GENERATIVE DESIGN SYSTEM
EVOLUTION AND CREATIVE OUTCOMES

Author: Yang Song
Program: March Architectural Design
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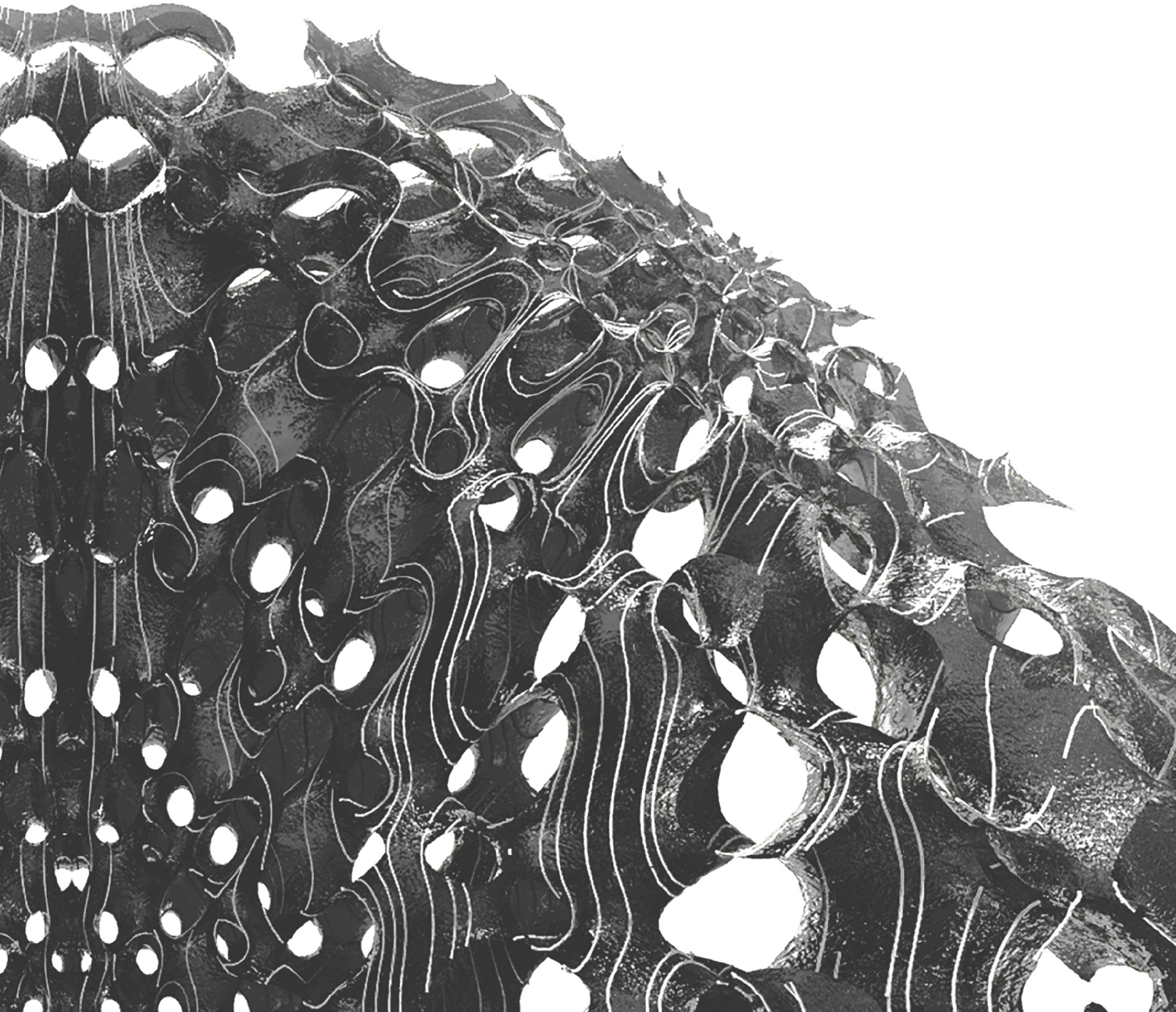

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Imprint

Author: Yang Song
Program: March Architectural Design
Theory Tutor: Abel Maciel
Cluster: RC9
Student Number: 17050210
Student E-mail: ucqbys4@ucl.ac.uk
Address: The Bartlett UCL, 22 Gordon St, Bloomsbury, London WC1H 0QB
Date of Submission: 13.07.2018

Catalogue

Abstract

This paper explains the concept of generative design system and compares that with the current design system. The design thesis focuses on the methodology of generating strategy in architecture design, including small architectural components and structure selections through generative design system by cutting and changing the parameters and choosing the best result.

Based on the principle and method of digital-tech for architectural generative design, this thesis analyses the present situation of residential digital design in the field of architectural generative design and shows us the rational features, technical method and development prospect of this system. Exploring the generative design system in Grasshopper and MAYA to adjust the parameters to fit the architectural form of the technique and achieving this system to be the guidance rules in this semester project. Using Topology Optimization system to adjust the structure of the components to bear the load and become much more reasonable and material-saving.

As the current literature shows, this evolutionary and creative system has several prominent features:

A) Multiple elements interact directly or indirectly.

B) Dynamic research feature.

C) Parameters affected by the process and interactive outcomes.

D) Attributes and active adaptabilities elements and hierarchy elements structure.

Combined with the project, using this generative design process can help designers to shape the plan more reasonable, controllable and structure-meaningful, the material utilisation rate can be maximised, the waste of economy and resources can be reduced. The most appropriate and stable structure can be realized with a minimum of materials. This technical method itself has a robust humanistic character and can give us more creative outcomes.

Keywords

Generative Design

Optimize Design

Evolutionary System

Creative Outcomes

Simulation

Material Saving

Architectural Design

1.0 LITERATURE REVIEW AND BACKGROUND

1.1 Introduction

In recent years, with the dramatic development of the electronic and software, the communication between our world and electronic is getting closer and closer. The way people thinking and expressing is becoming interceded and permeated significantly by electronic equipment and setup. The way designers releasing their inspiration and ideas is transforming simply and conveniently with the help of electronic technology.

The electronic designer Anthony Dunne indicates that designers should begin to think more about the aesthetic role of products in daily life. The design method is likely to enrich our daily lives to improve the quality of our relationship with artificial environment technologies and may even be overturned for the benefit of the community **(Dunne, 2008)**. If the design itself is so vital, then designers need to think about what kind of design method is better that they can more conveniently achieve the design goals and more readily accepted by consumer and society. A methodological and philosophical perspective that the world is in dynamic processes and consequences is provided by the generating system **(Kuhn, 1963)**. Similarly, Celestino Soddu supported that the morphogenesis process becomes a non-linear system in the method of using the algorithm. See the picture **Figure 01 ("Generative design," 2017),** the system operated by idea code to get the only non-repeatable and endless solution **(Soddu, 1994).**

Designers can choose the best project and the most valuable information among several different plans and make the design body and object more complicated and focused more on the design of innovation. Nevertheless, as Branko Kolarevic suggests that abandoning predictable results creates complexly between design and presentation **(Kolarevic, 2004)**. Whether to give up predictable and complex results has aroused widespread controversy. Whether to adopt the results of the design generated, depending on the needs of different designers' ideas on the products. Likewise, DeLanda wonders that whether these future design authors will be satisfied with the virtual form of design roles

(DeLanda, 2002). On the other hand, Nigel Cross even doubts that a machine can design **(Cross, 2001).**

In short, the generative method provides an unconventional conceptualisation way and editable working mode for the new generation of designers.

