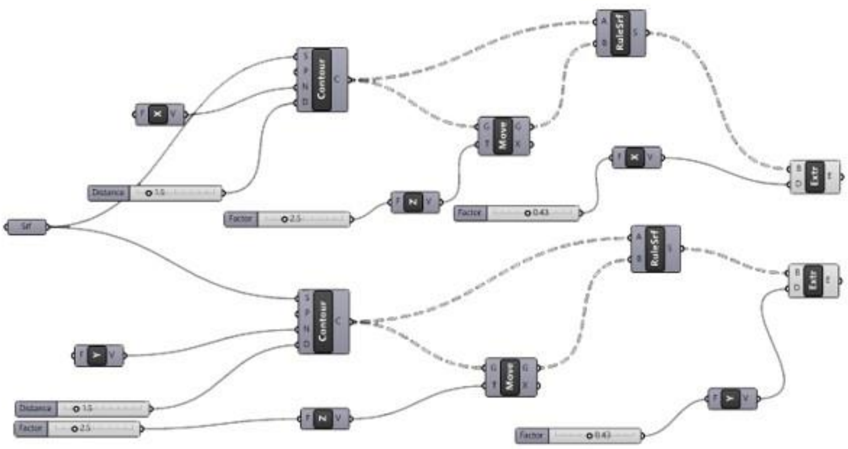

Figure 75 Algorithmic equations of waffle structure

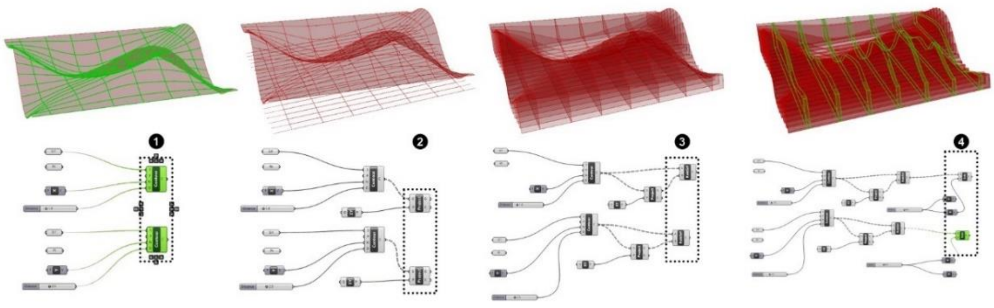

Figure 76 Process of Algorithmic equations of waffle structure

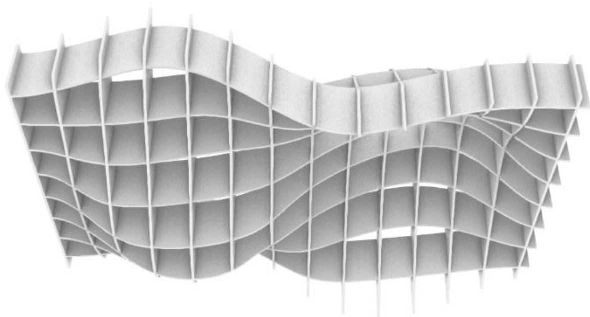

Figure 77 Computer modeling of waffle structures

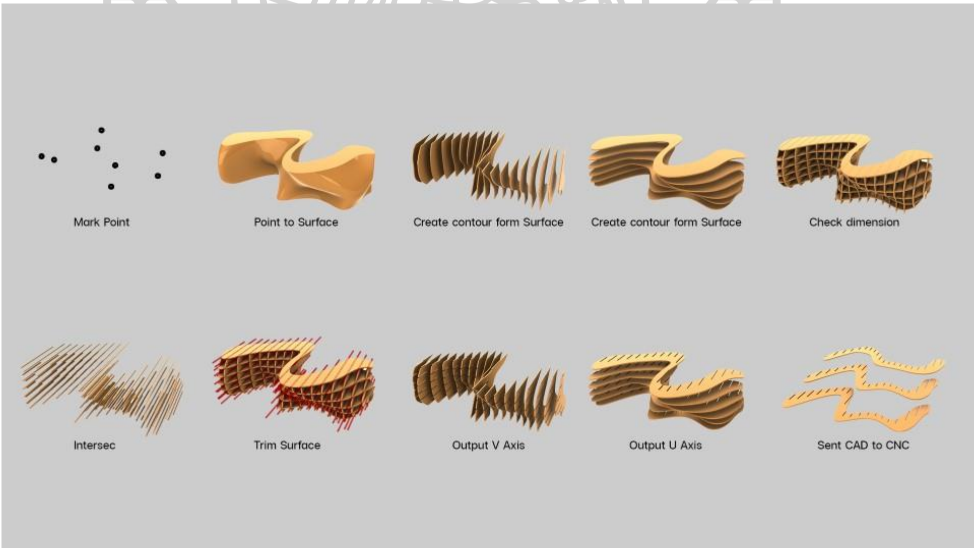

Figure 78 Process of Algorithmic equations of waffle structure

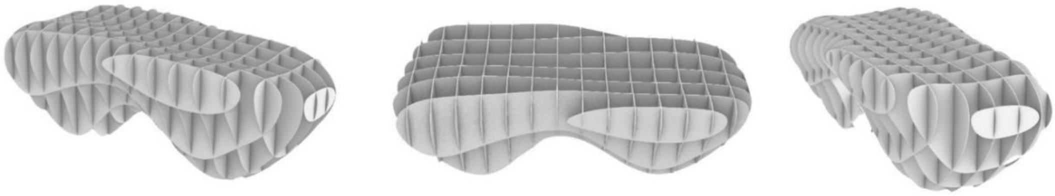

Figure 79 Three-dimensional model of a bench with the Waffle equation

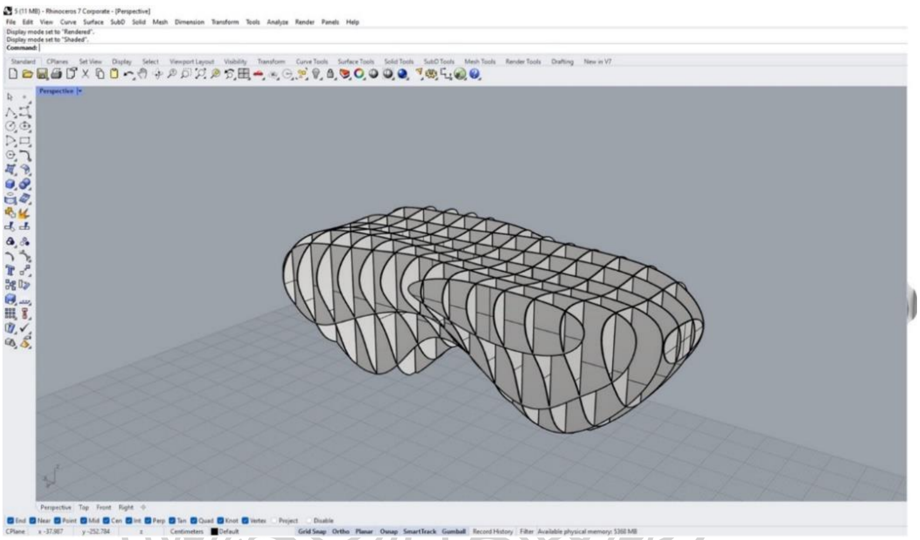

Figure 80 Three-dimensional model of a bench with the Waffle equation

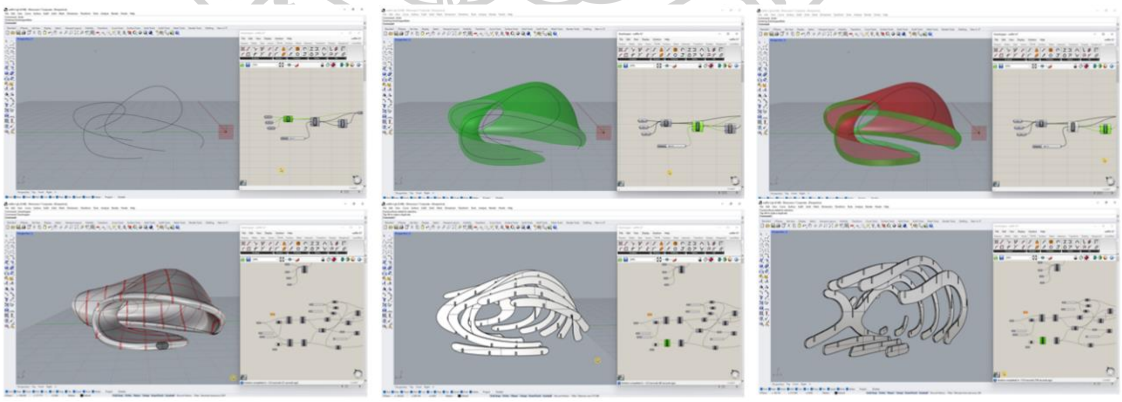

Figure 81 Process of Algorithmic equations of the rolled waffle structure.

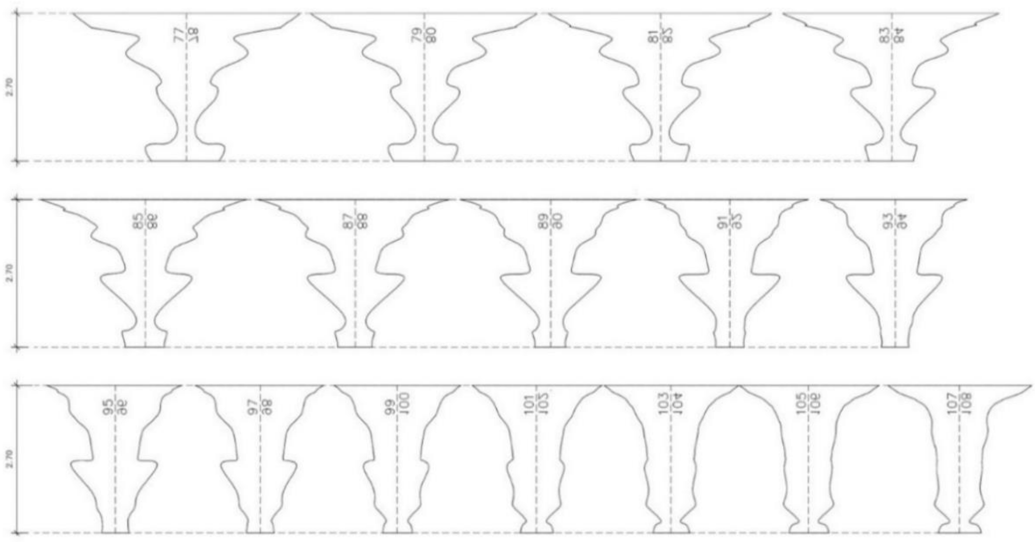

Figure 82 Technical drawing and numbering from a 3D model to send a 2D file to cut the material on a laser cutter or CNC machine.

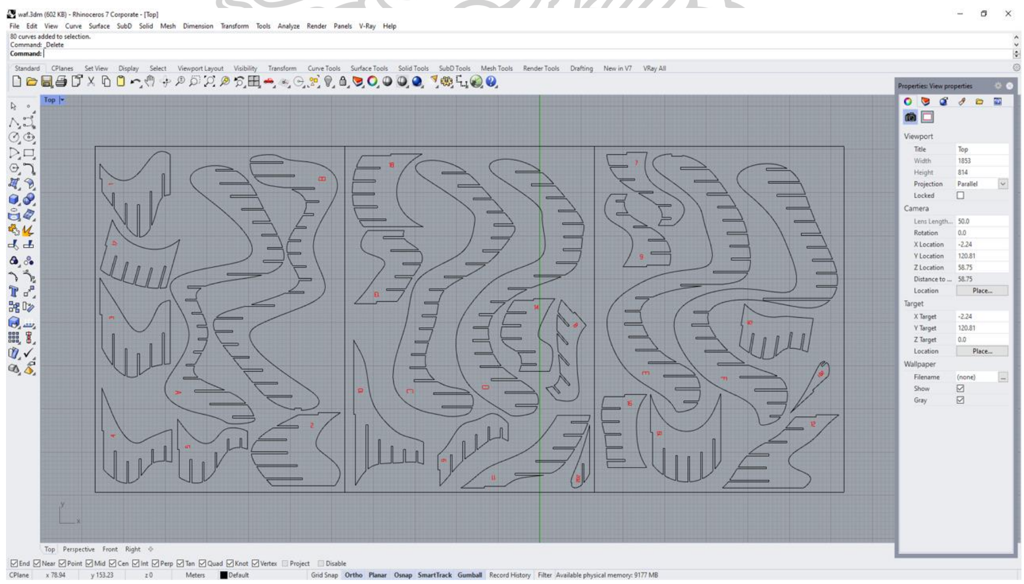

Figure 83 Technical drawing and numbering from a 3D model to send a 2D file to cut the material on a laser cutter or CNC machine.

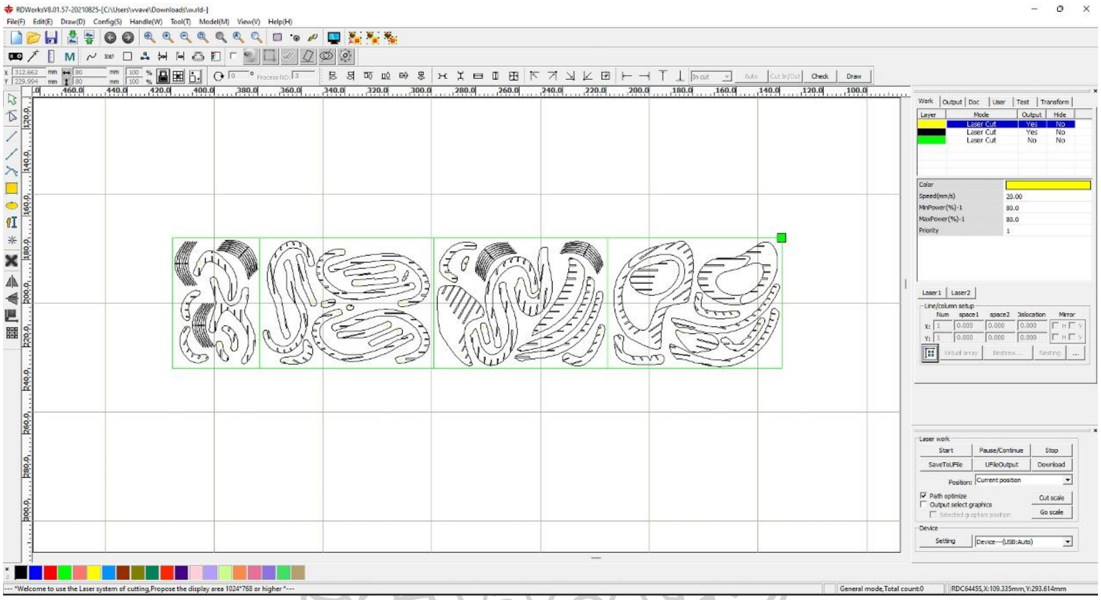

Figure 84 Import the file into the laser cutting machine's program.

Figure 85 Cardboard material is cut by a laser cutter for further assembly.

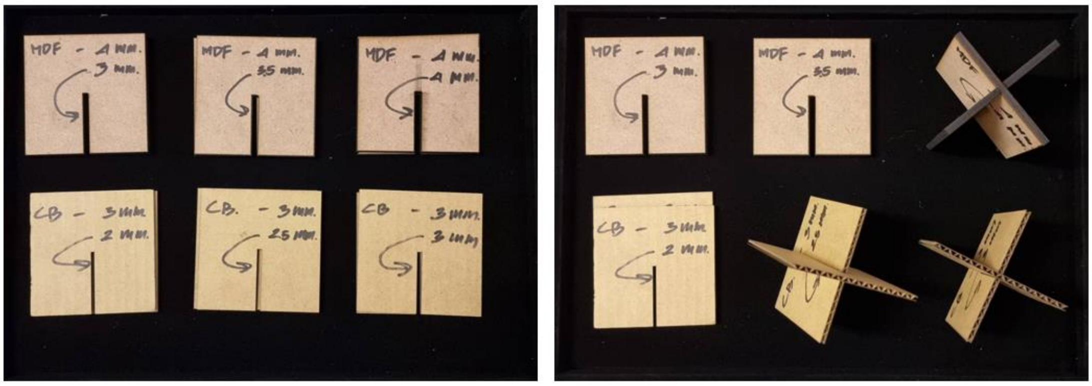

Figure 86 Experiment to find the right joint size.

Figure 87 Waffle Structure Experiment

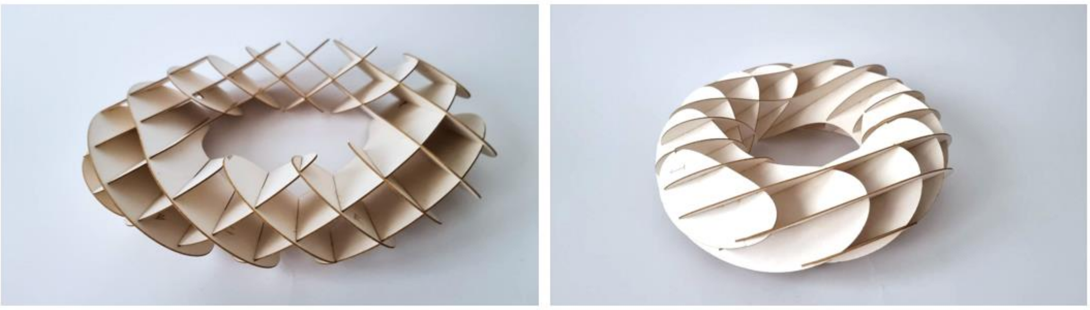

Figure 88 Experimenting with the donut-shaped circular roll structure and the waffle structure and the angle of inclination.

MATERIAL: CRAFT BOARD
TECHNIQUE: LASERCUT
TIME: 20-30 MINS
SIZE: W20x L20X H15 CM.

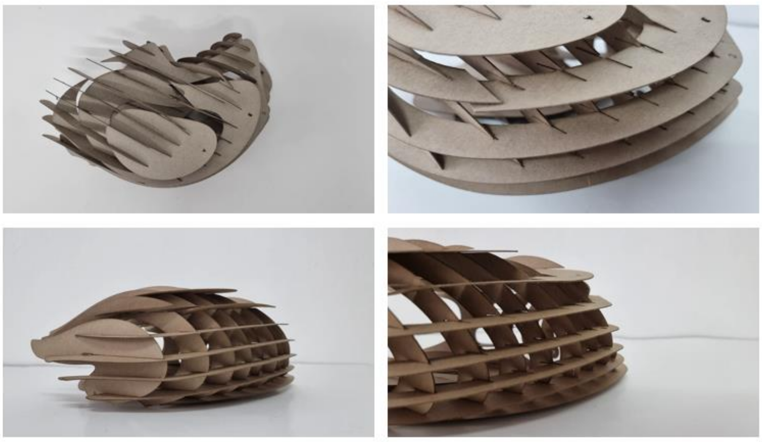

Figure 89 Experimenting with Kraft Board Paper

MATERIAL: CARDBOARD [THIN]
TECHNIQUE: LASERCUT
TIME: 25-40 MINS
SIZE: W25 X L25 X H20 CM.

Figure 90 Experimenting with Cardboard

MATERIAL: MDF
TECHNIQUE: LASERCUT
TIME: 90-120 MINS
SIZE: W 30 X L60 X H20 CM.