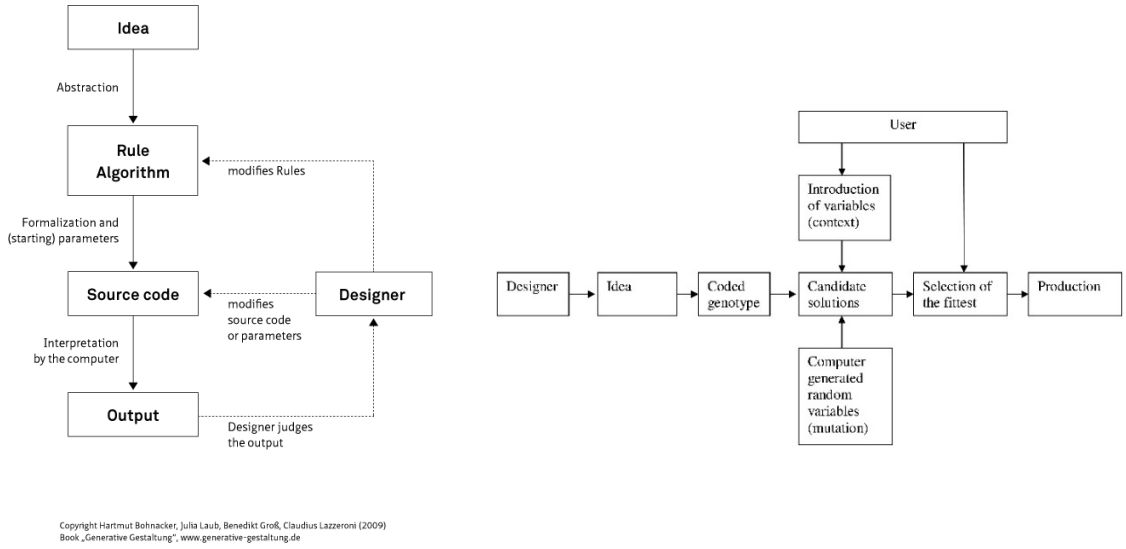


Figure 01: Process for creating a generative design

1.2 The current state of art – a general overview

Nowadays, digital computing is being broadly used as design tools, many designers cover artists and multi-directional creators have begun to use generative design methods to create and select their works and based on the generation system as its foundation and method, creativity and imagination are exerted on it.

Dextro has exploited a variety of interactive drawing systems. Simple plan elements or design languages such as points, lines and surfaces are self-organised and self-duplicated to generate new illustrations and animations (www.dextro.com), see the picture **Figure 02 (Wax, n.d.)**. Auto-Illustrator and Photoshop (www.auto-illustrator.com), in order to automatically add new design ideas to new projects, these software companies combine the images of the popular computer graphics program with its editing capabilities (www.signwave.co.uk). Groboto has devised a system that offers designers to generate changing and growing 3D models by personal demands and changes this system available

to widescreen by placing the code which is designed by the generative design systems (www.groboto.com). Autodesk has already released multiple software such as Fusion360, Dynamo, Netfabb and Inventor 3D in connection with medical, industrial, architectural and other aspects to generate the best form, reduce component weight and optimize the structure by generative design system (https://www.autodesk.com/solutions/generative-design), see the picture **Figure 03 (Author, 2015; Kazi et al., 2017)**.

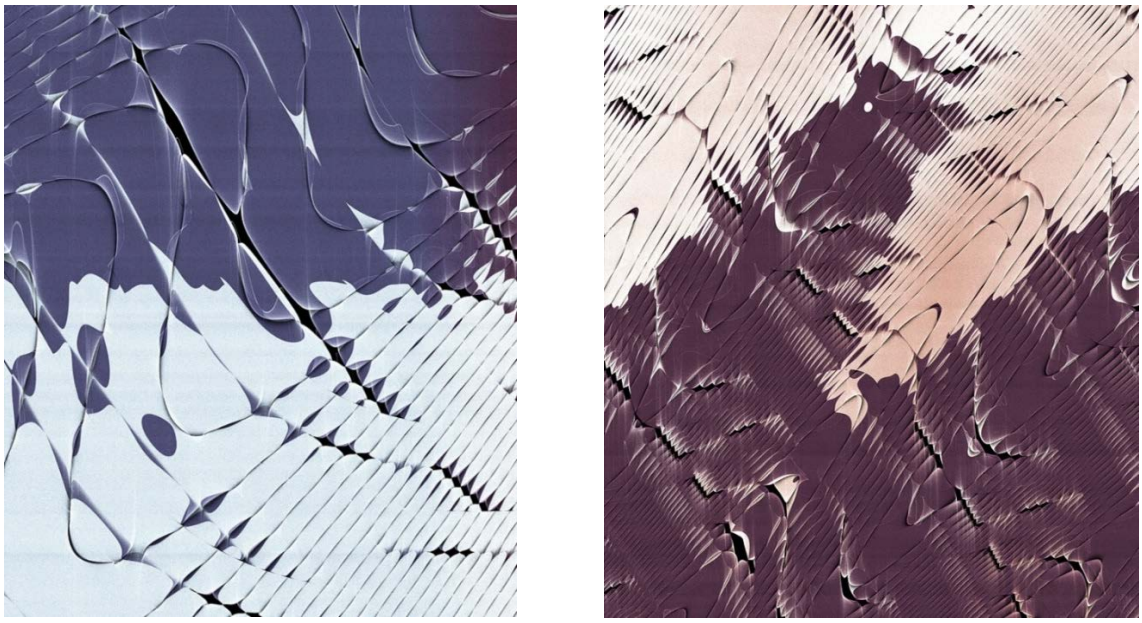


Figure 02: The outcomes about 'Set An Algorithm and Let It Go' the generative art of Dextro.

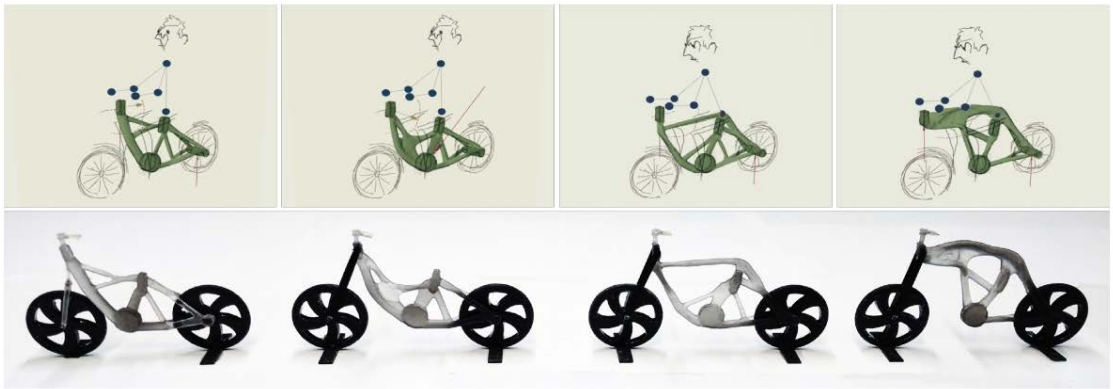


Figure 03: The user navigating the resulting solutions by operating the bike handle directly.