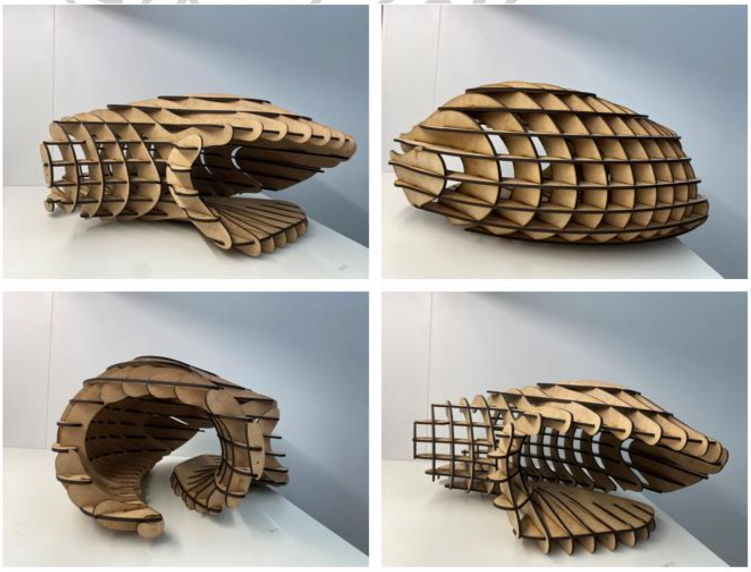

Figure 91 Experimenting with MDF

Figure 92 Simulation model for walls with parametric waffle structure design.

Figure 93 Experimenting with waffle structures with different shapes and materials such as plywood, cardboard, and craft board.

Figure 94 The bench chair model is replicated in real size with a parametric waffle structure design.

Figure 95 Examples of interior design work using a waffle structure

3.5.2 Experiment 2: Parametric Staircase Design

The parametric staircase showcased here exemplifies the application of parametric concepts within interior design. Completed within a concise timeframe of two weeks by a team of two designers, the project encompassed the design process, development of designs, and transformation of designs into components suitable for CNC cutting. Parametric techniques offer distinct advantages in interior design, notably precision and the capability to calculate the inclination of wood panel installation. This precision extends to angles of up to 180 degrees, presenting a challenge when employing traditional methods or relying solely on human calculation to achieve the desired design and ensure the seamless installation of wood panels, aligned with the designer's vision. In the design process, a computer model was generated, as illustrated in Figure 95, followed by the creation of a physical model through 3D printing to showcase the smooth curvature of the stairs, as depicted in Figure 97. Subsequently, the design was transcribed into a digital file in 2D format, which was then transmitted to a CNC machine to cut High Moisture Resistance (HMR) board wood, followed by painting, assembly, and installation at the designated location.

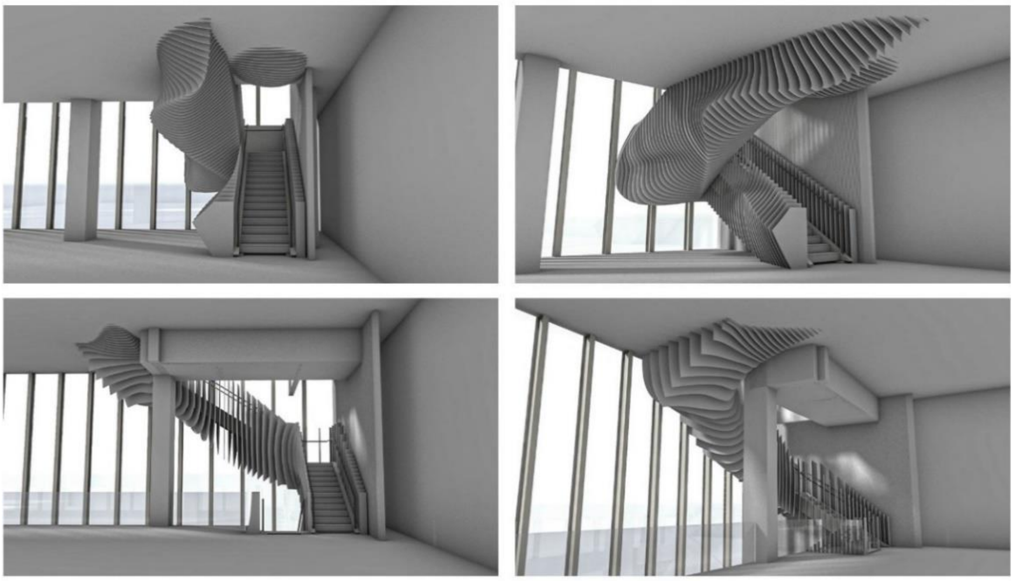

Figure 96 The process of creating a three-dimensional virtual simulation model of a staircase

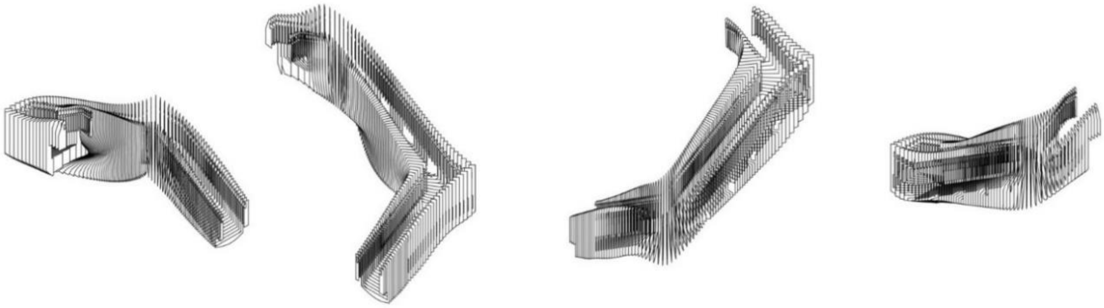

Figure 97 3D Virtual Simulation Model of Parametric Staircase Design.

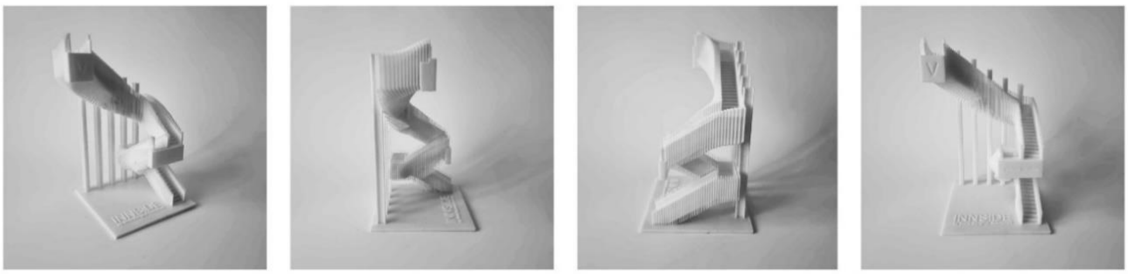

Figure 98 3D Printed Physical Model to Simulate Scale and Proportions.

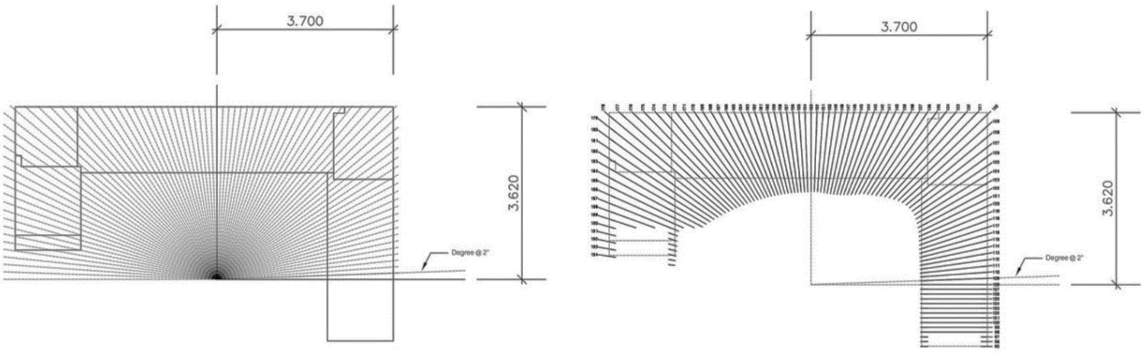

Figure 99 Computer-Aided Calculation of Parametric Stair Degree Fluidity.

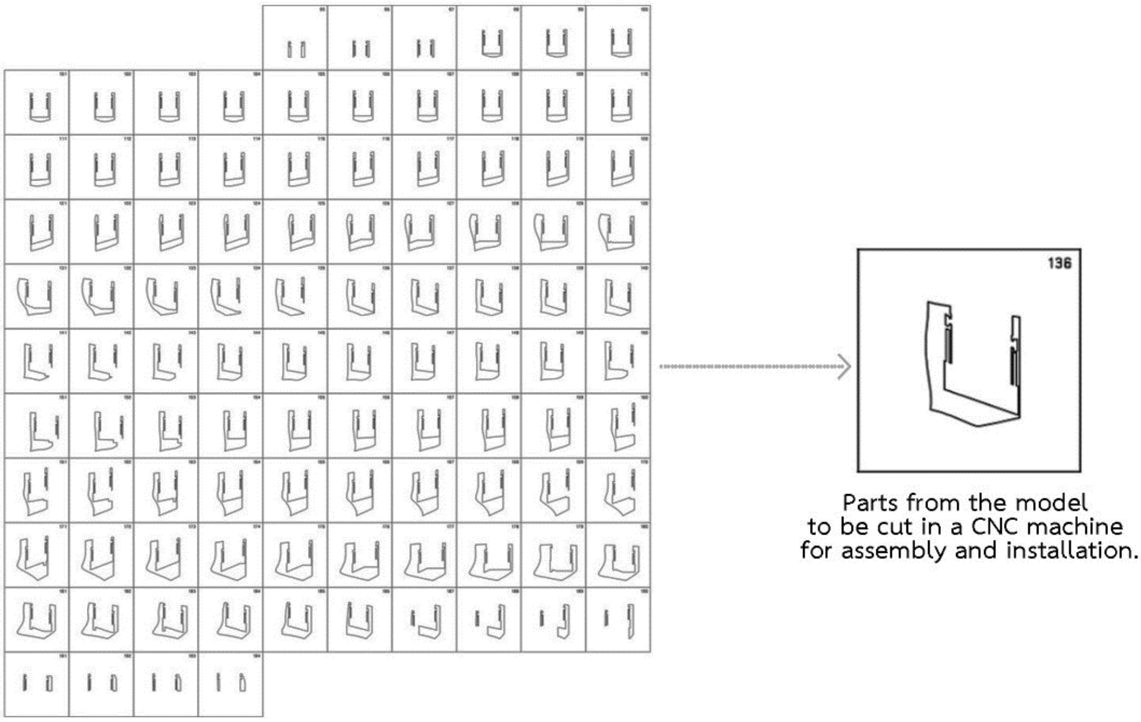

Figure 100 Drawing and Numbering to use files for CNC Cutting, Assembly and Installation.

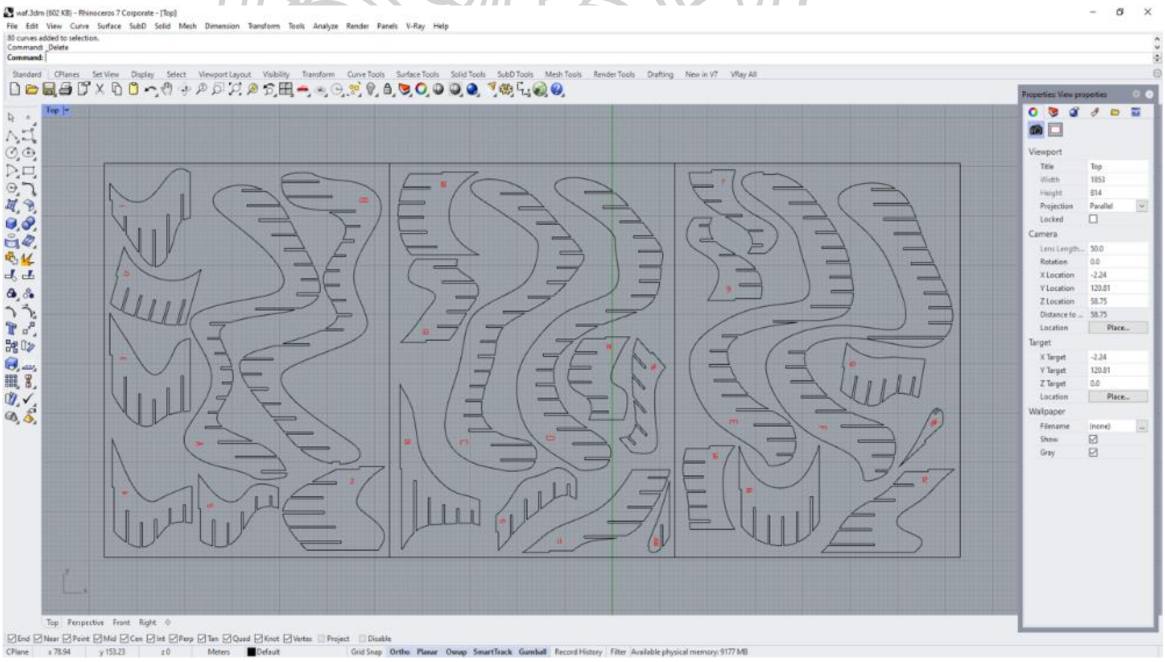

Figure 101 Example of Drawing and Numbering to send to the CNC machine.

Figure 102 Measuring Process for Check Area, Size, and Structure

Figure 103 Measuring Process for Check Area, Size, and Structure.

Figure 104 Measuring Process for Check Area, Size, and Structure.

Figure 105 Process for Installing Parametric Stairs.

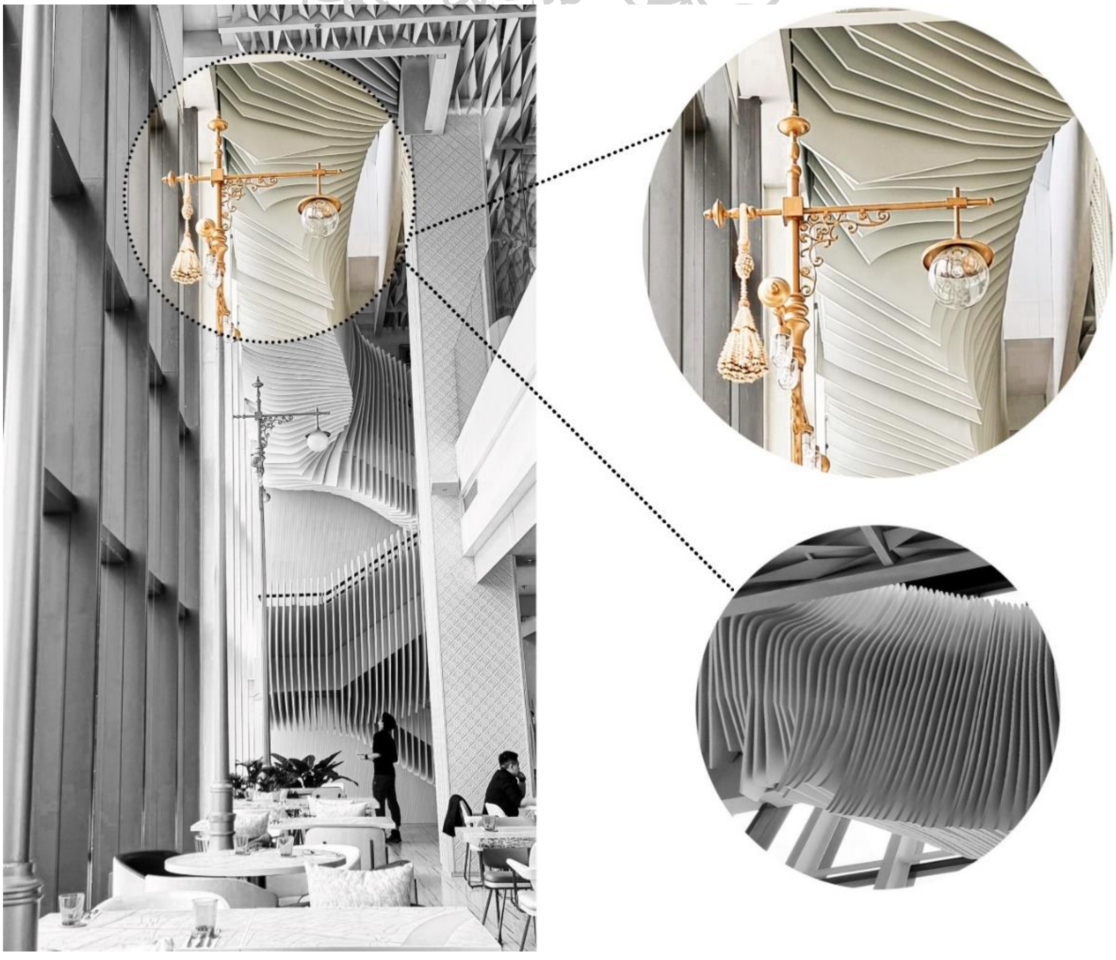

Figure 106 Process for Installing Parametric Stairs with Installation problems.

When the designers embarked on the task of designing the parametric staircase, the primary staircase structure had already been erected. Consequently, creating parametric clarity posed challenges, as certain areas of the main staircase lacked reserved space for accommodating the radius of curvature or protrusion of the workpiece. As a recommendation for interior design projects employing parametric techniques, it is advisable to develop a parametric model before commencing the construction of the main staircase or designated area. This preemptive approach facilitates the seamless integration of parametric design elements into the overall structure, thereby enhancing the efficacy of the design process.

Despite efforts to minimize errors through the use of parametric techniques, discrepancies may occur during on-site installation, as illustrated in Figure 107. Human involvement in the installation process is essential, and any deviation from precise numbering arrangements by technicians can lead to errors.

3.5.3 Experiment 3: Panel Well Decoration Methods

This slatted wall will exemplify the manufacturing and installation process, showcasing precision in specifying each panel and efficiency in assembly on-site.

Figure 107 Process for Installing wall decoration.

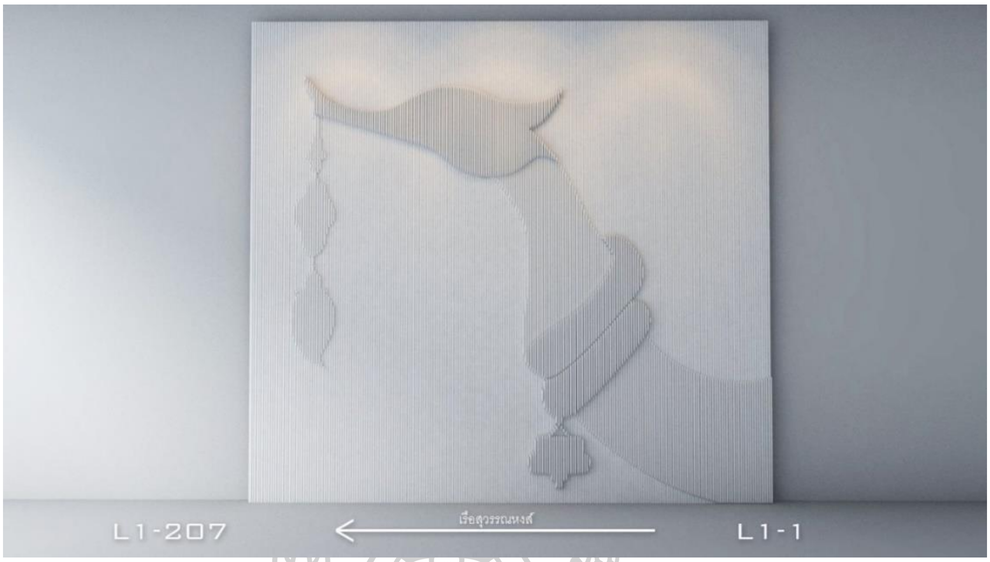

Figure 108 Process for Installing wall decoration

Figure 109 Process for Installing wall decoration

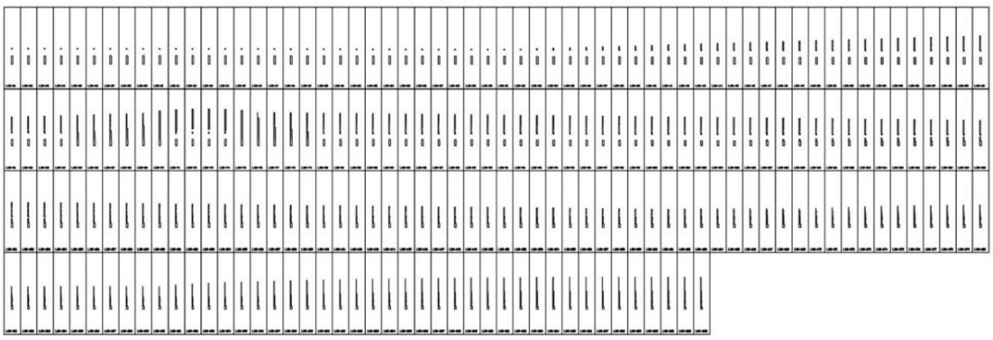

Figure 110 Technical drawing of wall decoration

3.5.4. Experiment 4: Voronoi 2D – 3D

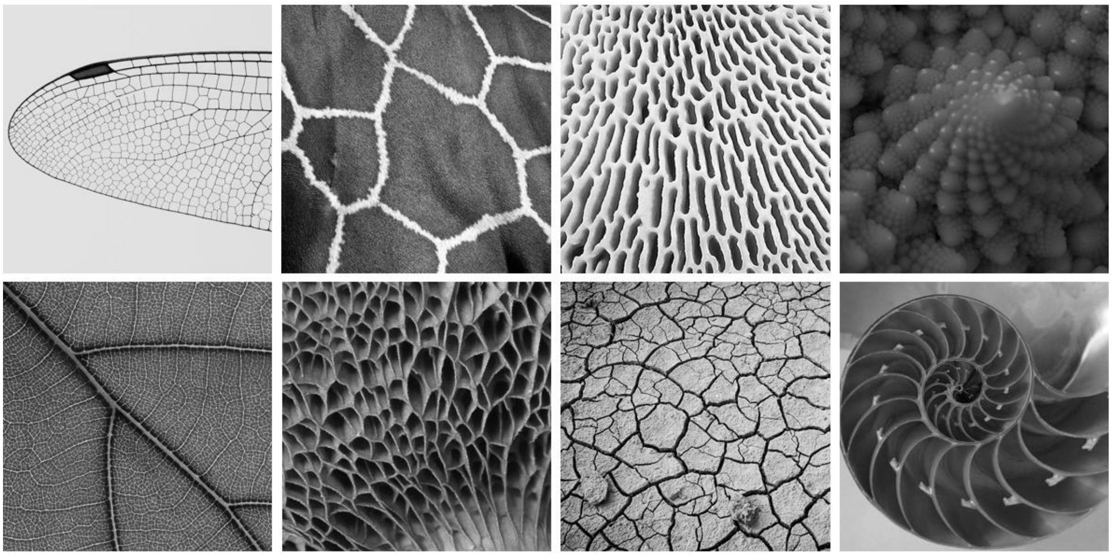

Figure 111 Examples of Voronoi pattern in nature

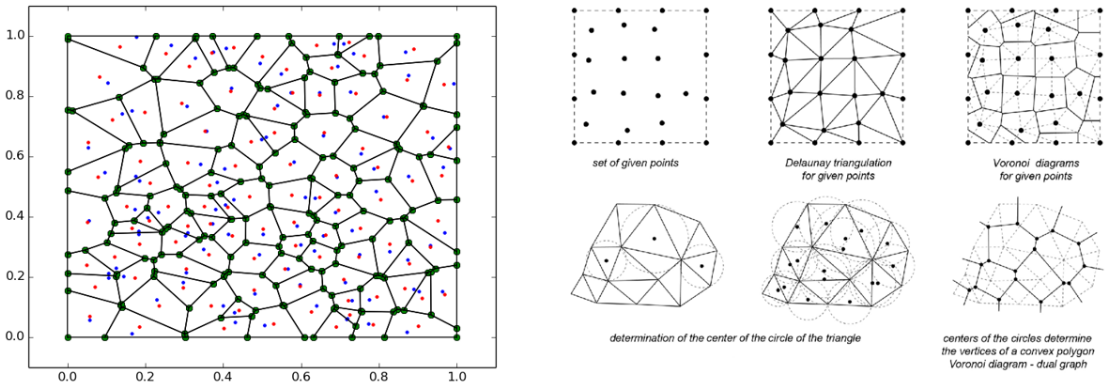

Figure 112 Examples of natural Voronoi cells diagram

Source: https://stackoverflow.com/questions/28665491/getting-a-bounded-polygon-coordinates-from-voronoi-cells

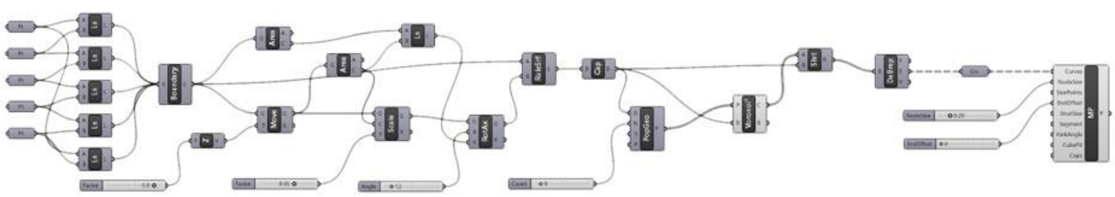

Figure 113 Parametric algorithm equations

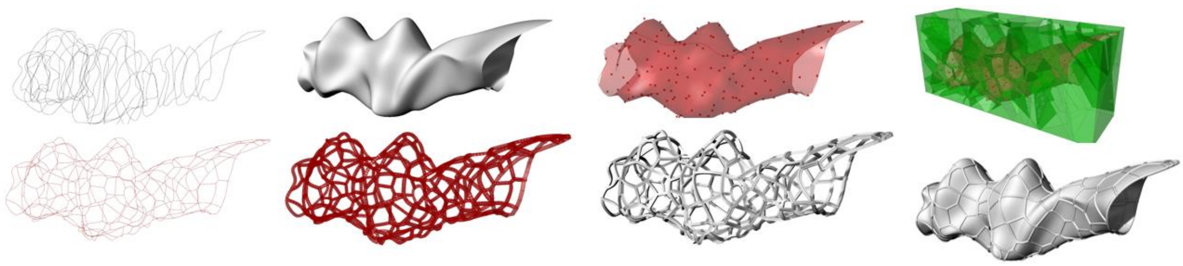

Figure 114 Parametric design process with Volonoi equation examples.

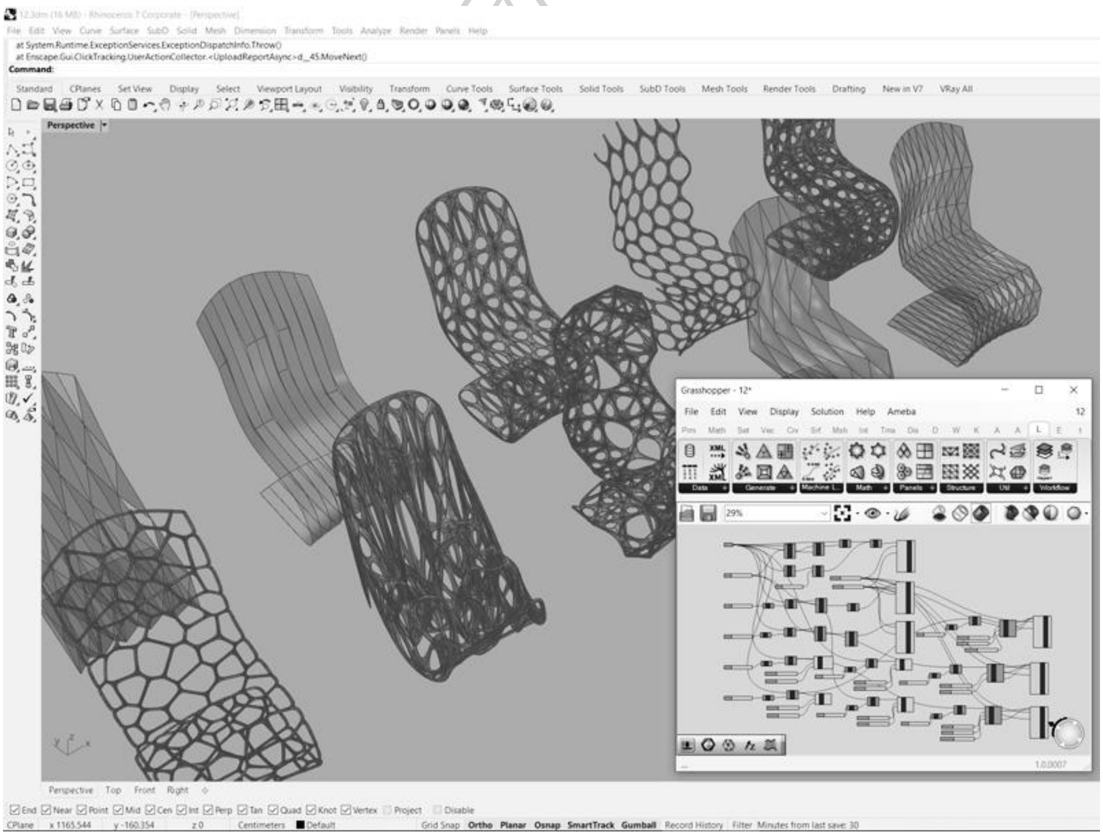

Figure 115 Computer simulation models for structural experiments Voronoi chairs

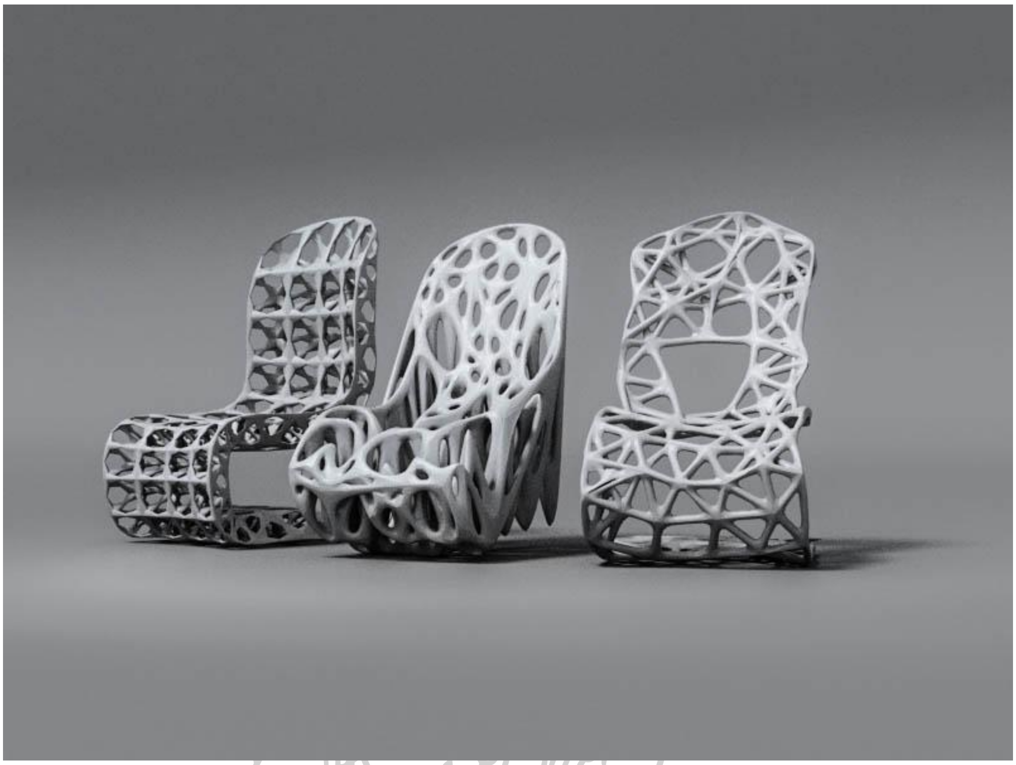

Figure 116 Computer simulation models for structural experiments Voronoi

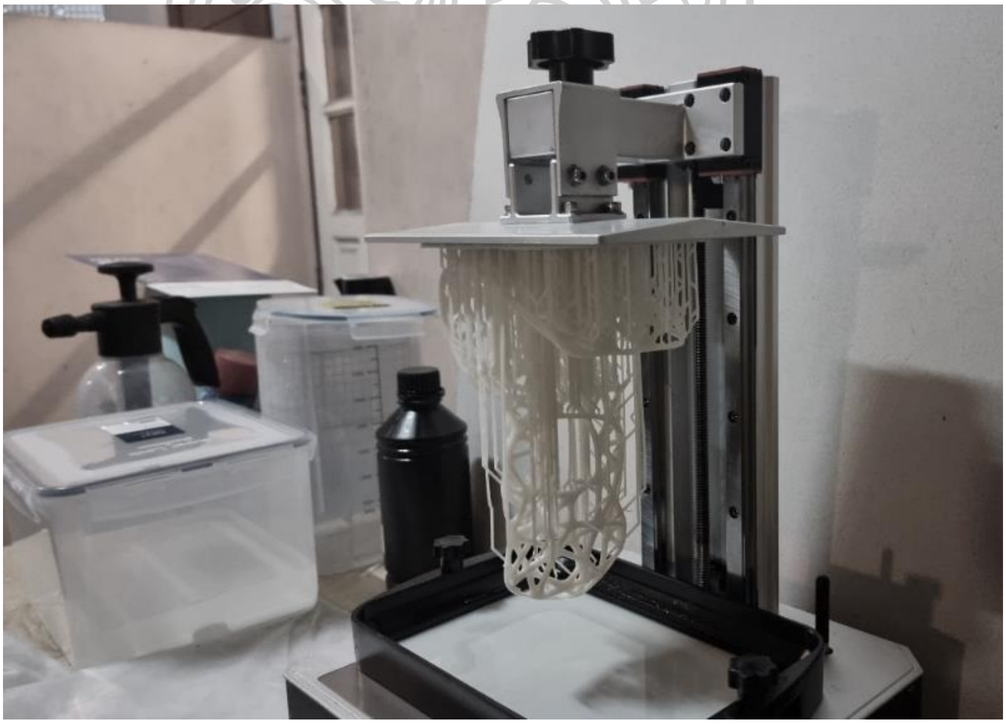

Figure 117 Experimental procedure for 3D printing.

Figure 118 The experimental procedure for 3D printing a parametric chair model is depicted, with the resin cleaning solution