According to software experts, generative design tools that produce and simulate optimum forms for products structures or even architectures without human intervention are sent to transform both the character of the designers and the real physical world. Compared with the typical design steps, the generative design can simulation thousands of reasonable and marvellous plan examples.

So far, researchers divided the method of generative design into the following five techniques:

A) Genetic algorithms;

B) Cellular automata;

C) L-systems and other gnenrative scripts;

D) Shape grammars;

E) Swarm intelligence and Multi-agent societies.

Although each of the five generative design computational methods having a broader significance, covering a range of disciplines ranging from basic sciences to art and technology, the commentary is limited to the application to architectural design. The design process becomes part of completing the design, which is the result of interaction between the generative design system and the natural design bases **(Whitelaw, 2015).** The state of art of designing in this mode is coordinating the relationship between the design process, nature and generative design system with the help of different generative design techniques.

1.3 Topic 1: Simulation, Architectural Design, Generative Design

The Autodesk promoted the creative development of architectural design and generative design system for the design of split-new research and office space in the MaRS Innovation District of Toronto. See the picture **Figure 04 (Nagy et al., 2017).** Generative architectural design system uses the same workflow as the generative manufacturing but contains more complex parameters and diversified goals. In this project, architects designed their own geometric generative system by developing six parameters and preferences including: work style preference, adjacency preference, low distraction, interconnectivity,

daylight and views to the outside, see the picture **Figure 05 (Nagy et al., 2017)**. So that, they can automate the process of exploring thousands of formations and discover the trade-offs for the most reasonable design and the highest-score solutions **(Nagy et al., 2017)**.

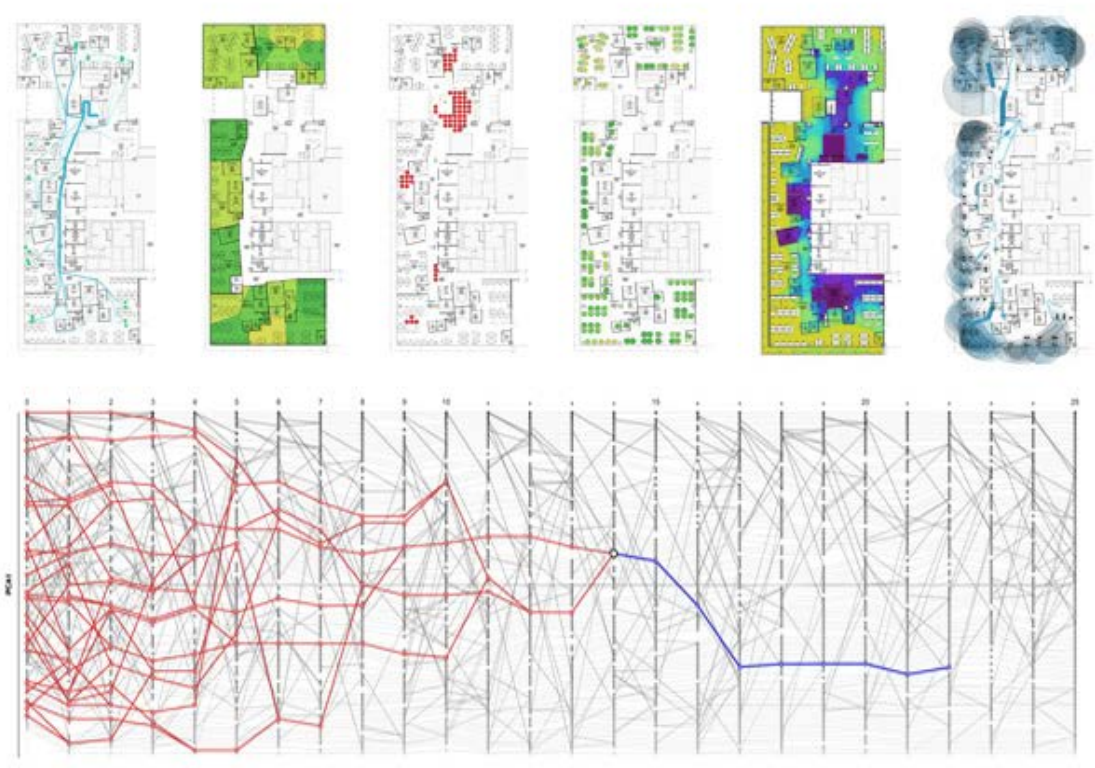


Figure 04: Design metrics (from left to right: adjacency preference, work style preference, buzz, productivity, daylight, views to outside).

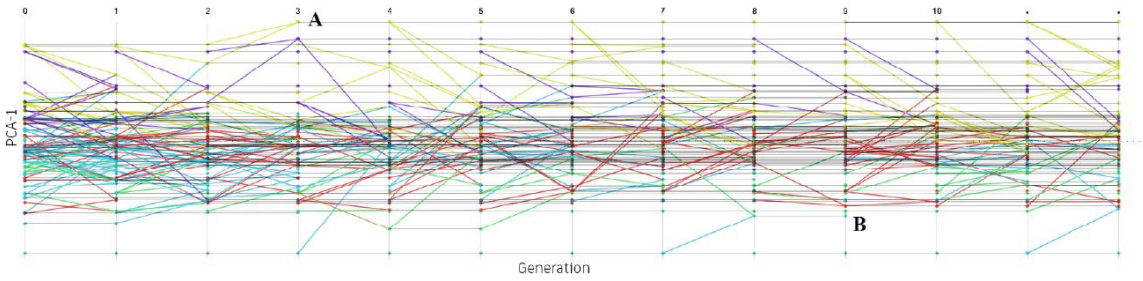


Figure 05: Time plot showing lineages of designs through generations (color indicates design cluster and parameters)

The success of this program indicates that the functionality of a generative design extends to more people-oriented design approach to satisfied the occupant's space quality needs and the space organization.

However, some experts pointed out the shortcomings of this simulation system. For many complex problems, the exact states of relevant variables cannot be measured because they always be disrupted with many kinds of human behaviours and activities. There is insufficient knowledge on how to even simulate the system**(Hanna et al., 2010).** Designers use controlling variables and multiple simulations to solve this problem.

This approach provides many advantages for designing office spaces, including enhancing human creativity and gnosis, confirming extensive input from previous projects and current demands, managing complexity, navigating through the actual data and providing transparency on design assumptions about design features and project objectives **(Villaggi et al., 2018).**

Generative design and simulation system helps designers to select a design that meets all the requirements of the parameters and is optimized through computer assistance under the common control of many parameters.

1.4 Topic 2: Optimize Design, Energy Saving

Airbus and Autodesk have exploited one of the most effective examples about the usage of generative design in generative design in aircraft, see the picture **Figure 06 ("Generative Design at Airbus | Customer Stories | Autodesk," n.d.).** They designed the world's largest metal 3D printed airplane component partition. Because of the requirements include disconnections for emergency stretcher access and to hold a fold-down seat for cabin attendant, the design is challenging for the general design system. The designers have developed a process to produce an unconventional structure to simulate the cellular shapes and bone growth.

See the picture **Figure 07 ("Autodesk and Airbus show the future of aerospace design and manufacture in pioneering generatively designed 3D printed partition," n.d.),** because the stronger and lighter micro-lattice new bionic partition structures are

designed, each partition is thirty kilograms (45%) lighter than current one designed by general design system. If this component applied to the A320 airplane, the annual emissions of carbon dioxide would be reduced by 465,000 metric tons **(Bagassi et al., n.d.).**

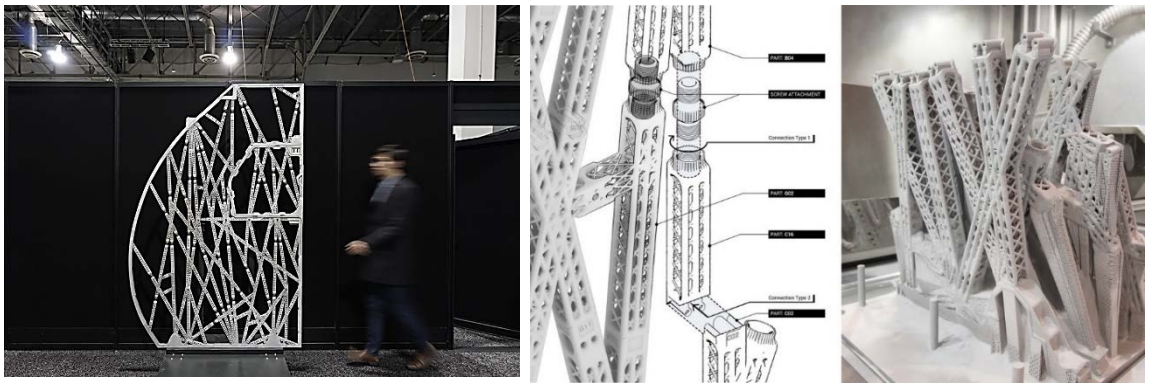


Figure 06: The lattice structure optimised to be strong and light

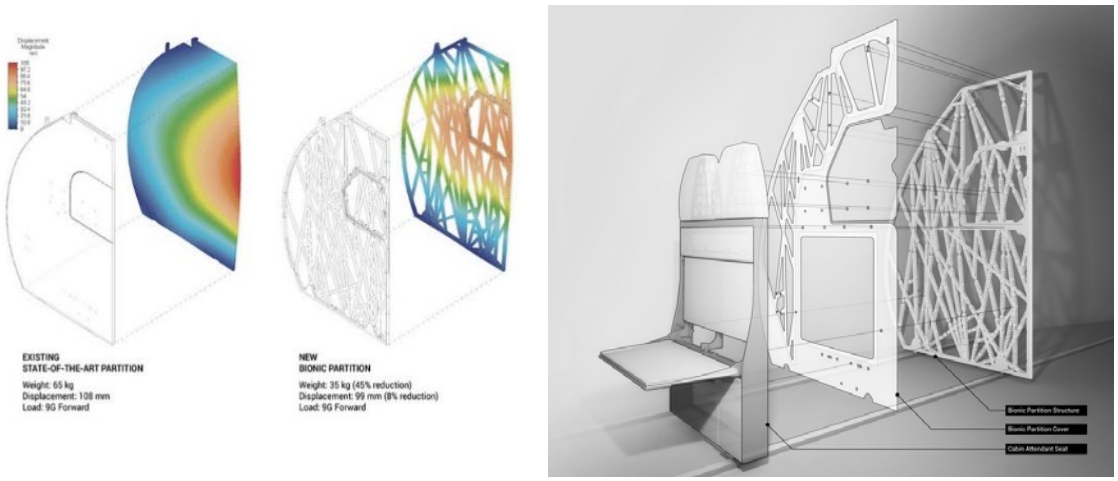


Figure 07: Stress tests comparing the existing partition to the bionic partition.

Generative design system considers a clear base model and gives designers a variety of options and creative outcomes, see the picture **Figure 08 ("Autodesk and Airbus show the future of aerospace design and manufacture in pioneering generatively designed 3D printed partition," n.d.).** A macro and micro-geometry optimization process are iteratively executed. At the macro scale, the algorithm sketch lines to network many reference points, meanwhile at the microscale a logic similar to bone growth is applied to

support the highest strength areas of the structure **(Zhu et al., 2013)** .

The well-developed design process in this system, including the generation of design principles, will lead to significant improvements and enhancements, especially in optimizing component features and functional enhancements. Reduced structural weight results in shorter design times as well as reduced aircraft operating costs.

To provide valuable real-time feedback optimized solutions can be linked to the pre-computer dataset results for some specially designed modular cases **(Chronis et al., 2012).**

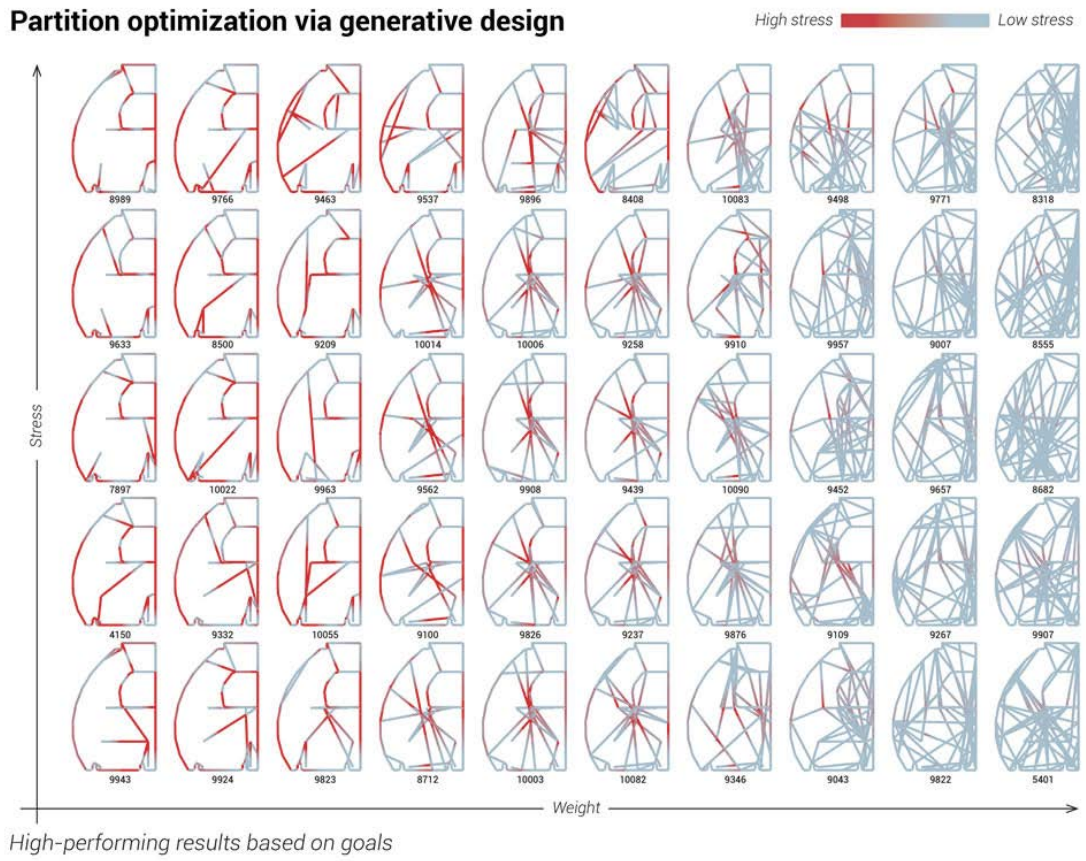


Figure 08: The results of a simulation test for stress.