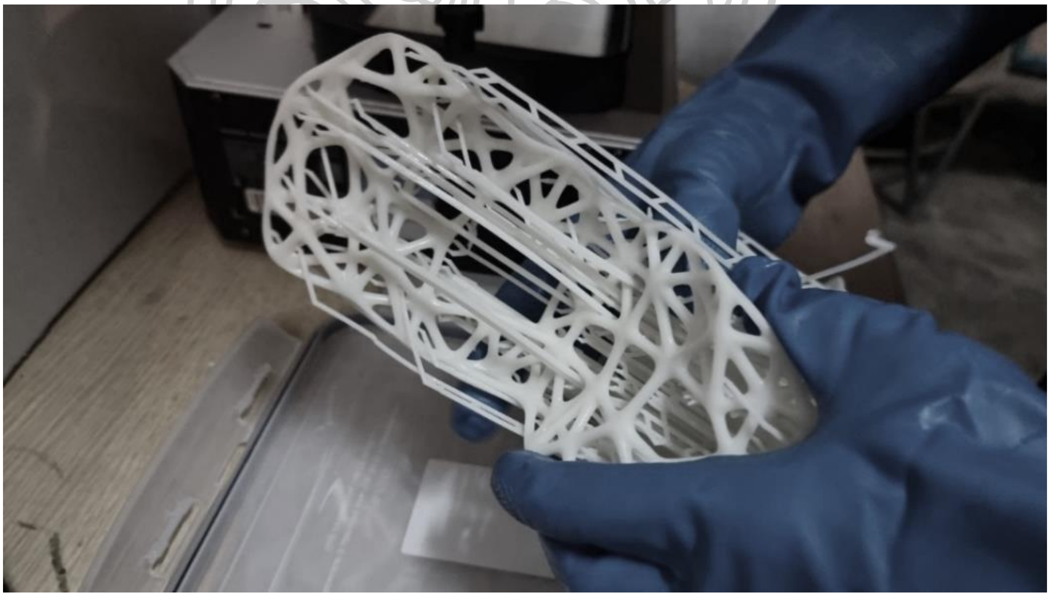

Figure 119 Experimental steps for removing support from the simulation model

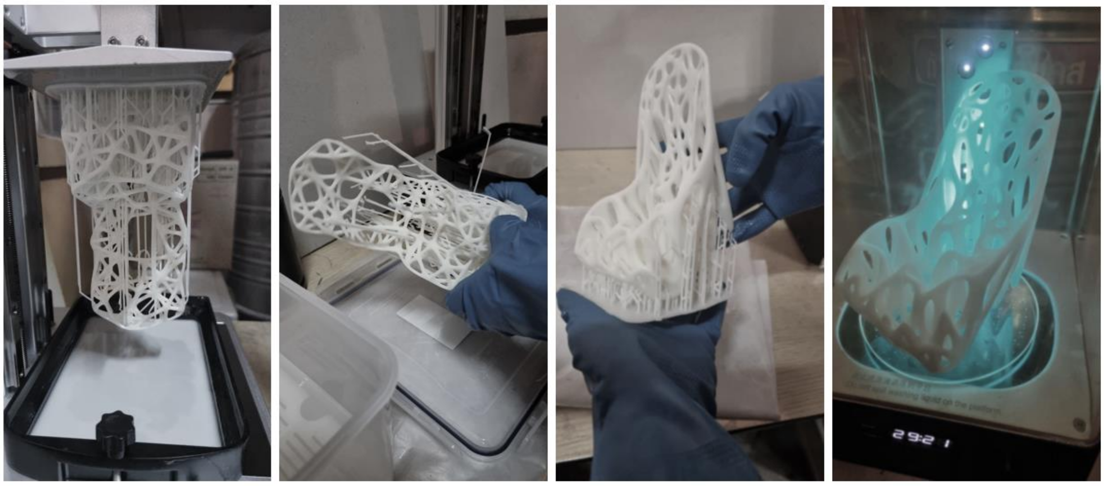

Figure 120 Experimental procedure for 3D printing with a parametric chair

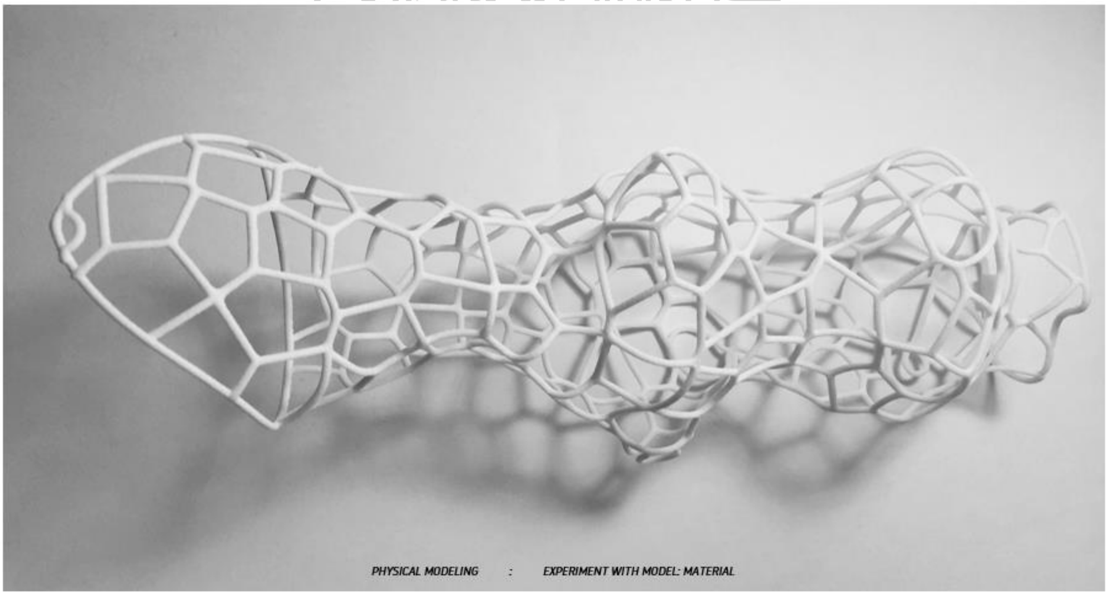

Figure 121 Three-dimensional model of the Voronoi structure

3.5.5 Experiment 5: Organic joint with Voronoi

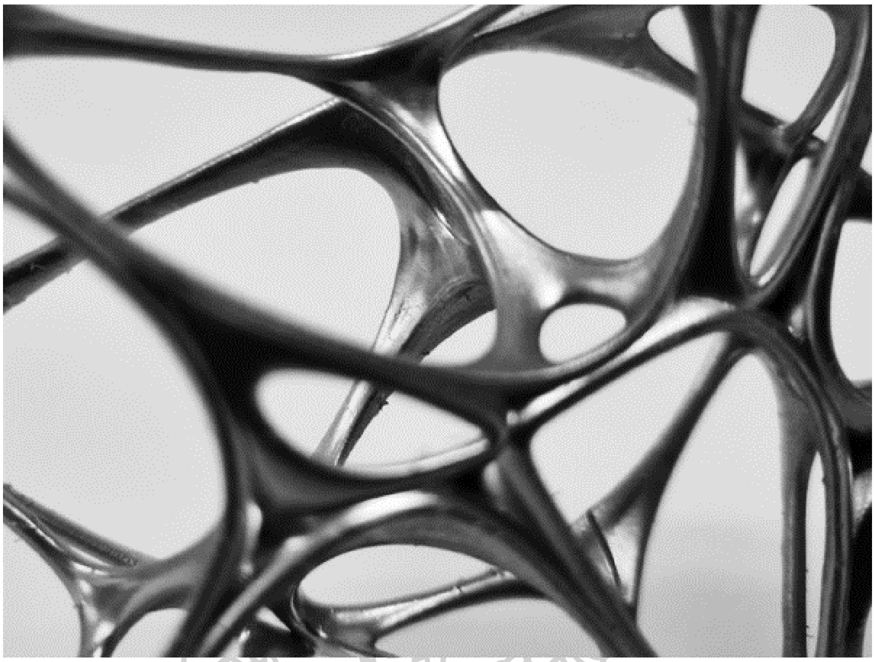

Figure 122 Experimental procedure for 3D printing with a parametric chair.

Figure 123 Computer simulation models for structural experiments Voronoi and Organic joint with chair

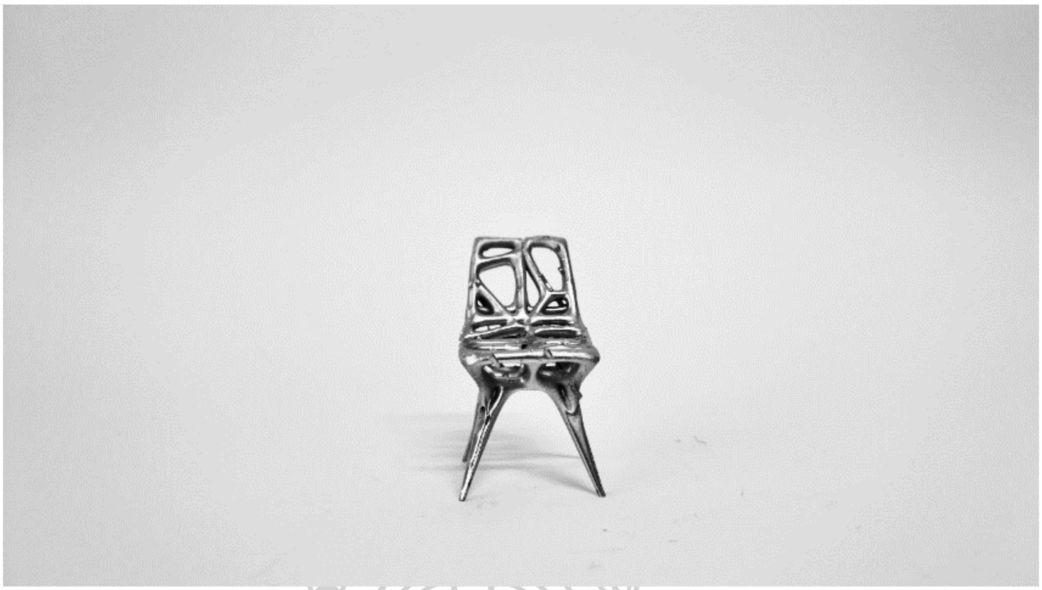

Figure 124 3D Printed Physical Model to Simulate Scale and Proportions.

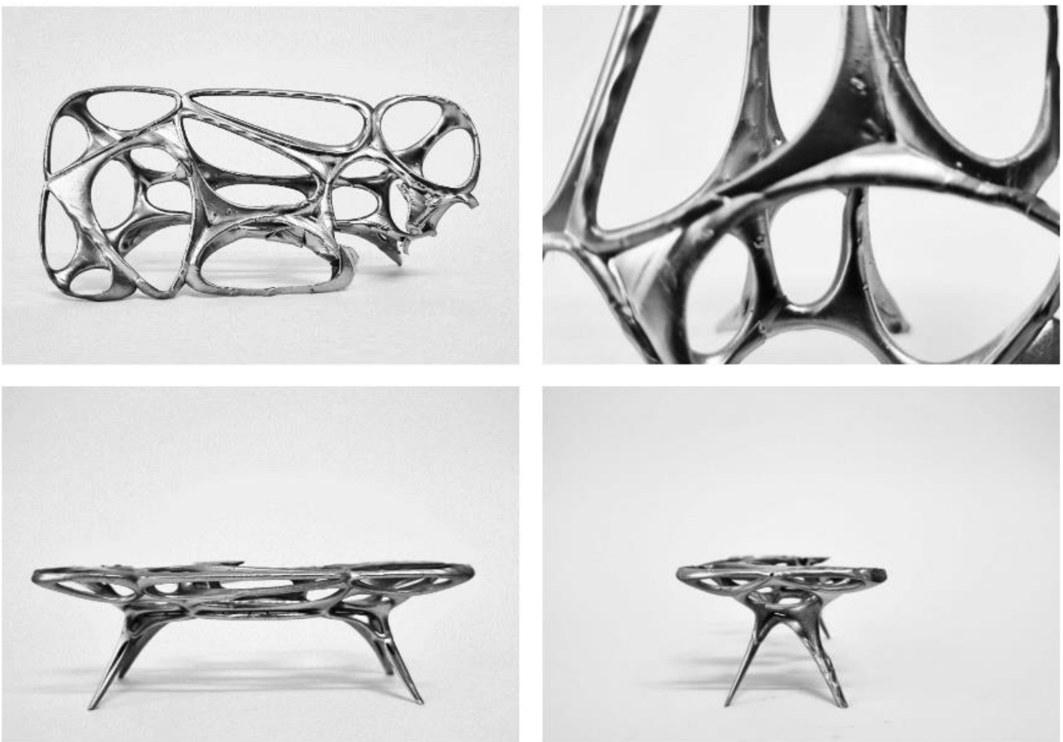

Figure 125 Experimental procedure for 3D printing.

Figure 126 3D Printed Physical Model to Simulate Scale and Proportions.

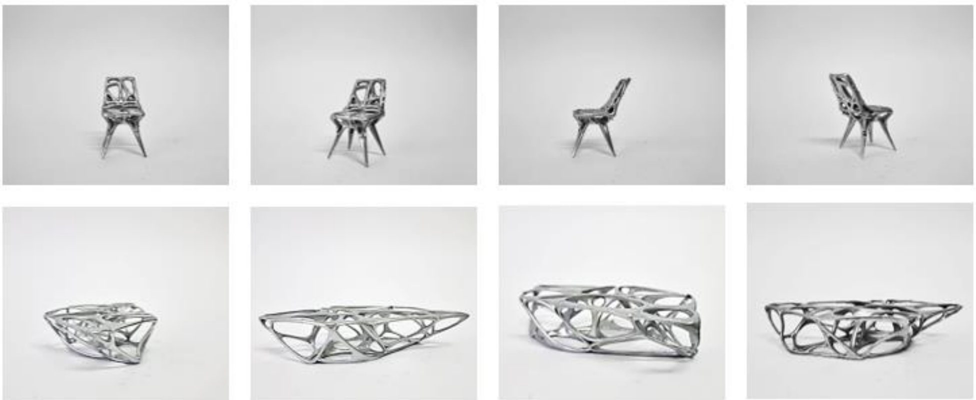

Figure 127 3D Printed Physical Model to Simulate Scale and Proportions.

Figure 128 Organic joint with Voronoi

Figure 129 Experimental procedure for 3D printing.

Figure 130 Experimental procedure for 3D printing.

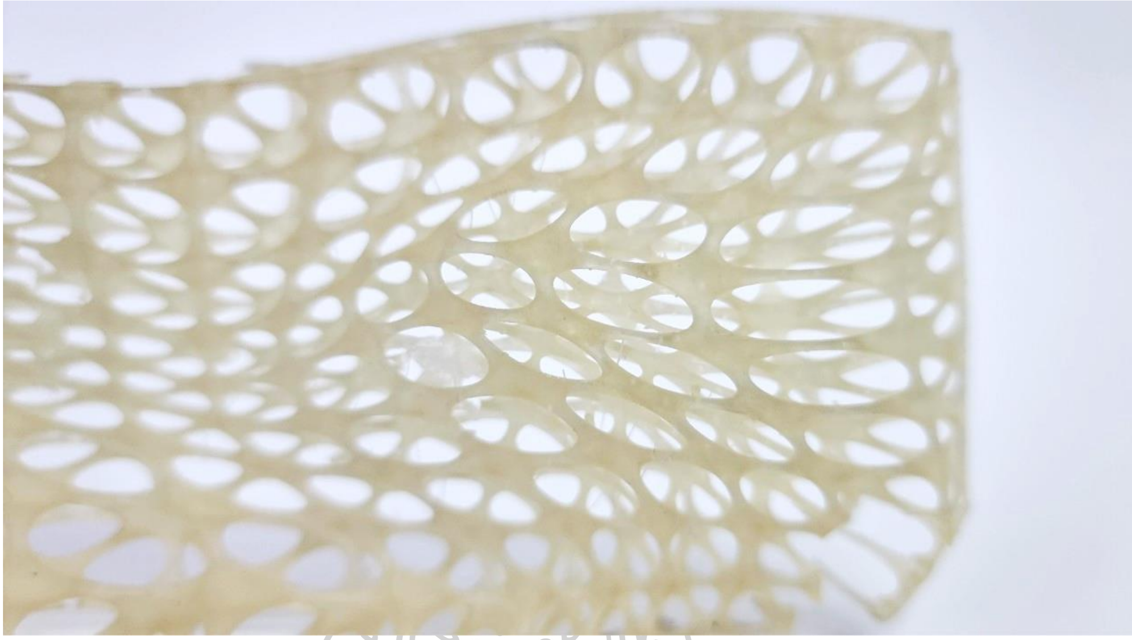

Figure 131 Experimental procedure for 3D printing.

Figure 132 3D Printed Physical Model to Simulate Scale and Proportions.

Figure 133 3D Printed Physical Model to Simulate Scale and Proportions.

3.5.6 Experiment 6: Voronoi Furniture

Figure 134 Voronoi and Organic Joint equation furniture set

Figure 135 Voronoi and Organic Joint equation furniture set

Figure 136 Voronoi and Organic Joint equation chair

Figure 137 Voronoi and Organic Joint equation chair

Figure 138 Voronoi and Organic Joint equation chair

Figure 139 Voronoi and Organic Joint equation furniture set

Figure 140 Voronoi and Organic Joint equation furniture set

Figure 141 Voronoi and Organic Joint equation chair

Figure 142 Voronoi and Organic Joint equation chair

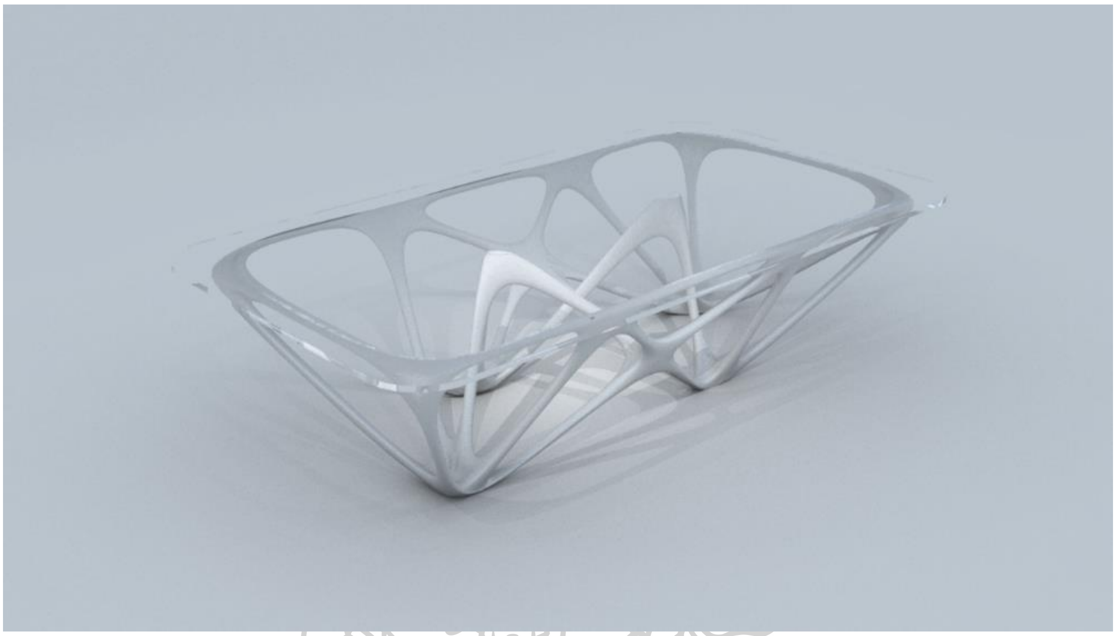

Figure 143 Organic Joint coffee table

Figure 144 Organic Joint coffee table

Figure 145 Voronoi and Organic Joint equation furniture set

Figure 146 Voronoi and Organic Joint equation furniture set

Figure 147 Voronoi and Organic Joint equation table

Figure 148 Voronoi and Organic Joint equation furniture set

Figure 149 Voronoi and Organic Joint equation chairs

Figure 150 Voronoi and Organic Joint equation chairs

3.5.7 Experiment 7: Biomorphic Coral-Inspired Table

The researcher created a table inspired by coral concepts. This involved identifying load and transfer points using scientific and mathematical principles, drawing inspiration from the physical characteristics of coral cell structures. Surface calculations were then employed to optimize structural surface area and minimize unnecessary sections, thereby reducing the weight borne by the structure itself and resulting in the development of the Biomorphic Coral-Inspired Table. In terms of production, furniture fabrication can utilize synthetic fibers sourced from materials such as PLA plastic or Polylactic Acid, a recycled bioplastic capable of biodegradation and repurposing as fibers for printed items.

Moreover, environmental conservation was seamlessly integrated into the project alongside considerations of art and design. The resulting shape bore a striking resemblance to coral formations, serving as a poignant reminder of escalating environmental crises, particularly the degradation and disappearance of coral reefs due to global warming. Consequently, the table transcends mere furniture, emerging as a powerful work of art that ignites heightened awareness and concern for the environment.

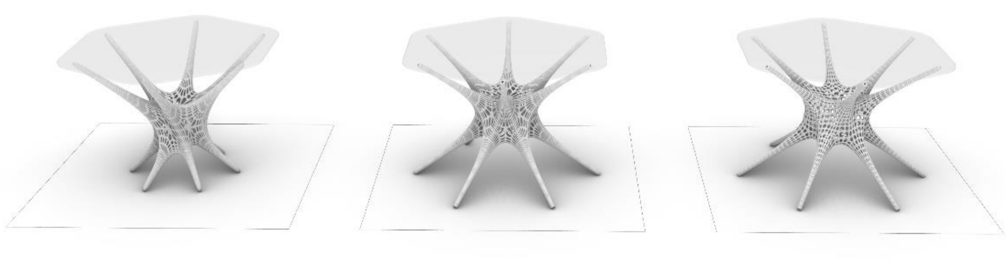

Figure 151 Table from organic joint equation combined with coral shape

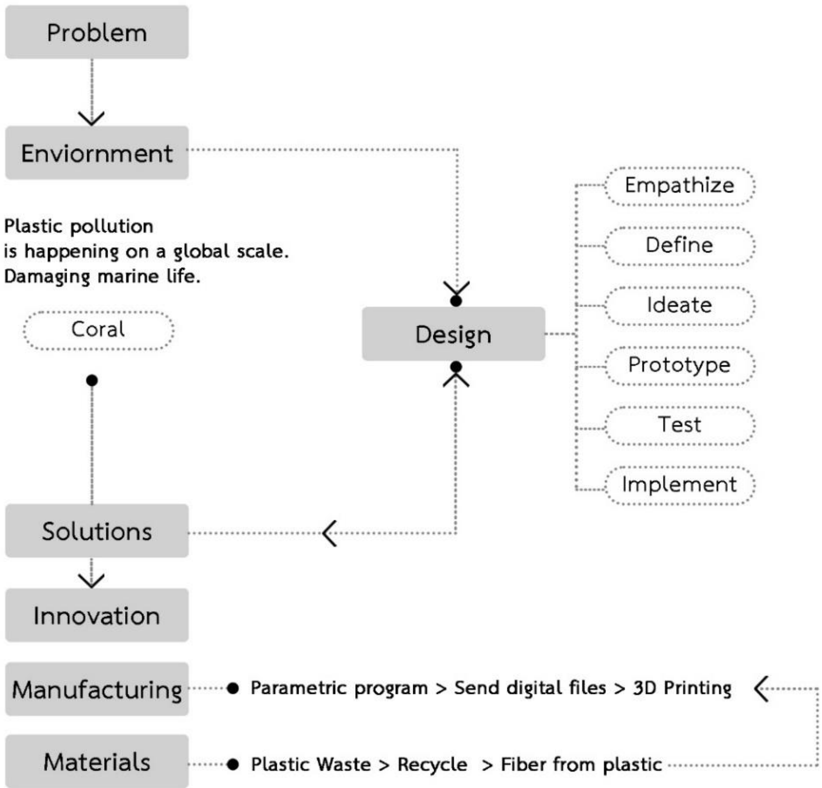

Figure 152 A framework of experimental principles for parametric equations, organic design, and coral concepts.