1.5 Topic 3: Evolutionary System

The evolutionary system is the computer selection and reproduction, which based on the natural processes of simulation. This technology has found widespread use in computer animation and graphic design; it is also used in architecture, engineering projects

and industrial design. The system depends on the general parametric model specifications to allow for the generative design of a variety of possible outcomes of the designers. In the quest for a certain goal, the parameter space must be broad enough for both generative programs and specific design constraints. **(Oxman and Oxman, 2010).**

At first, designers generated the potential design 'population' with a series of random parameters, which can be displayed intuitively to them. The aesthetic sense of designers selects and decides the best visual design program. Those visual design programs are generated with one another to output a new generation of design to inherit the previous meaningful parameters and characteristics. Just like we cultivate fruit trees, we blend the best of each generation's genes and traits, but the fruits are full of people's subjective consciousness choice. The alternative means of exploiting this evolutionary system process is that the parameters can be coded demonstratively by designers. See the picture **Figure 09 ("Reimagining Education Through Generative Learning," n.d.)**, for example, designers find the lightest, cheapest set of chair material while they select the most solid and material-saving chair shapes. The qualification function of this situation is coded into the evolutionary system and the computer will generate populations of chairs and the successful structures independently under the control of designer's input parameters, see the picture **Figure 10 ("The Future of Manufacturing is Here," n.d.)**.

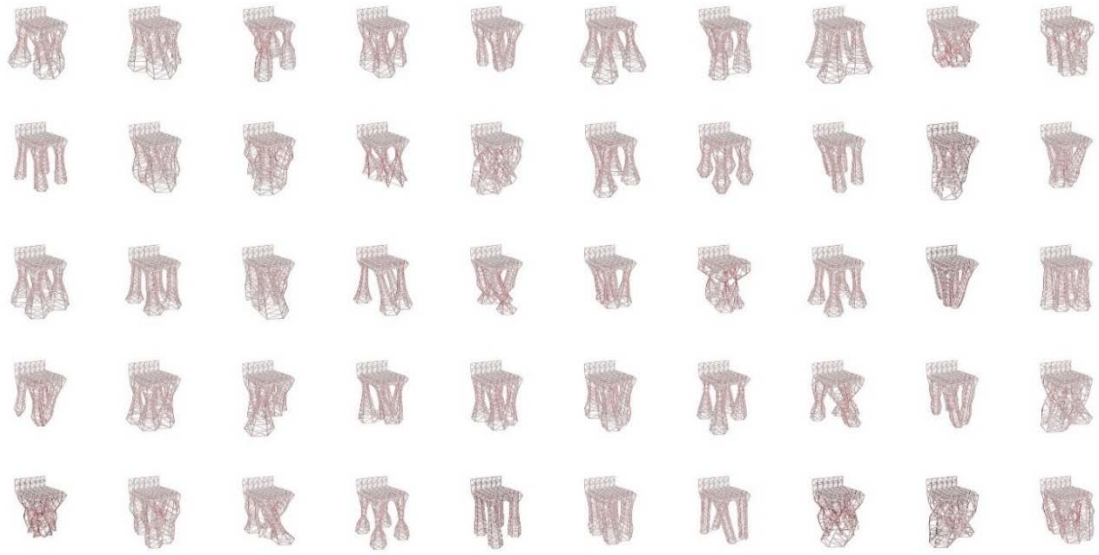


Figure 09: Generative design options of a chair.

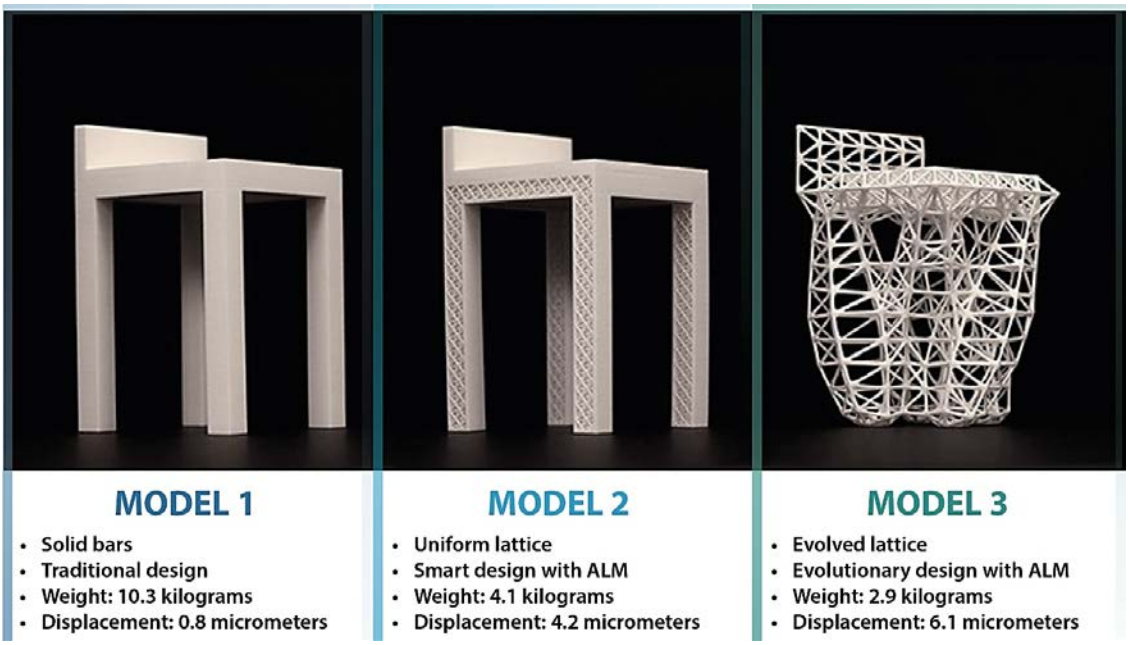


Figure 10: Different models based on different evolutionary system techniques.

Where creative designs are sought with some aesthetic value, the previous technique of interactive evolution is more practical **(Liu, 2010).** It requires designers to continually communicate with the evolutionary system because it is difficult for a computer to encode the qualities like 'good', 'beauty' and other subjective aesthetic awareness requirements.

1.6 Discussion

Architecture Design is one kind of scientific artistic creation process, this design method needs to form an operational procedural approach and developments for the full use of architectural design tools step by step. The technical method itself has a strong humanistic character. Each step in generative design begins with the designer's science predictions and hidden assumptions and has a kind of subjectivity or preconceived future results at the beginning of the design.

The computer is machinery and rigid can only be based on the programmer to design the program execution flow. However, when designers being complex encounter relationships and have many feasible options, the computer's powerful storage function

and high-speed computing capability can take all aspects of the building prototype into consideration. With the help of Computer modelling, generative design can make building prototypes, optimizations and decisions possible and reasonable. In contrast, the human way of thinking is intuitive and flexible. Many details can be overlooked in the search for complex causal relationships, leading to the keen proposition of a framework model. Generated design can give full use to both designers and computers for their advantages.