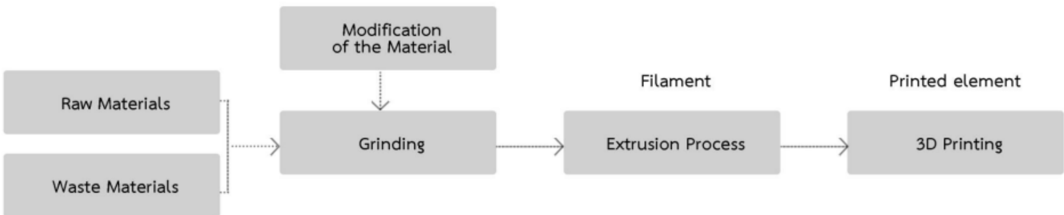

Figure 153 The conceptual process for utilizing waste materials in 3D printing is outlined

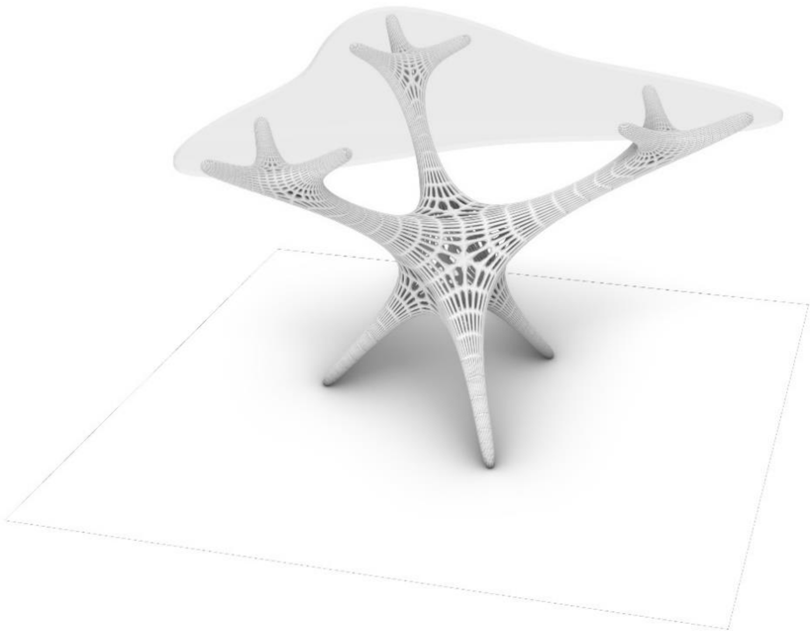

Figure 154 Table from organic joint equation combined with coral shape.

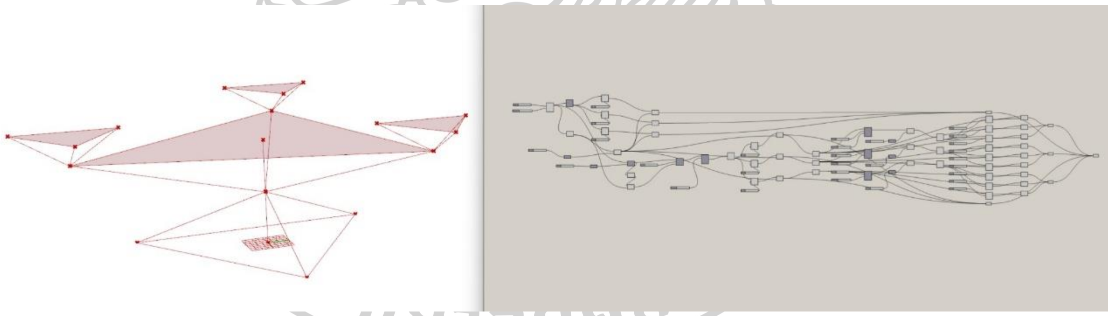

Figure 155 Determination of force loading and transfer points and writing parametric equation scripts.

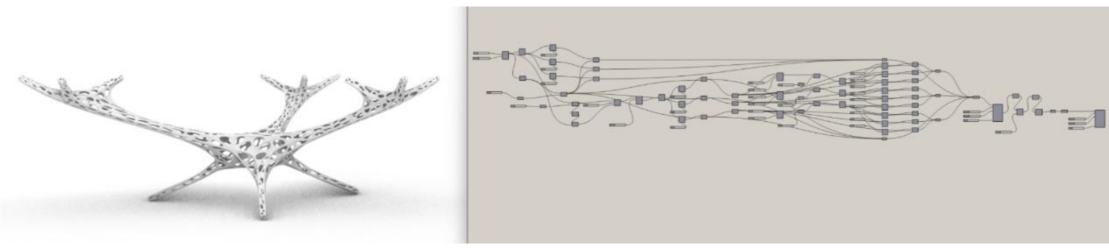

Figure 156 Biomorphic Coral-Inspired Table: Parametric Equations Script

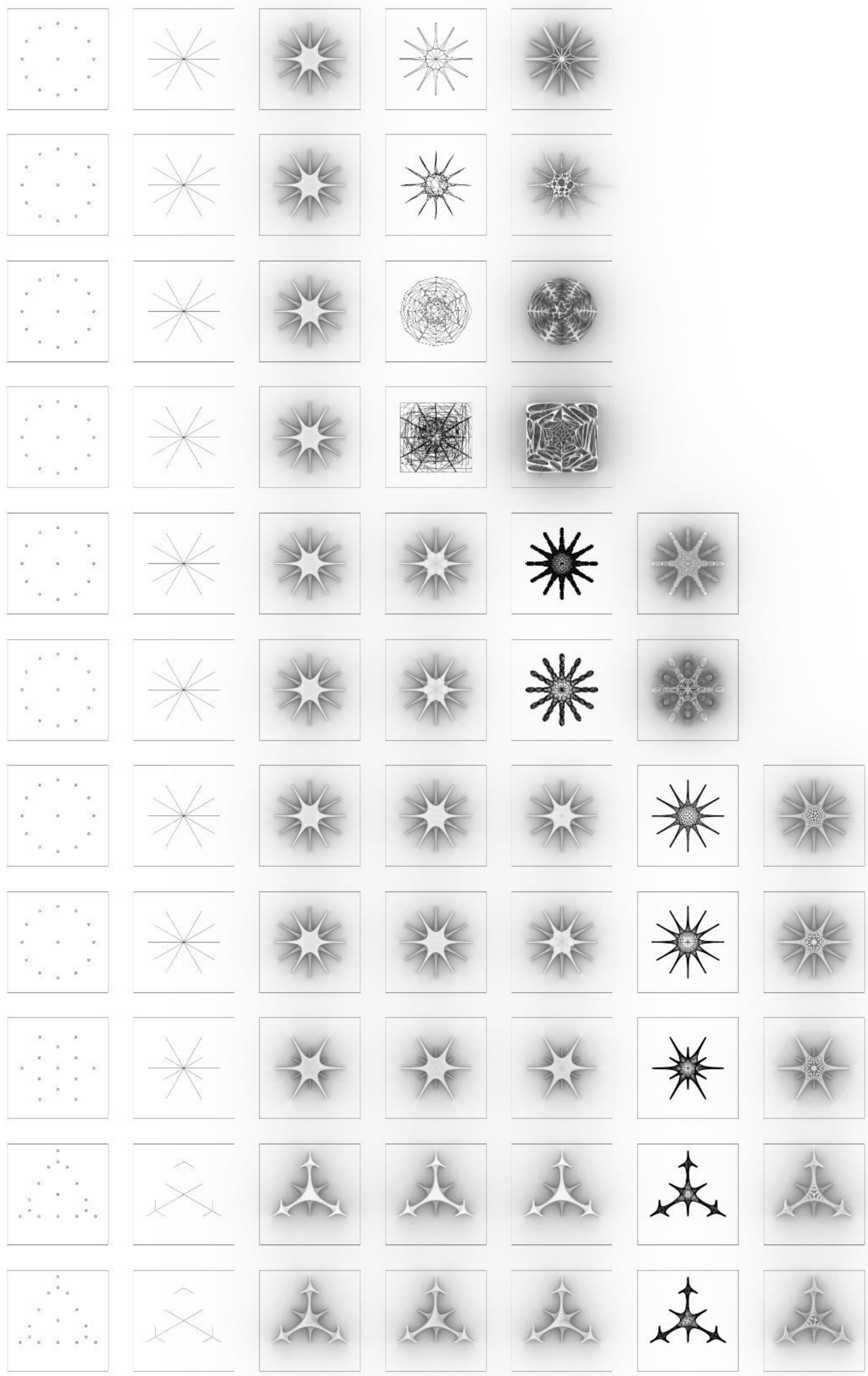

Figure 157 The simulation of table model development, incorporating the organic joint equation and a coral-shaped design.

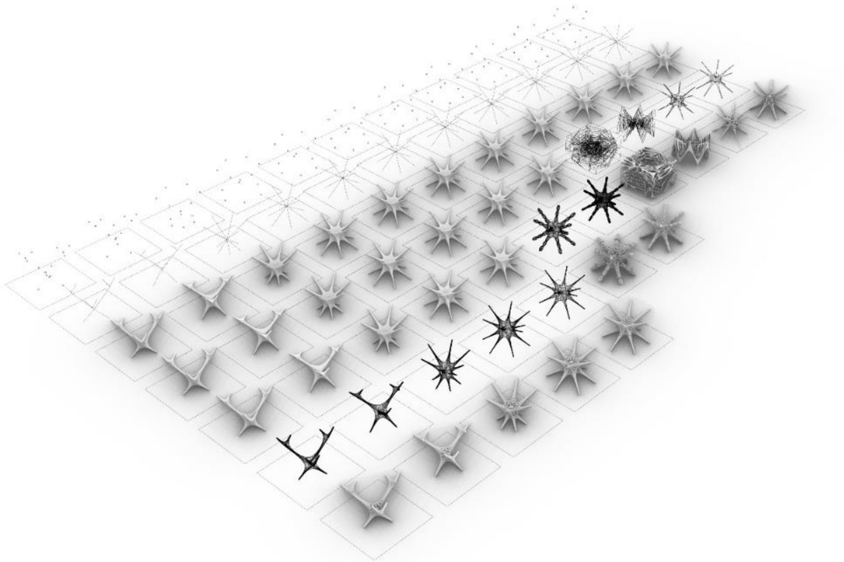

Figure 158 The simulation of table model development, incorporating the organic joint equation and a coral-shaped design.

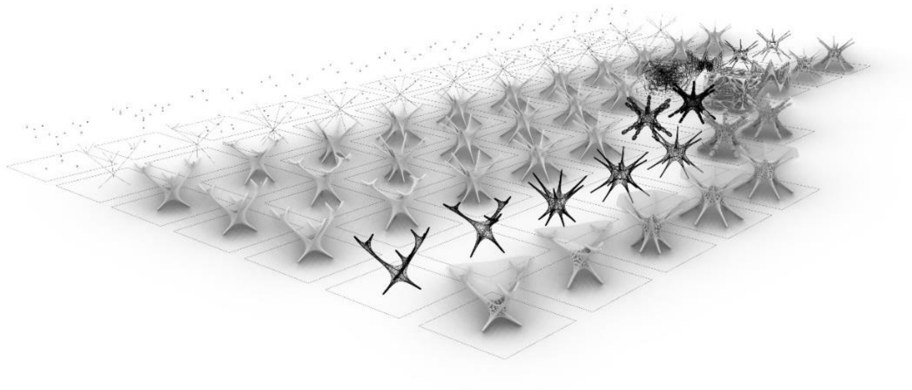

Figure 159 The simulation of table model development, incorporating the organic joint equation and a coral-shaped design

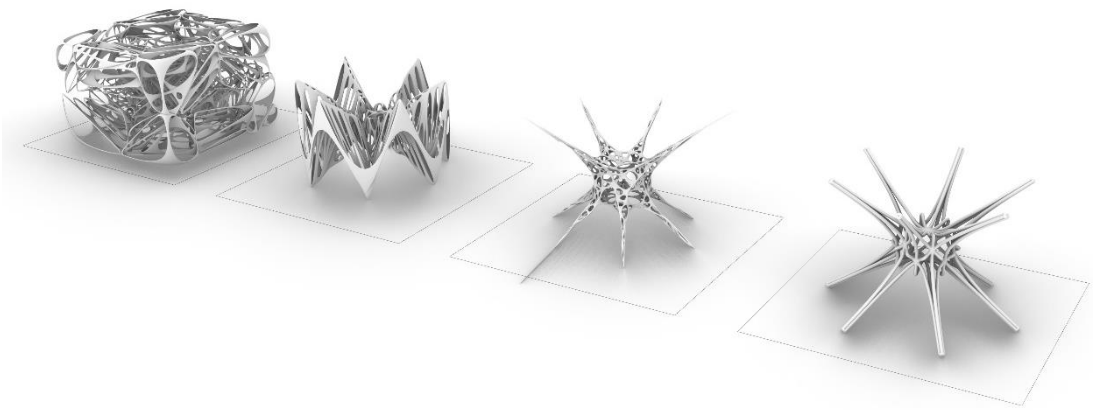

Figure 160 Tables from organic joint equation combined with coral shape

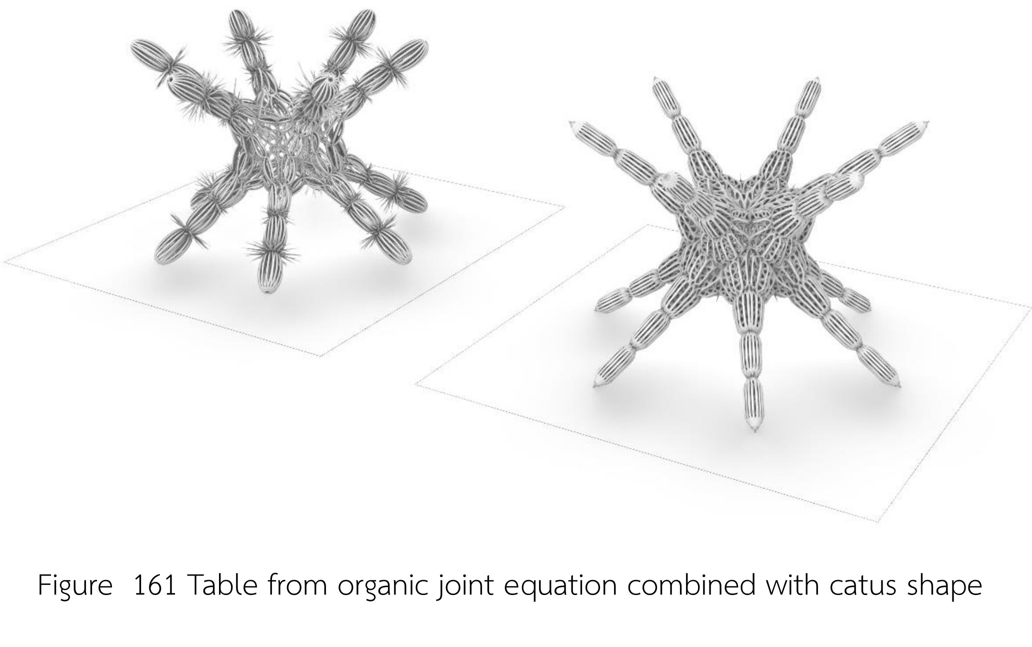

Figure 161 Table from organic joint equation combined with catus shape

Figure 162 Tables from organic joint equation combined with coral shape

Figure 163 Table from organic joint equation combined with coral shape

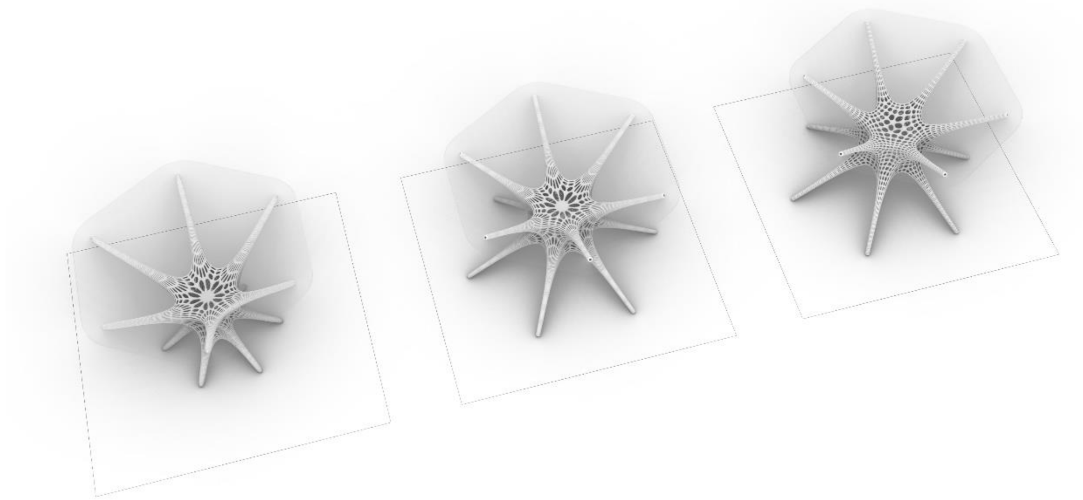

Figure 164 Tables from organic joint equation combined with coral shape

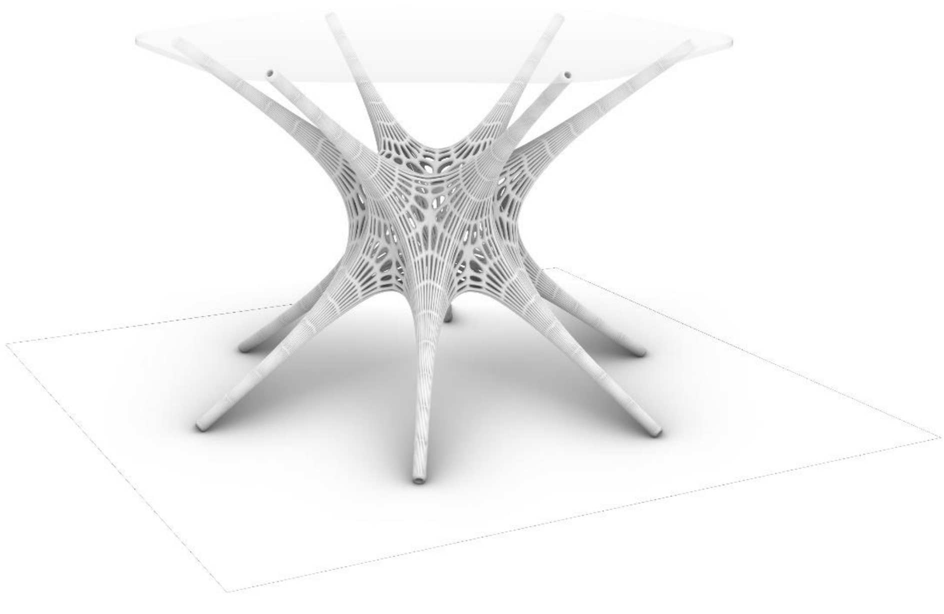

Figure 165 Table from organic joint equation combined with coral shape.

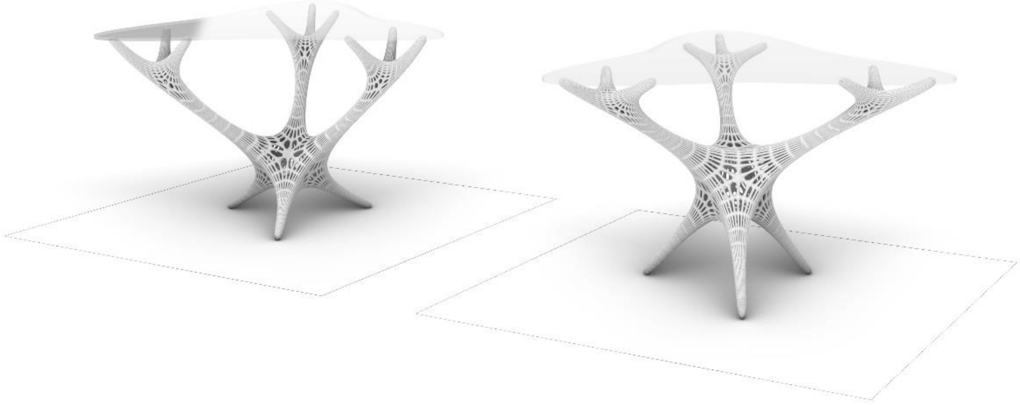

Figure 166 Table from organic joint equation combined with coral shape.

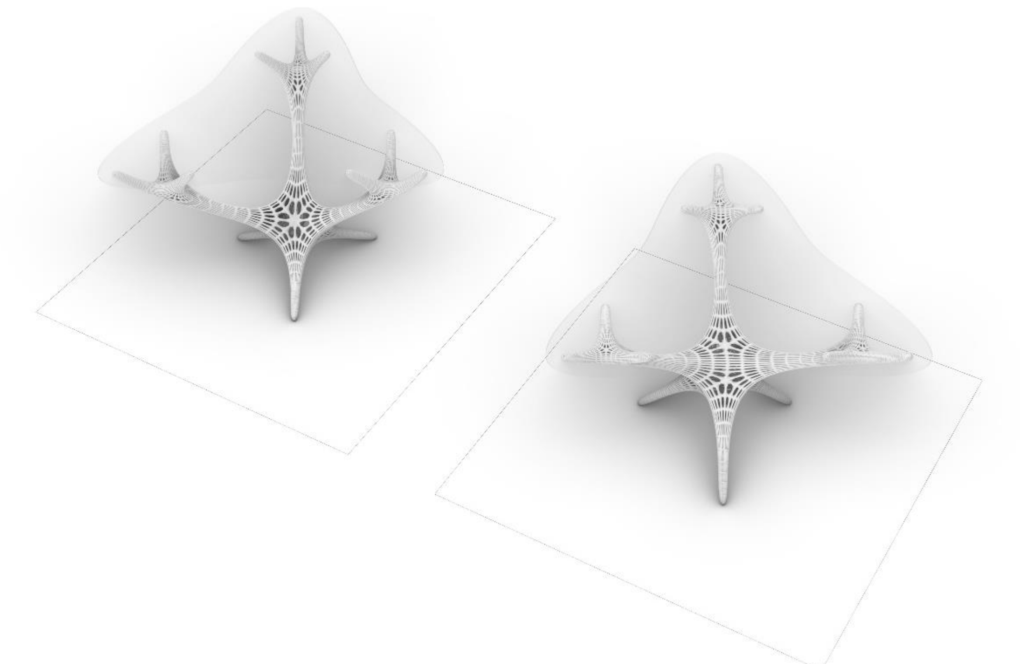

Figure 167 Table from organic joint equation combined with coral shape.

Chapter 4
Research Results

4. Research Results

The outcomes of the research are bifurcated into two categories: interior design and furniture design, both employing parametric concepts. This design approach amalgamates art and design with mathematics and science, adhering to established principles. In furniture and interior design endeavors, functionality holds paramount importance, thereby guiding the design process with ideas grounded in scientific and mathematical principles. Factors such as force transmission and the reinforcement of furniture strength in accordance with anticipated usage patterns are meticulously considered. Furthermore, the integration of art is imperative to ensure aesthetic appeal, resulting in the fusion of the aforementioned concepts within each piece.

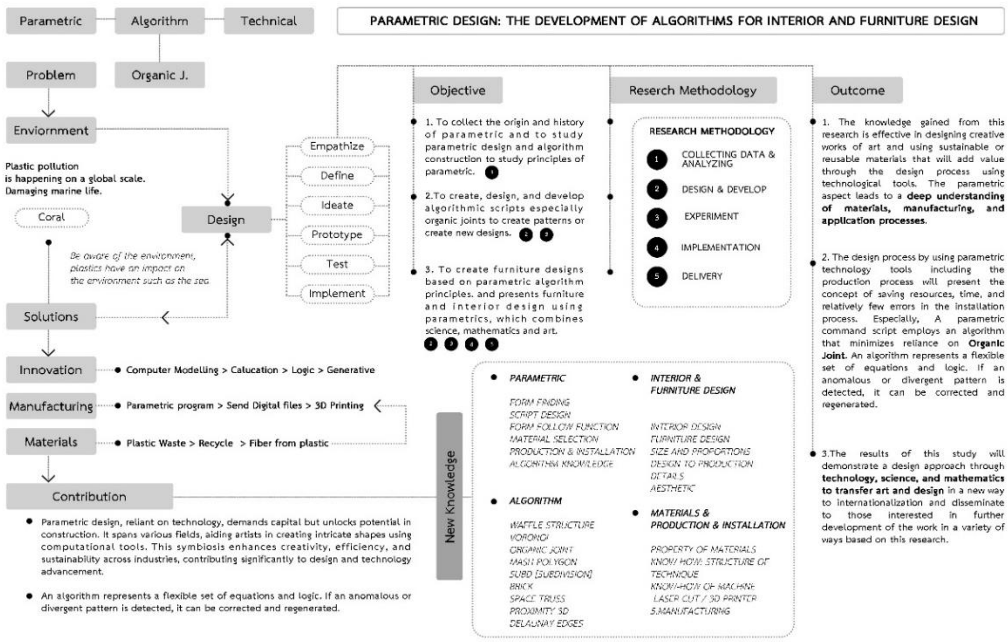

Figure 168 Concept summary diagram

4.2 Research Results

4.2.1 Interior design

Design guidelines must take into account the principles and methods of parametric work and different types of design work. Designers must carefully consider the feasibility of the manufacturing process, space, utility, time, complexity, and installation methods. Designers should define real-world design problems and use parametric thinking and digital parametric design tools where applicable (Assasi, 2019). The creation of codes and parametric equations to create designs can be applied in various design applications such as architectural design, product design, furniture design and fashion design.

This research focuses on designing a staircase using parametric design methods due to the project's complexity, both in terms of the unique design and the method of assembly. In addition to the limited design and assembly time, this staircase only took two weeks to complete. It only took one designer to survey the site, design, develop and produce detailed drawings for cutting and installation. Parametric programs are therefore a good help in calculating details and making quick adjustments using parameters, and computers help to calculate the flowability of parametric ladder degrees. Another advantage of parametric is that a production process that can transfer detailed information of the workpiece to new methods. For example, this staircase uses HMR wood panels that are cut to order with a CNC machine, which is convenient and fast in the production process. The case study of this staircase design includes the following steps: 1. Measurement method to check area, size, structure, and various limitations. 2. Creating three-dimensional virtual models from computer models using parametric equations for design and model development. 3. Printing a three-dimensional physical model to understand the size and proportions. 4. Using computers to help calculate the flowability of parametric ladder degrees. 5. Drawing and numbering to use files for CNC cutting assembly and installation. 6. Send the file to the CNC machine for cutting. 7. Installation steps required to build scaffolding to attach the panels to the main staircase and for painting. 8. Deliver the work.

From the basics of design with the concept of parametric design, this idea consists of writing command scripts to instruct the computer to work with an algorithm or a set of logical methods to achieve results that the designer has previously foreseen. The highlight of parametric design is the ability to create anything from simple designs to complex patterns that can be processed by humans. The advantage lies in the speed of the design process, as the results can be displayed while you adjust the parameters or edit equation sets. Another important point is the production process, where detailed information about the workpiece can be transferred to new methods such as 3D printing, laser cutting and CNC (computer et al.), which are convenient and fast in the production process. In this production process, for example, CNC cutting on HMR wood and spray painting were carried out. More than 200 parts were assembled on site to create a parametric staircase design that perfectly matches the interior design.

This research focuses on the design of stairs using parametric design. The aim is to understand the design principles and process of parametric design, including manufacturing and installation methods. It is concluded that the advantage of parametric design work lies in the ability to create designs that are too complex for humans to process and to be able to show the processed design steps when editing parameters or editing sets of equations. This allows designers to see the finished product and quickly make changes and adjustments. Whereas if we just use humans to design, there may be errors, but if we use parametric technology to assist with the calculations, it will deliver results. This is different from the traditional process of sketching or general molding methods. Therefore, parametric design methods help in design where humans act as facilitators in controlling variables, parameters and conditions such as time, complexity of work, assembly and installation to achieve results that are suitable for the use or area in question.

The results of this knowledge can serve as a guide for the presentation of designs, art products and interior design using new techniques and can be applied in the future. It is a conceptual design approach with scripting to create shapes using parametric programming to obtain a design piece that is different and unique.

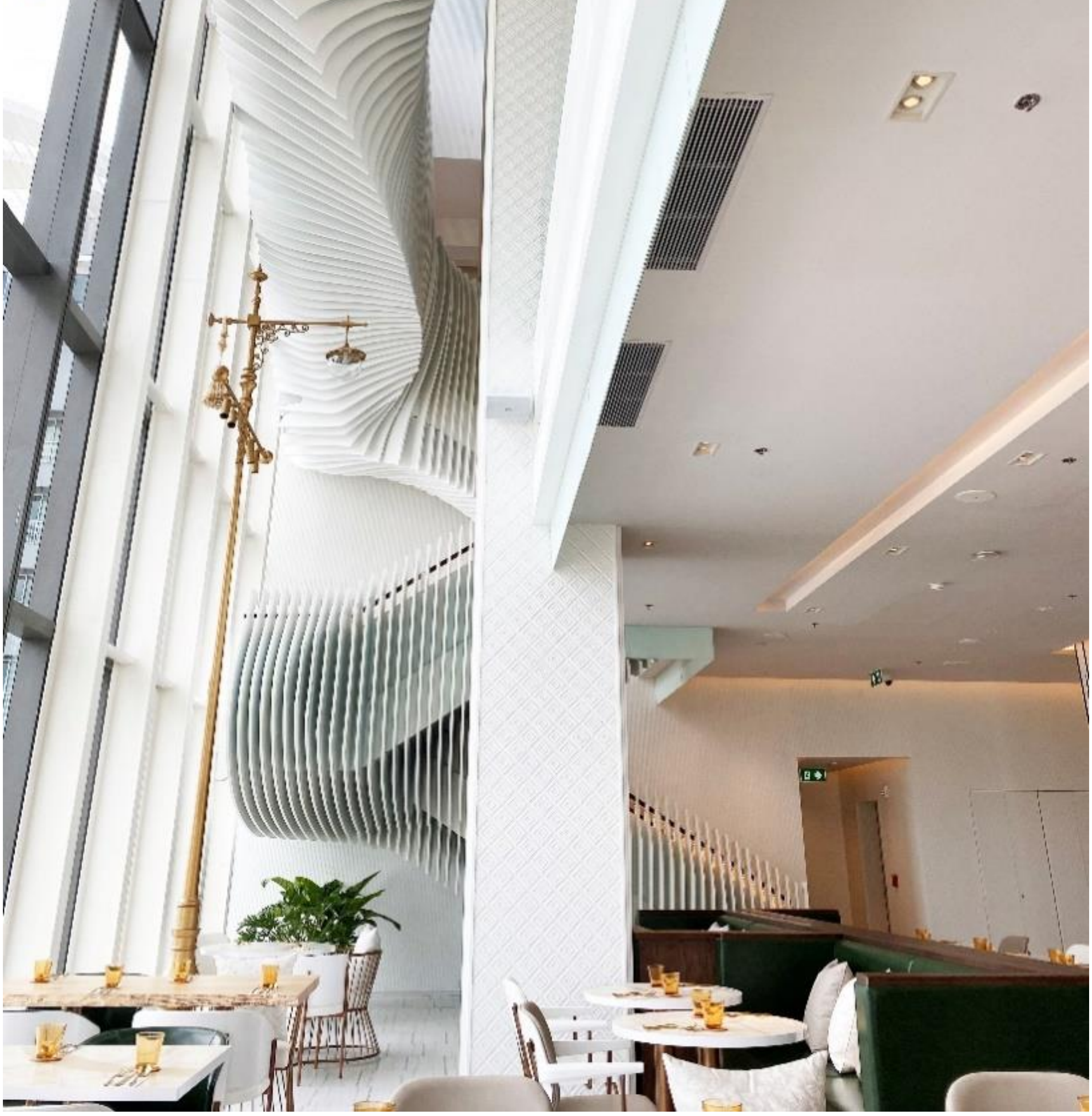

Figure 169 Final the Parametric Staircase

Figure 170 Final of The Parametric Staircase and Installation

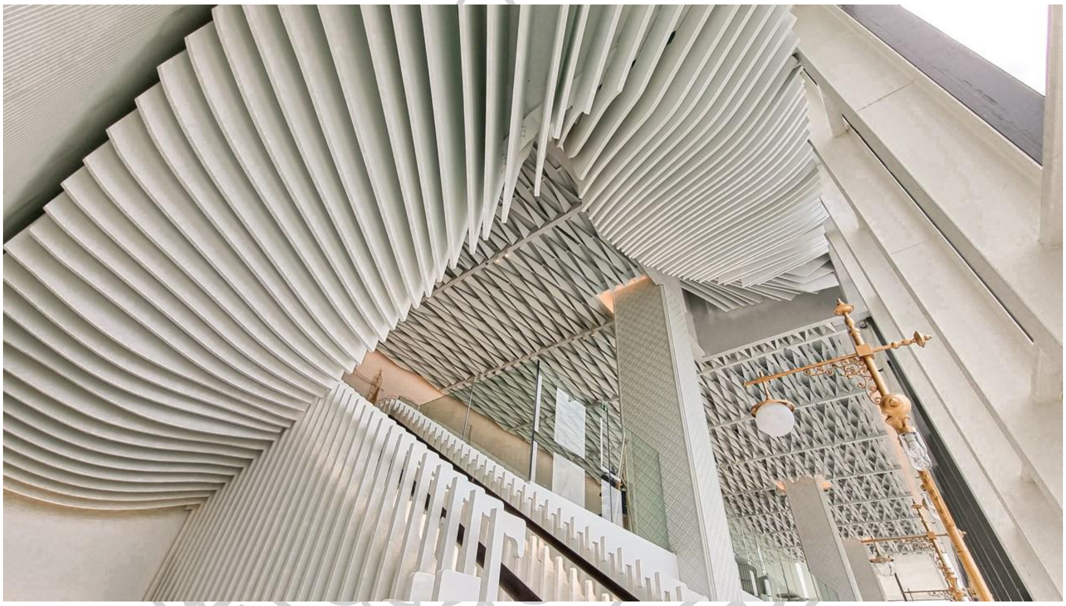

Figure 171 Final of The Parametric Staircase and Installation

Figure 172 Final the Parametric wall

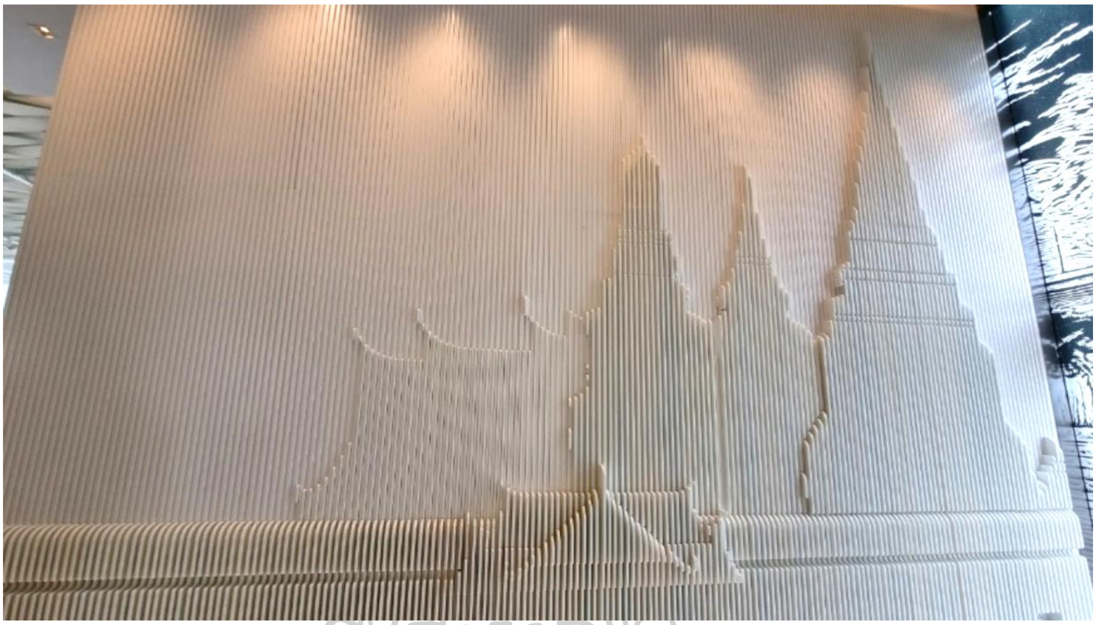

Figure 173 Final the Parametric wall

Figure 174 Final the Parametric wall

4.3.2 Furniture

The creation of furniture utilizing parametric concepts encompasses various forms, necessitating a fusion of production knowledge with design expertise. Taking parametric furniture design as an example, the researcher devised a table employing the concept of corals. This involved identifying load and transfer points based on scientific and mathematical principles, leveraging the physical characteristics of coral cell structures. Surface calculations were employed to optimize structural surface area and minimize unnecessary sections, thereby alleviating the weight borne by the structure itself and culminating in the creation of the Biomorphic Coral-Inspired Table.

In addition to considerations of art and design, the researchers integrated environmental conservation into the project, noting the striking resemblance of the resulting shape to coral formations. This alignment with natural phenomena serves as a poignant reminder of the escalating environmental crises, particularly the ongoing degradation and disappearance of coral reefs amidst global warming. Consequently, the resultant piece transcends mere furniture, serving as a work of art that fosters heightened awareness and concern for the environment.

In terms of production, furniture fabrication can utilize synthetic fibers derived from materials such as PLA plastic or Polylactic Acid, a recycled bioplastic that biodegrades and can be repurposed as fibers for printing items. Thus, it can be inferred that the application of parametric principles in furniture design offers a multitude of options, spanning from the design phase to production, installation, and even the selection of materials.

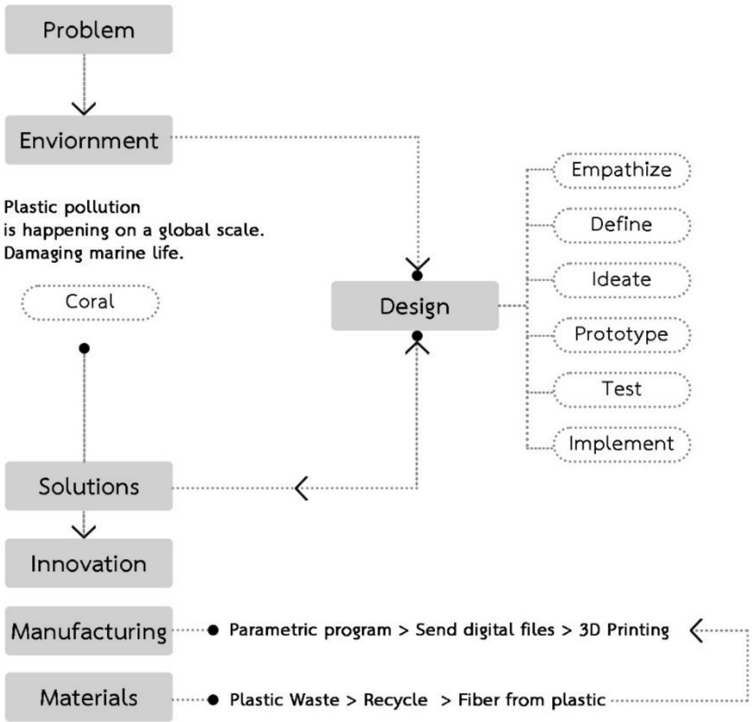

Figure 175 A framework of experimental principles for parametric equations, organic design, and coral concepts.