In the time they create their ideas, the computer-generated to produce a large number of data results to prove which design performance is the best. Apart from this, generative design let designers and artists create optimized shape solutions and internal structure systems. Some of these forms are unachievable or difficult to design with traditional manufacturing methods. Instead, it gives people the opportunity to use new methods. Last but not least, generative design can optimize for materials, manufacturing methods and cost, and make the internal separation of components and optimized surface texture, as well as existing components, make them lighter and stronger.

1.7 Conclusion

Generative design mainly oriented to architectural disciplines and other emerging cross-disciplinary areas. These design methods need the actual data and straight feelings to start imitating the prototype system. However, some experts pointed out the shortcomings of the generative design system.

A) For many complex problems, the exact states of relevant variables cannot be measured because they always are disrupted with many kinds of human behaviors and activities. There is insufficient knowledge on how to even simulate the system.

B) The complexity of many current projects has proven that they exceed the maximum capacity of the generative system.

C) The complexity and variety of results have created obstacles for designers to choose from. At the same time, the criteria for "good" and "bad" have also become vague without borders. These are indeed the shortcomings and deficiencies of this system, but through the improvement of technologies and systems, we believe we can overcome those.

Nowadays, generative design techniques can manufacture out different distinctive products. This design system also indicates a new technology surgery and revolution of new method. Architectural design is one kind of scientific artistic creation process, generative design method needs to form an operational procedural approach which can help it generate more professional and meaningful. This process needs to be developed step by step, to play a role as the architectural design tool because this technical method itself has a strong humanistic character and more creative outcomes.

2.0 Hypothesis

Generative design is a new interactive design method by using artificial intelligence and simulations integrated into the design process, using a designer-defined system to discover new and high-performance results of the design process.

Three essential parameters form the necessary framework of generative design:

A) A series of parameters including design indicators, functions and space requirements describing the design goals.

B) Generate geometric space model or simulation data results, guiding the design result and defining the design space for possible design scenarios and for setting function requirements.

C) A heuristic search algorithm such as automatic generation algorithm can help us to find the diversity of the program and the design of the optional and the genetic algorithm can search the entire design space finding a variety of high-performance design options based on the target.

What are the methods for generative design? What kind of design information should be captured to support the rationale of design and process? The continuous improvement of design techniques has also caused some controversy and confusion in the context of reducing the designer's workload.

Can generative design make designers more creative? Can generative design improve design more reasonable, structure-reasonable and competitive? If the process is only about changing the parameters, what will the designers do during the process? Does it needs the designer's subjective participation to be involved in the process of generative design? If not, which part should designers be involved in the generative design process? In the process of theoretical study investigation and research, a lot of confusion has arisen. Since the generative design is a new design method controlled by parameters, it should be an upgraded version of the parameter design. The essential difference between "generative design" and "parameter design" is that the generative design introduces the non-complete

random and non-simple iteration evolutionary mechanism and the idioms are self-optimized in a dynamic and self-organizing manner. The information that generative design feedback to the architects and designers should be more diverse and selective.

For architectural studies, it has long been witnessed that the process is continuously turning to integration and development of simulation tools, while also promoting feedback loop design performance and intentions. **(Malkawi, 2004)**

3.0 Methodology

3.1 Theory

First, at the beginning of the research, I have carefully analyzed and summarized the contents of previous research surveys to understand the methods of generative design. This research includes the differences between the generative design methods and traditional methods, the advantages and disadvantages of generative design compared with other design methods and the characteristic nature of this method. Based on the understanding of the basic concepts, I conducted a systematic analysis of the case of the projects which applied the generative design method successfully. I explore about the relationship between design, aesthetic and user satisfaction through the study of Autodesk Studio Program, experience the relationship between generative design and user satisfaction through real building cases. Compared the airbus lightweight structural form generative design result with the mechanical testing and anaesthetic standards cases and other successful cases.

Following this, I started to use the real project to explore whether the generative design can make designers more productive and creative and how the designers are involved in the process of this method. The two main directions are shaped generation and pattern generation, see the picture **Figure 11.**

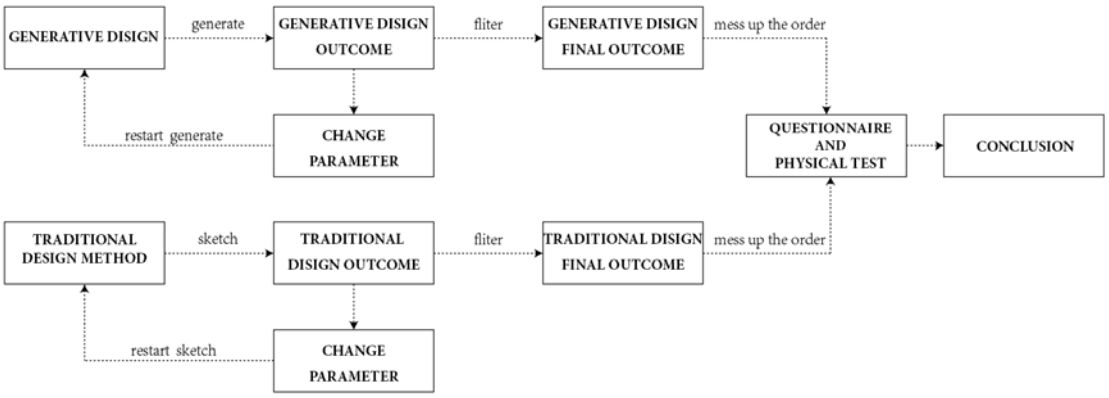


Figure 11: Methodology workflow

3.2 Shape Generation

Regarding shape generation, I used the same number of boxes to build different structures. In order to generate different shapes, I limited the parameters of the growth process by setting parameters in Grasshopper and build the structures in Rhino, see the picture **Figure 12**. The number of scenarios generated by the generated design process is compared to the number of scenarios generated by the traditional design in the same design period to test about the productivity of these methods. After that, I fix the space shape parameter and only change the size of each box component to fill up the previous structure shape. This method can test the efficiency of the generative design and traditional design when dealing with changes in the parameters.

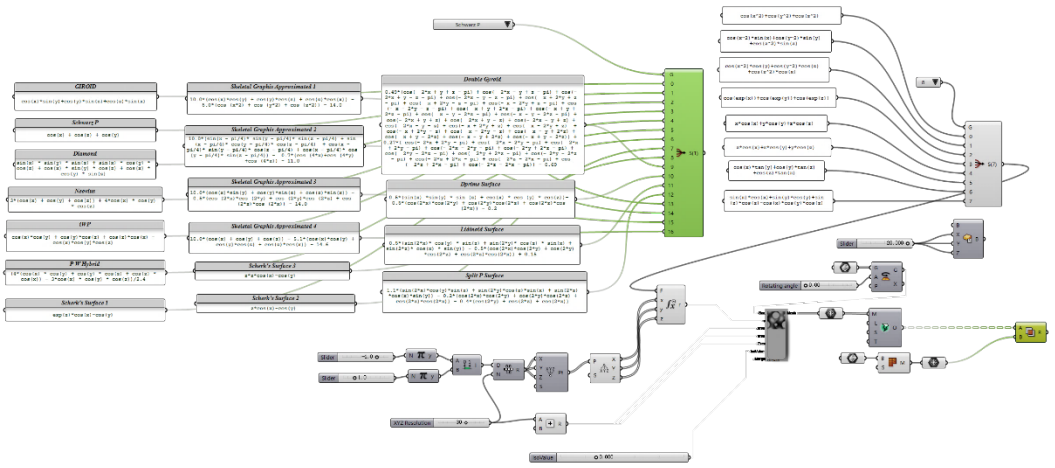


Figure 12: Shape generative design process in Grasshopper

3.3 Pattern Generation

Regarding pattern generation, I used different generative design methods to generate the pattern and compare that with the one I made by sketching and drawing. I use Gray Scott (Reaction-Diffusion Shader), L-System, Diffusion Limited Aggregation (DLA) and rain-flow simulation system in Grasshopper to generate patterns for the same curved surface, see the picture **Figure 13**. In this test, I try to figure out whether the generative design can provide designers with a choice of diversity and whether the generative design method will be more flexible, efficient and successful on an unconventional or non-linear surface.