Figure 176 Table set by parametric design

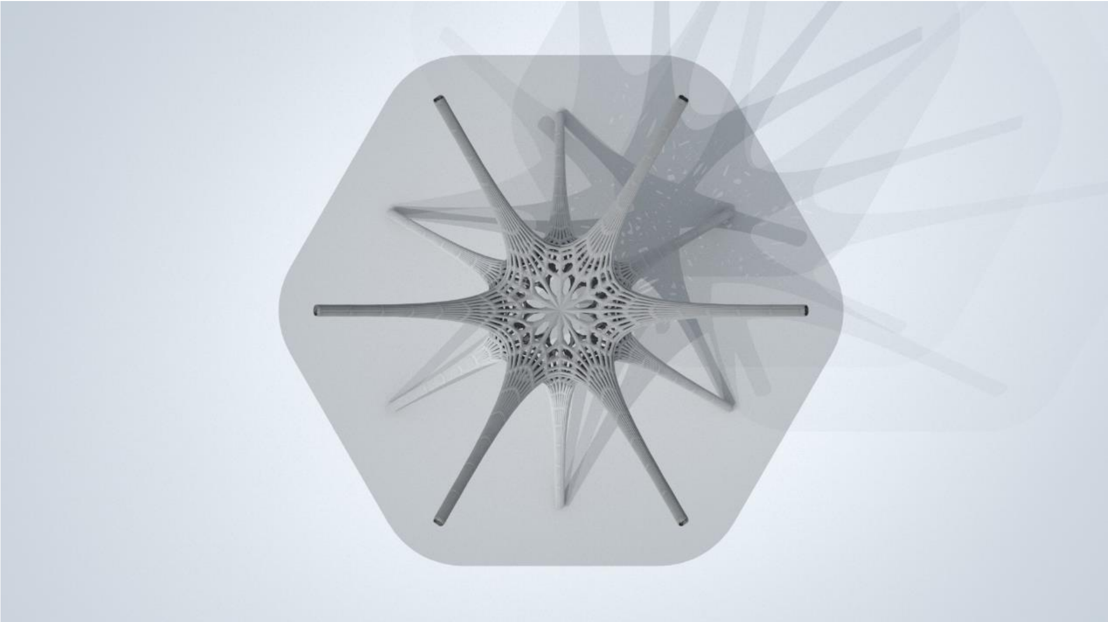

Figure 177 Table from organic joint equation combined with coral shape

Figure 178 The table with organic joints seamlessly integrates a coral-shaped design with concealed lighting elements, resulting in an aesthetic

Figure 179 Table from organic joint equation combined with coral shape

Figure 180 Table from organic joint equation combined with coral shape

Figure 181 Table from organic joint equation combined with coral shape

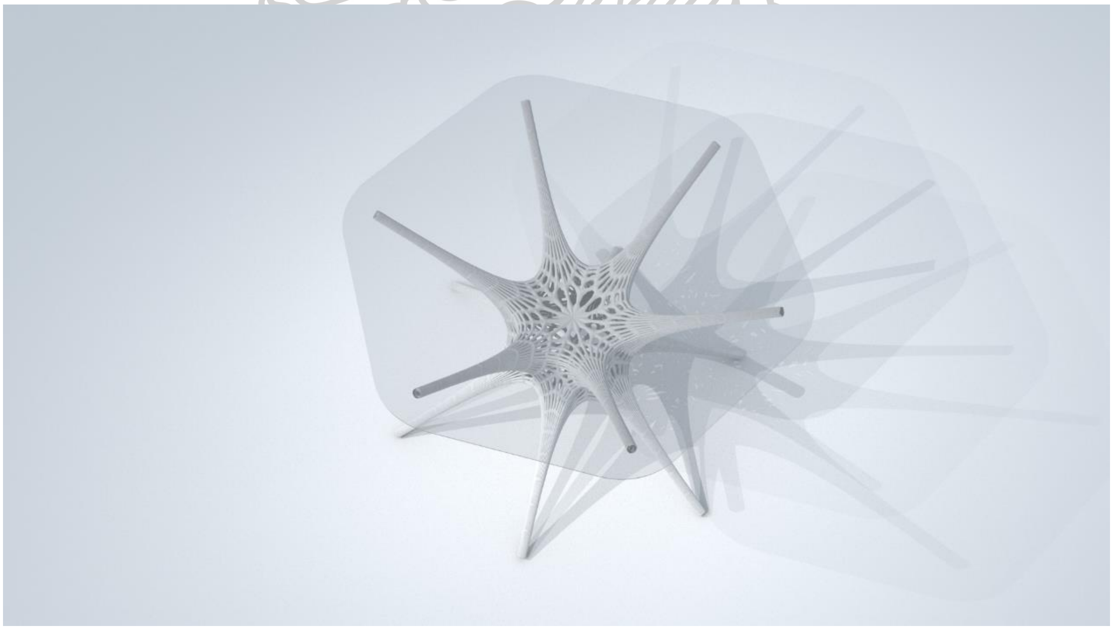

Figure 182 Table from organic joint equation combined with coral shape

Figure 183 Table from organic joint equation combined with coral shape

Figure 184 Table from organic joint equation combined with coral shape

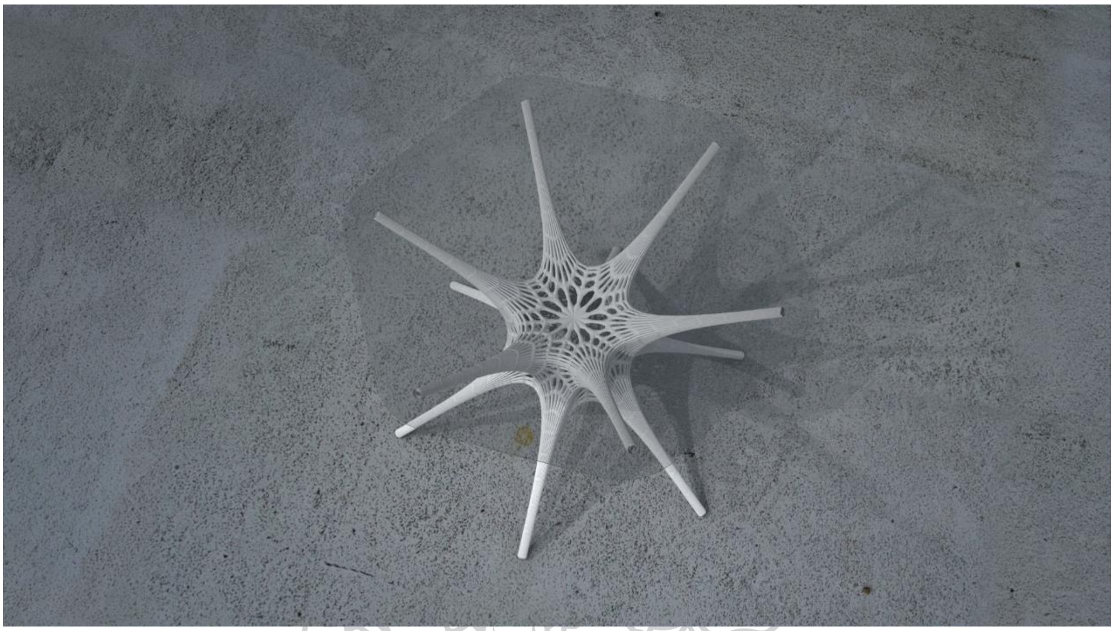

Figure 185 Table from organic joint equation combined with coral shape

Figure 186 The table with organic joints seamlessly integrates a coral-shaped design with concealed lighting elements, resulting in an aesthetic

Figure 187 Table from organic joint equation combined with coral shape

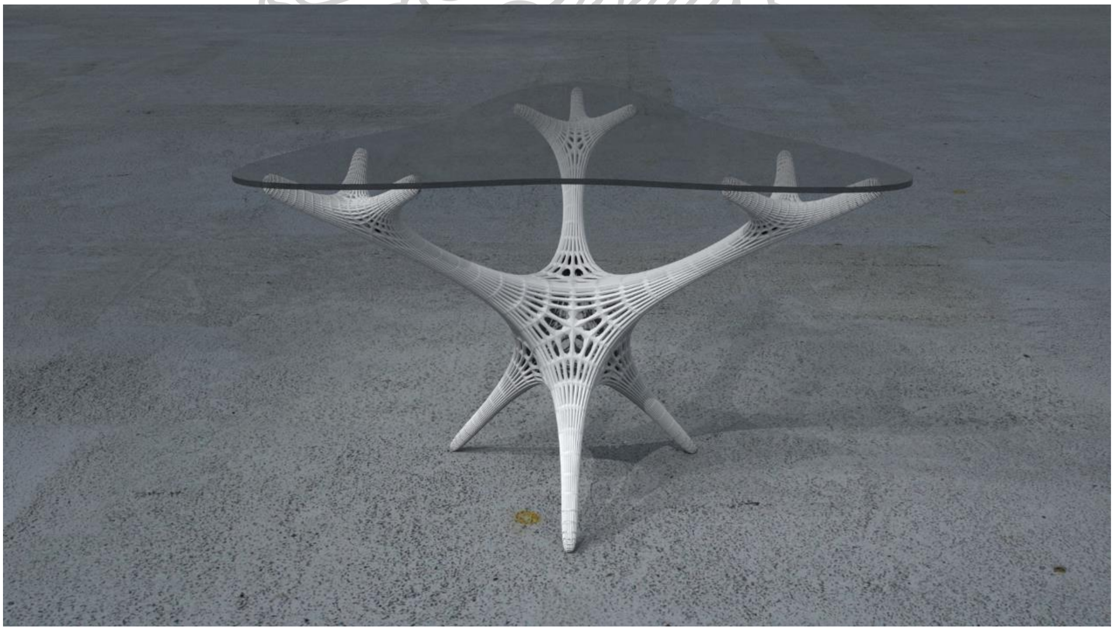

Figure 188 Table from organic joint equation combined with coral shape

Figure 189 Table from organic joint equation combined with coral shape

Figure 190 The table with organic joints seamlessly integrates a coral-shaped design with concealed lighting elements, resulting in an aesthetic

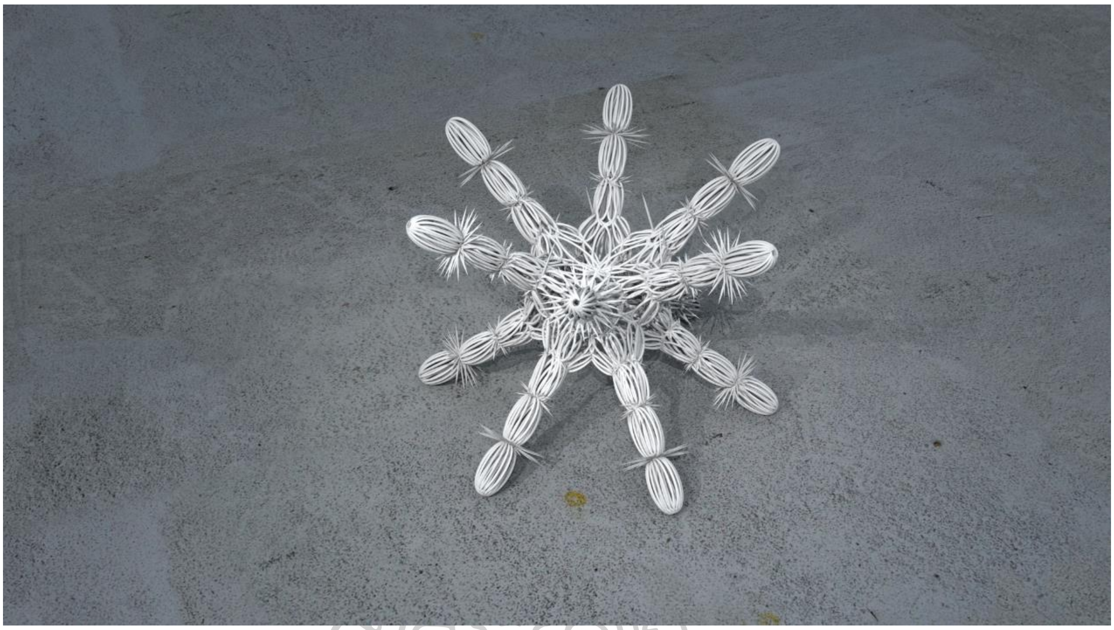

Figure 191 Table from the organic joint equation combined with the shape of a cactus

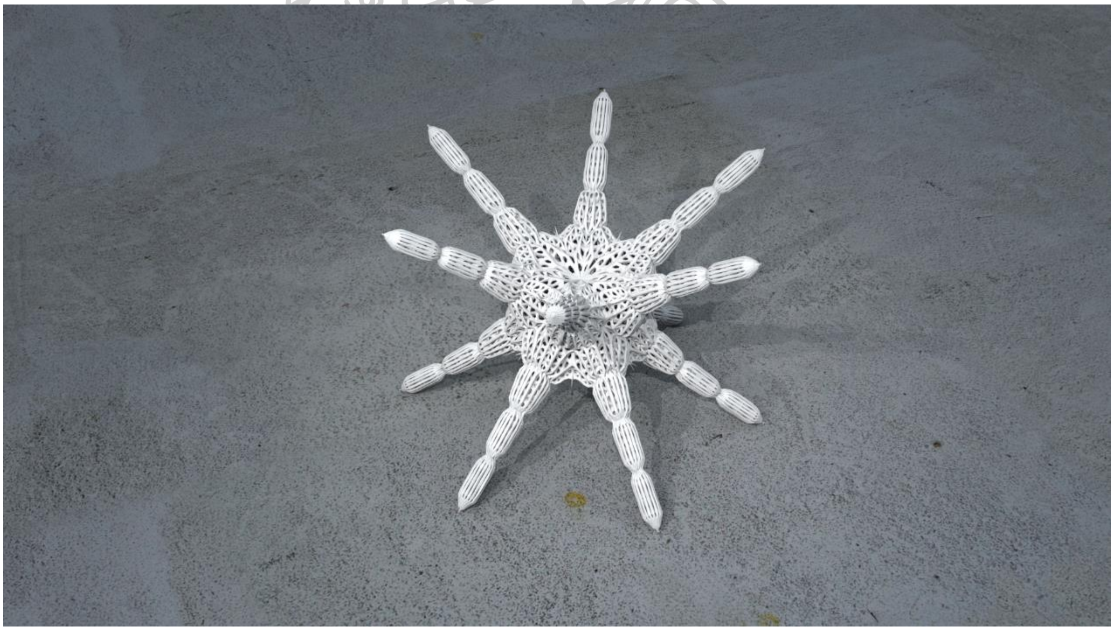

Figure 192 Table from the organic joint equation combined with the shape of a cactus