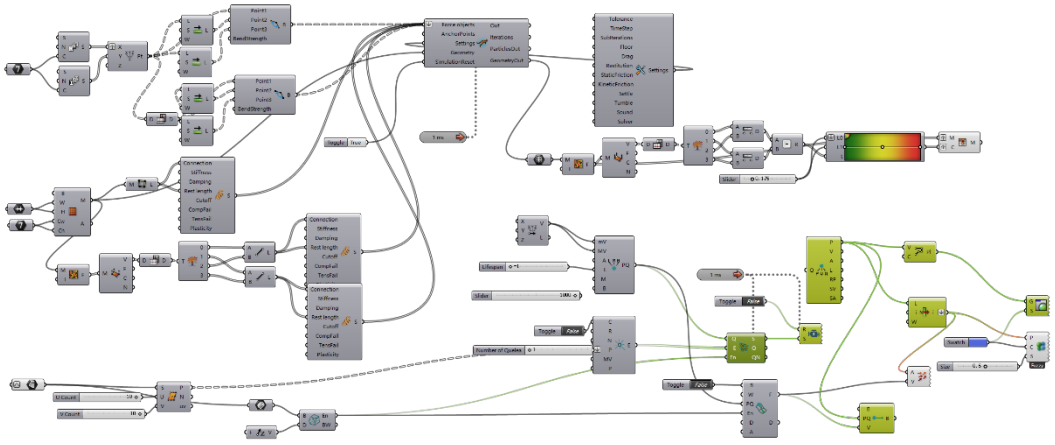


Figure 13: Pattern generative design process in Grasshopper

Finally, I use the collection of opinions, simulation experiments and material properties tests to verify the results of the above experimental methods and whether they satisfy the designer's original intentions. Furthermore, these tests also verify that whether the generative design can provide a reasonable design solution in the case of changing different parameters.

3.4 Overview

About shape generation test, the results of generative design methods are displayed together with the results of the traditional design methods in the same paper. Meanwhile, give it to twelve people who were randomly picked on the street and in the architectural design studio and let them choose a good-looking and personally-liked design option. It can be tested to certificate if the generative design will give the designers more creative and better results and whether the generative design can provide more alternative options.

About pattern generation test, the verification also uses the same method in the shape generation part to prove whether the generative design can offer more diversified options and more reasonable and precise results especially on the unconventional and non-linear surfaces. In the experiment of generating patterns, the purpose of it is using less material to get more support. It is not fast and efficient in the ordinary design methods

without the guidance of generative design parameters. Stress testing the generated solutions to find out the relationship between saving material and structural reliability to verify whether generative design can provide designers with more rational and optimized alternative design options.

Through the above study, I will summarize and find the answer about the hypothesis and quarry the solution about what kind of design information should be captured to support the rationale of design and process.

4.0 Results and Discussion

4.1 Theory

The traditional architectural design method is the design concept that the architect directly generates from the competent factors such as “creativity” and “experience”. There is not a century of material media between architects and design ideas. The control of functional parameters, space settings, shape design, streamline analysis and other factors and parameters are consigned mostly to the pre-design stage in the traditional architectural design process. **(Turrin et al., 2011)** According to Woodbury and Burrow, revelation and comparison are two main benefits of exploring design solutions. **(Elsen et al., 2012)** When designers are investigating the traditional architectural design process, it always shows a significant shortage because of the lack of divergent steps in these processes. The designers can only explore a handful of alternatives at design works, even these designers are also only a small part of the design team. As a result, the relatively narrow range of possibilities is more easily noticed by most designers. Architects tend to identify strongly preferred design directions, limited design goals and clear concepts as early as architectural design initially unlike in other disciplines which are called a primary generator. **(Darke, 1979)**

However, the ‘Architectural Generate Design Method’ is the result of an architect’s design process followed by a generative system **Figure 14 and 15.** The various objective conditions of the “creativity” and “experience” values of architects are exchanged for design concepts through a material medium. This material medium is the generation system mentioned above.

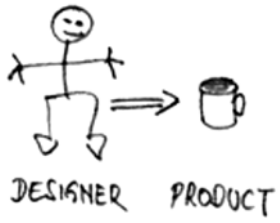


Figure 14: Traditional design approach

Figure 15: Generative design approach

In the experiment of applying the methodology to verify the hypothesis, the discussion of the results of this paper is mainly divided into two parts, one is about the generative design of shapes and the other is about the generative design of the pattern. All the research experiments and the results obtained are to aim to answer and verify the following questions and hypothesis: Whether generative design makes designers more creative or not? Can generative design improve the design more reasonable, structure-reasonable and competitive? If the process is only about changing the parameters, what will the designers do during the process? Does it need the designer's subjective participation to be involved in the process of generative design? If not, which part should designers be involved in the generative design process?

4.2 Shape Generative Design

About the shape generation part, the result is that generative design can make designers more creative. Furthermore, generative design method can also give designers more alternative options.

First of all, the primary method of the experiment is using Cellular Automata (CA) generative principle to test about the two-dimensional and three-dimensional generative outcomes. A main parameter control principle has been set: death occurs when there are other numbers of neighbors; survival occurs when each cell has two or three neighbors; renaissance occurs when there are only three neighbors around a blank cell. Observe and record at the same time interval (every forty seconds) in both two-dimensional **Figure 16** and three-dimensional tests **Figure 17**.