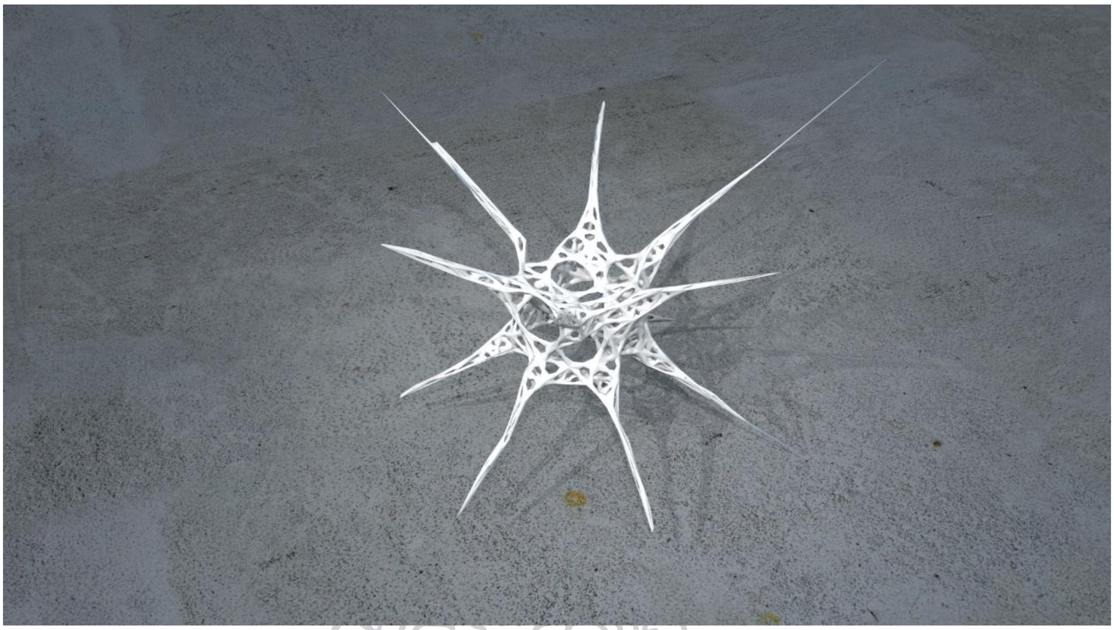

Figure 193 Table from organic joint equation combined with coral shape

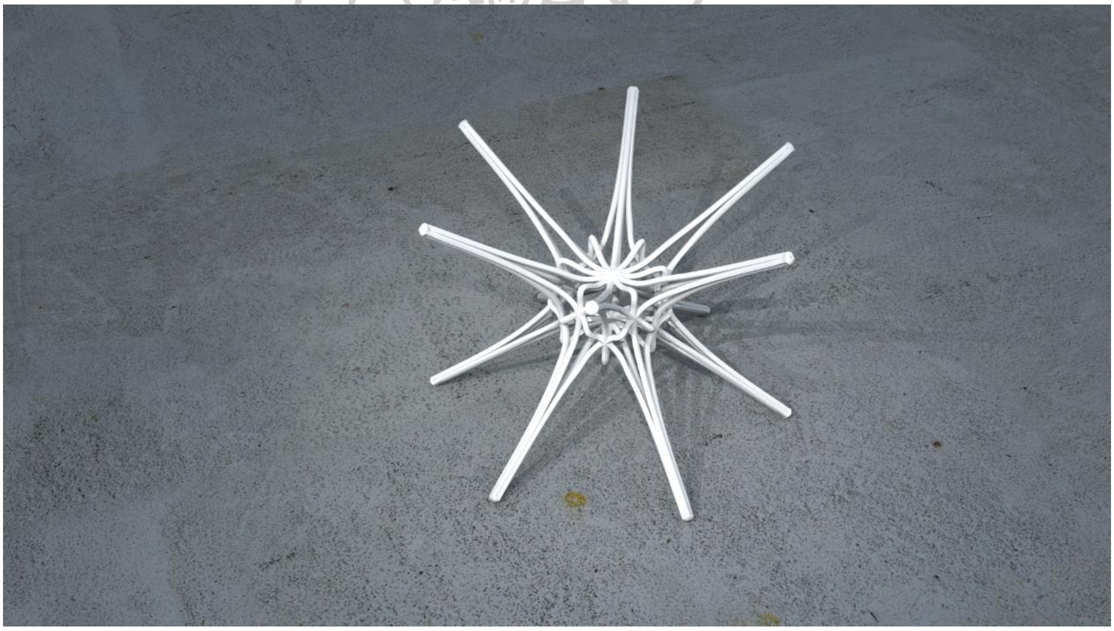

Figure 194 Frame table legs

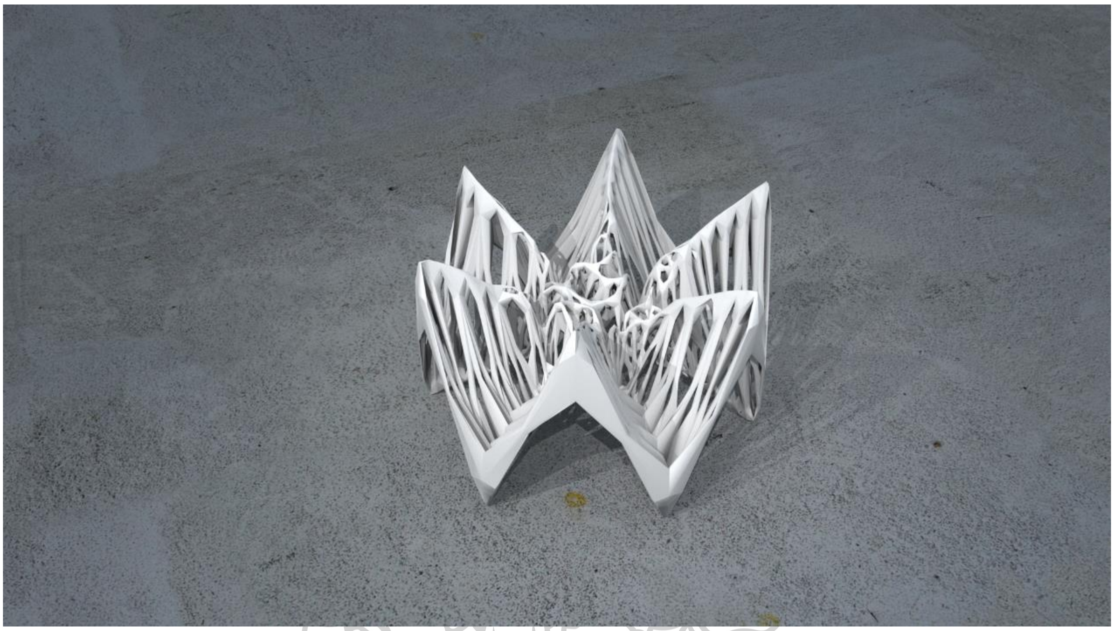

Figure 195 Table from Voronoi equation

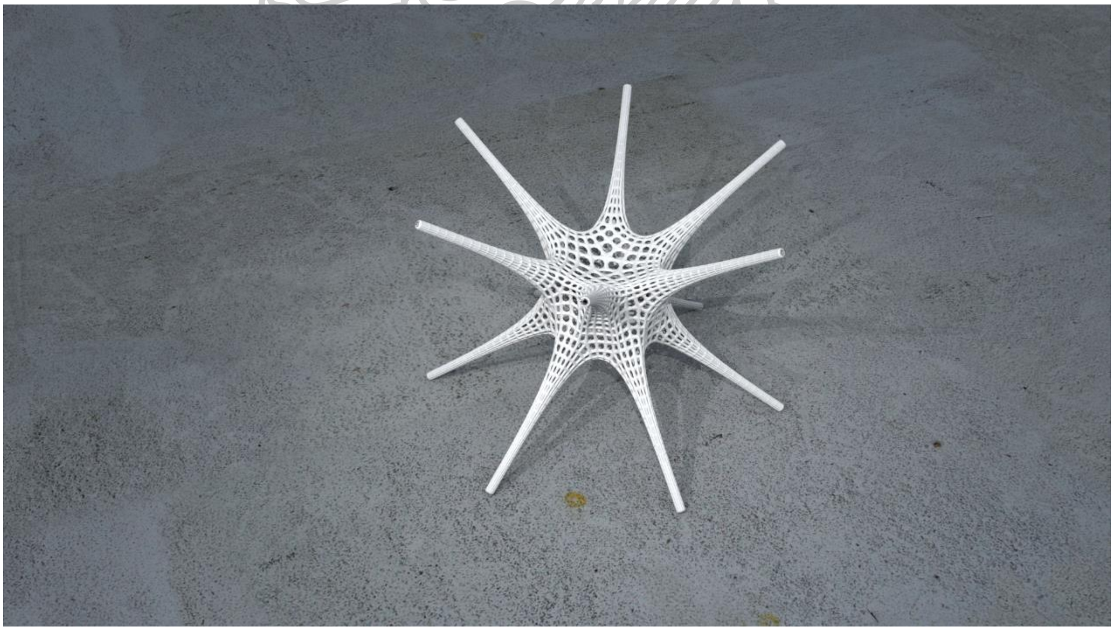

Figure 196 Table from organic joint equation combined with coral shape.

Figure 197 Table from organic joint equation combined with coral shape.

Figure 198 Table from organic joint equation combined with coral shape.

Chapter 5
Conclusion

5. Conclusion

5.1 Conclusion

In conclusion, parametric design has been widely used to explore design possibilities in various fields such as engineering, architecture, interior, and industrial design. One of the predominant software tools was Grasshopper, a graphical algorithmic platform seamlessly integrated with Rhinoceros, which is widely used for 3D modeling. By applying parametric equations, designers were able to create dynamic and flexible designs, proficiently tackle complex problem-solving tasks, deconstruct intricate structures and present their creations with exceptional precision.

Parametric design has been observed to have a wide range of potential applications and is constantly developing in various fields such as engineering, architecture, interior and industrial design. The phenomenon has been associated with the unique and diverse forms it offers, its application in various forms of computation and the many possibilities in design fields. Parametric design has been proposed to serve as a guide for designs that require uniqueness and differences in form and design method. It is used in a wide variety of fields because parametric designs can be customized, edited in real time and adapted to different needs or conditions. The ongoing development of parametric methods has influenced various industrial systems, such as 3D printers, that seek to meet their demanding design requirements. These advances have spawned new definitions, solutions and applications in various disciplines that have led to new opportunities.

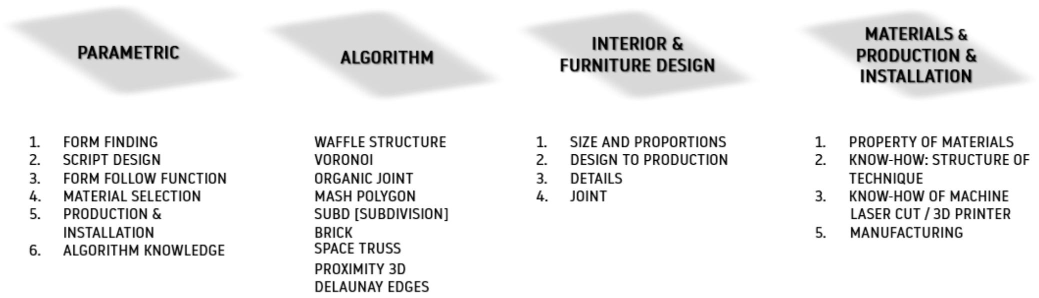

Figure 199 Diagram Conclusion

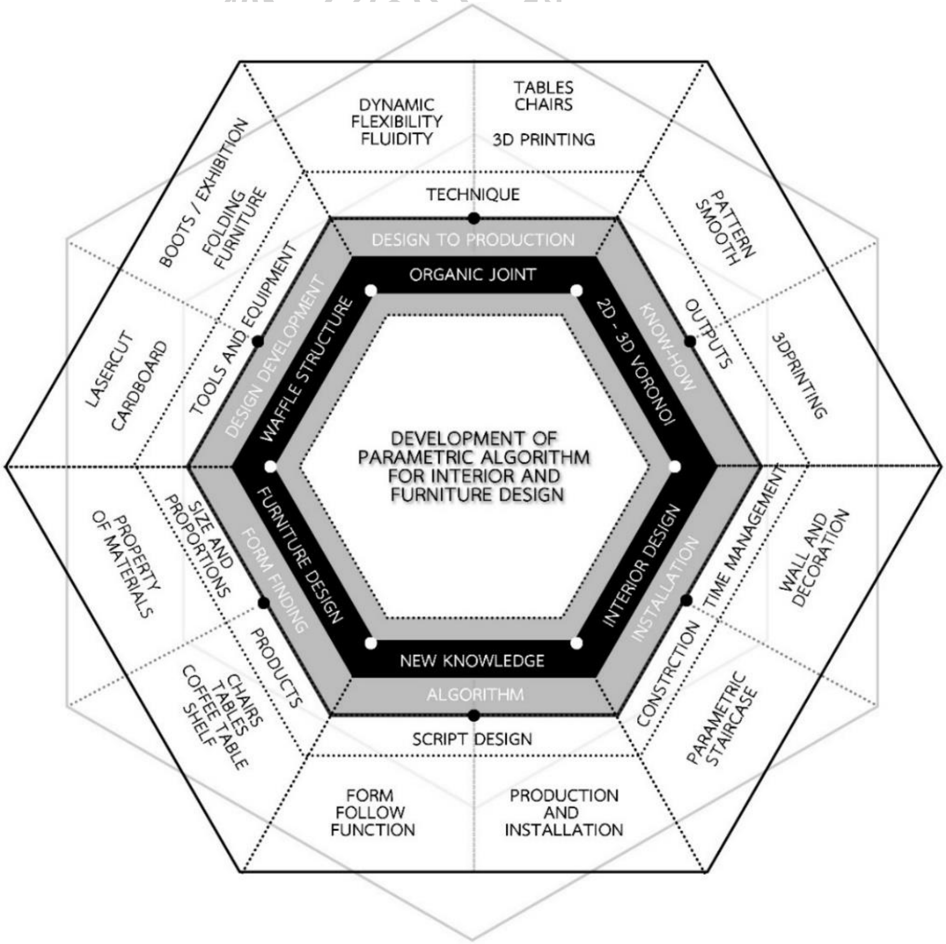

Figure 200 Diagram Conclusion

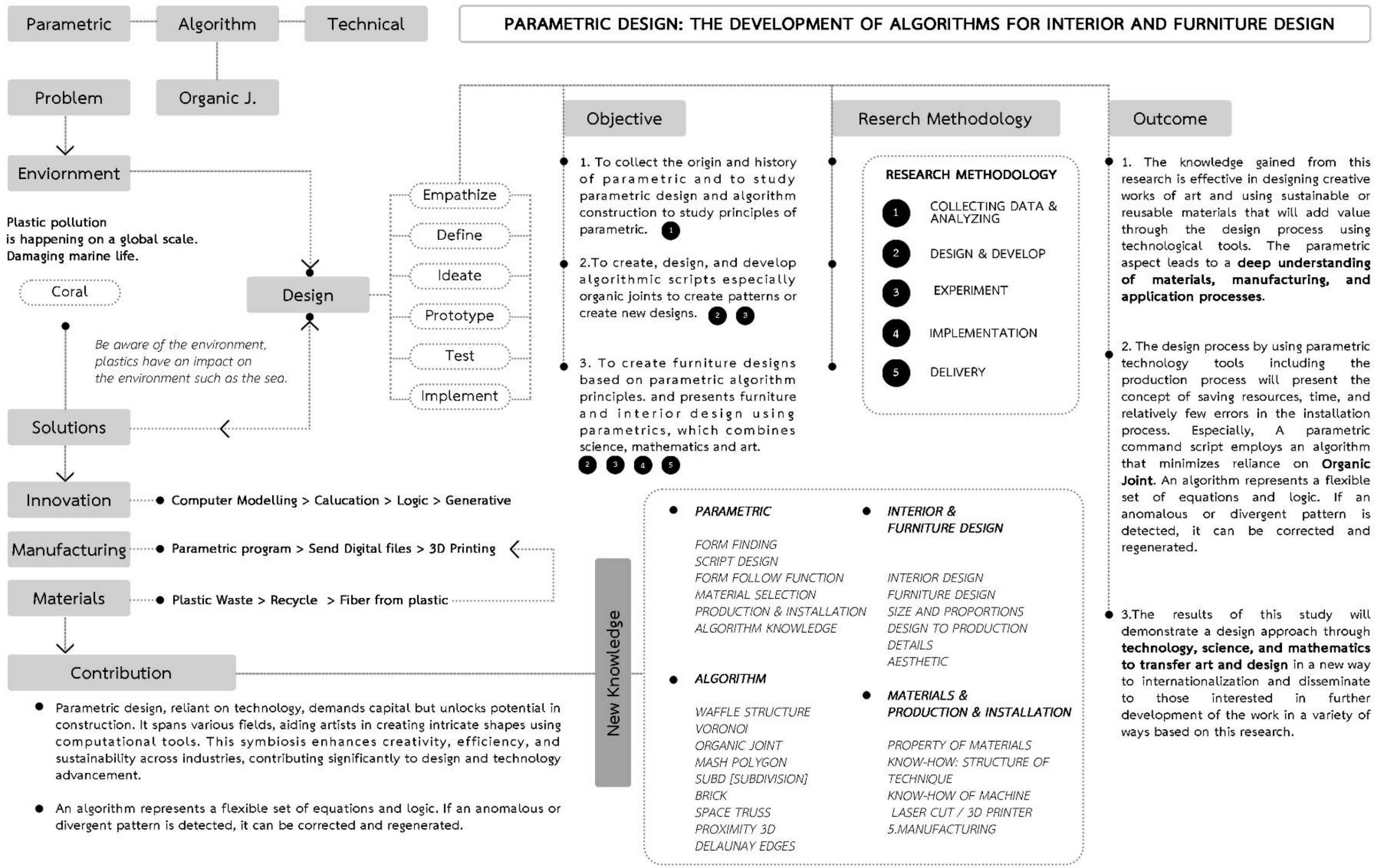

Figure 201 Concept summary diagram

Objective 1. To collect the origin and history of parametrics, to study parametric design and construction of algorithms to investigate the principles of parametrics.

The results of the study indicate that the principles of parametric can be divided into two different methods: 1. Experimentation with Simulation Models: In this method, simulation models are used to conduct experiments and recognize mathematical theories. Illustrative examples are Antoni Gaudí's exploration of hanging sand formations or the immersion of objects in soap, aligning to Frei Otto's theory of optimal surfaces in form finding. 2. Use of computer programs, the second method involves the use of computer programs as an assistant in the calculation of mathematical principles. In the majority of Zaha Hadid's works, the application of the program is primarily focused on the calculation of shapes. Consequently, a comprehensive understanding of program principles is essential, accompanied by the ability to develop new scripts and equations. These findings underscore the diverse methodologies used in parametric design. They range from firsthand experimentation with physical models to the sophisticated use of computer programs in the creation of contemporary design expressions.

Objective 2. To create design and develop algorithmic scripts, especially organic joints to create patterns or create new designs.

Parametric principles are complicated and require specialized expertise, which distinguishes them from traditional design methods such as manual drawing with hands. Applying manual skills in this context can lead to distortions of the principles and complications. Parametric design involves the application of scientific and mathematical theories, with parametric tools playing a pivotal role in calculating equations to derive mathematical solutions.

Objective 3. To create furniture designs based on parametric algorithms. and presents furniture and interior design using parametric techniques that combine science, mathematics, and art.

Parametric furniture design enables effective and precise processes at every stage, from the first design phase to the production process. Today, the application of parametric is possible through computer programs that help calculate the mathematical theories and principles necessary to achieve the desired shape in the design. This methodology offers the distinct advantage that it can be visualized and edited in real time, which speeds up the overall design process. Moreover, creating it in a computer program ensures that the resulting file is in a digital format that allows for seamless transfer to a three-dimensional printer for accurate reproduction of the workpiece.

This research offers a critical perspective on the design of creative works for the future. It illustrated the application of parametric principles in both furniture and interior design. The growing popularity of parametric methods in the future was attributed to their design patterns and efficient production methods, resulting in resource and labor savings, including error avoidance. Additionally, the scripts or equations provided served as valuable resources for those who wished to explore the topic further, offering a guide for presenting designs and artistic products using innovative techniques.

In conclusion, the contemporary parametric method continues to advance. It is used in a wide variety of fields, as parametric designs can be customized, edited in real time and adapted to different needs or conditions. The ongoing development of parametric methods has influenced various industrial systems, such as 3D printers, that are trying to meet their demanding design requirements. These advances have given rise to new definitions, solutions and applications in various disciplines, leading to new opportunities.

5.2 Discussion

This research analyzes the concept and process of applying mathematical proportions, commonly known as parametric design, in the manufacture of furniture using the example of the waffle structure. This structure is characterized by its ease of disassembly and remarkable load-bearing capacity. From a scientific and mathematical point of view, parametric programming offers considerable advantages for product design, particularly in furniture and interior design. Versatile applications include calculations, proportioning, stress analysis and esthetic enhancements, all based on the formulation of algorithms, scripts or design applications. This metric-oriented approach enabled precise measurement of distances and proportion calculations, resulting in furniture that can be readily disassembled and is reliably weight-bearing capabilities. The integration of parametric programming into furniture design showed significant potential for further development.

It is concluded that the advantage of parametric design lies in the ability to create designs that are too complex for humans and to show the processed design steps when editing parameters or equations. In this way, designers can see the finished product and quickly make changes and adjustments. On the other hand, errors can occur when only humans design, but if the parametric technology helps with the calculations, it will deliver results. This is different from the traditional process of sketching or general molding methods. Therefore, parametric design methods help in designing where the human is the facilitator in controlling variables, parameters and conditions such as time, complexity of work, assembly and installation to achieve results that are suitable for use or in any area.

5.3 Suggestions

From the research results, the researchers derive recommendations for preparing for parametric design, because parametric design first requires preparation and planning. For example, if the space for design and installation was originally planned for something other than parametric work, this may limit the scope and possibilities of parametric work even more than would otherwise be the case, including time for the design and production steps for installation, as parametric work in the construction industry is quite demanding. Therefore, it is necessary to allow time for the production steps, which can take a lot of time. Drawing details, installing parts and manufacturing are also overly complex.

To propose this, research needs to understand and address these challenges, including:

1. Parametric design tools and techniques can be complex and require specialized knowledge. It can be difficult for interior designers to acquire the necessary skills and knowledge to use parametric design effectively in projects.

2. In terms of cost and resources, implementing a parametric program can involve software and technology costs, and parametric work is currently still a challenge in the construction industry. For this reason, the expenses and costs in this section are estimated to be high.

3. Efficiency and time management. While parametric design can result in highly customized interiors, it can also require more time and effort during the design and construction phases. Parametric design can be time consuming, especially when creating complex and highly customized interiors. It can be a challenge to balance customization with the project's timeline and budget.

4. Integrating parametric design approaches with traditional interior design methods and processes continues to be a challenge, so it is important to find a balance if collaboration is to occur.

5.4 Contribution

Using parametric algorithms for creative design is heavily dependent on technological resources throughout the design, production and installation stages. This approach often requires significant capital due to the relatively high costs associated with these processes. This is because parametric design methods should be more widely recognized and adopted, mainly because current innovations and construction processes are not yet fully developed. Nevertheless, with added capital investment, the construction industry can unlock its potential for remarkable results. Parametric design has a wide range of applications in various fields, including design and computer-aided manufacturing, urban planning, computer-aided manufacturing, landscaping and medical devices, sculptures and art installations. It allows artists and sculptors to explore intricate shapes that would be challenging to design and produce using traditional manual production methods. However, by incorporating parametric techniques, they can use computer-aided tools to create shapes with increased visual complexity and accuracy. Combining parametric principles with computer technology allows for the creation of complex and visually captivating designs that go beyond the limits of traditional manual methods. This symbiotic relationship enhances artistic potential, improves the creative process and allows for a more refined and sophisticated method of shaping their expressions.

Parametric design empowers developers and designers the opportunity to explore different possibilities, optimize designs and respond to individual needs or specific contexts. The integration of parametric design improves efficiency, sustainability and creativity in various industries and thus contributes significantly to progress in design and technology.

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