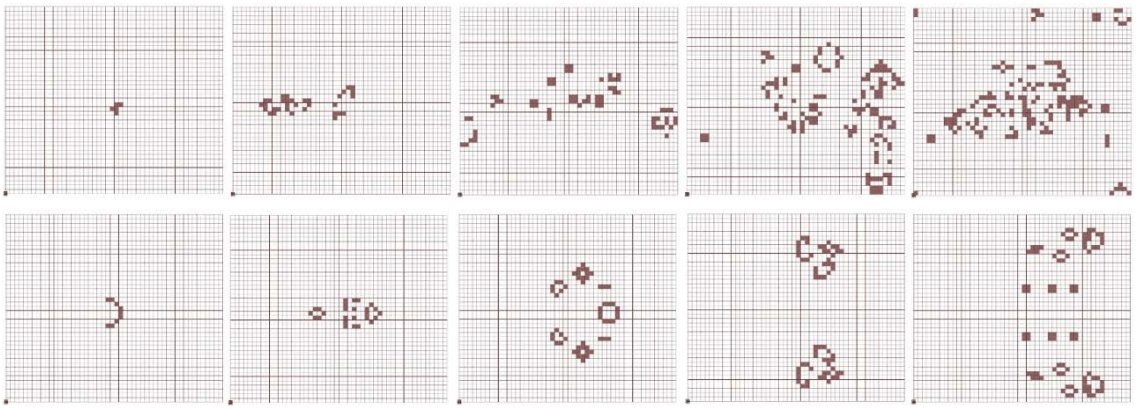


Figure 16: Four mainstream cell configurations in two-dimensional

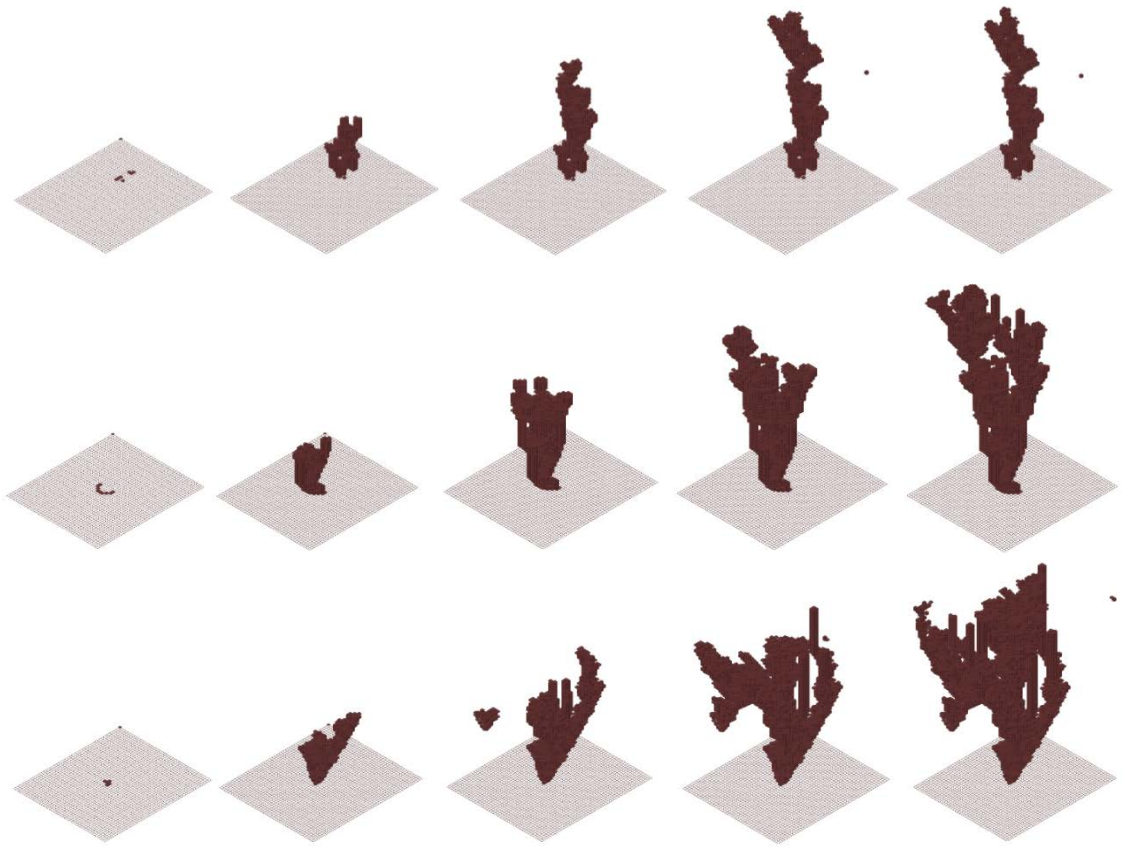


Figure 17: Four mainstream cell configurations in three-dimensional

As a consequence, generative design method can indeed provide more creative design ideas.

Second, I extract the spatial structure from the whole shape generated by the CA method and also extract the similar generative principle. Make forty same boxes grow in the six-unit multiply six unit space under the guidance of the same generative principle, see the picture **Figure 18**. At the same time, set the time for designing a structure by traditional design method as the interval time and compare the number and variety of structures generated by generative design method over the same time frame.

As a result, some dangling boxes appear in the options generated by the generative design method, which does not meet the requirements of the structure. Consequently, it requires the designers to change the generated parameters or filter the results of generative design.

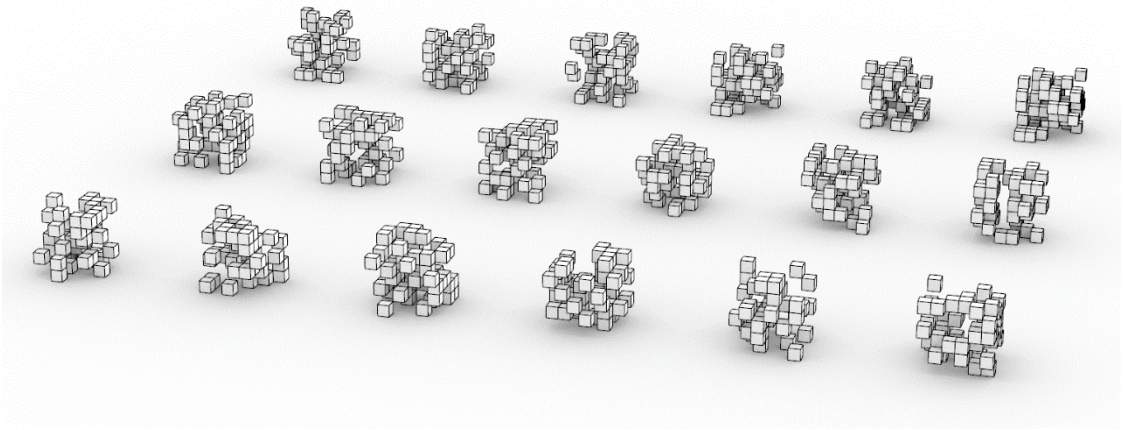
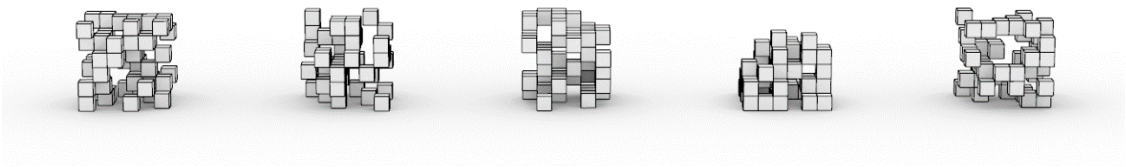


Figure 18: Structures generated by the generative design method

At last, I mess up the order of the structures generated by the traditional way and the generative design method, rearrange the order and print them into a questionnaire, see the picture **Figure 19 (Structure 4 is made by traditional method)**. Further, distributed them to twelve passers-by and twelve designers in the studio randomly. Let the participants choose the option that is considered to be the most creative and beautiful one.



Structure 1 Structure 2 Structure 3 Structure 4 Structure 5

Figure 19: mess up the order of structures generated by two methods

As a result, 84 per cent of the passers-by believed that the structure produced by the generative design method is the most novel and beautiful one and only 16 per cent of the passers-by chose the structure produced by the traditional method. Similarly, 92 per cent of the designers thought that the structure generated by the generative design method is the most creative and meaningful one and only 8 per cent of the designers considered the structure produced by the traditional method, see the picture **Figure 20**.

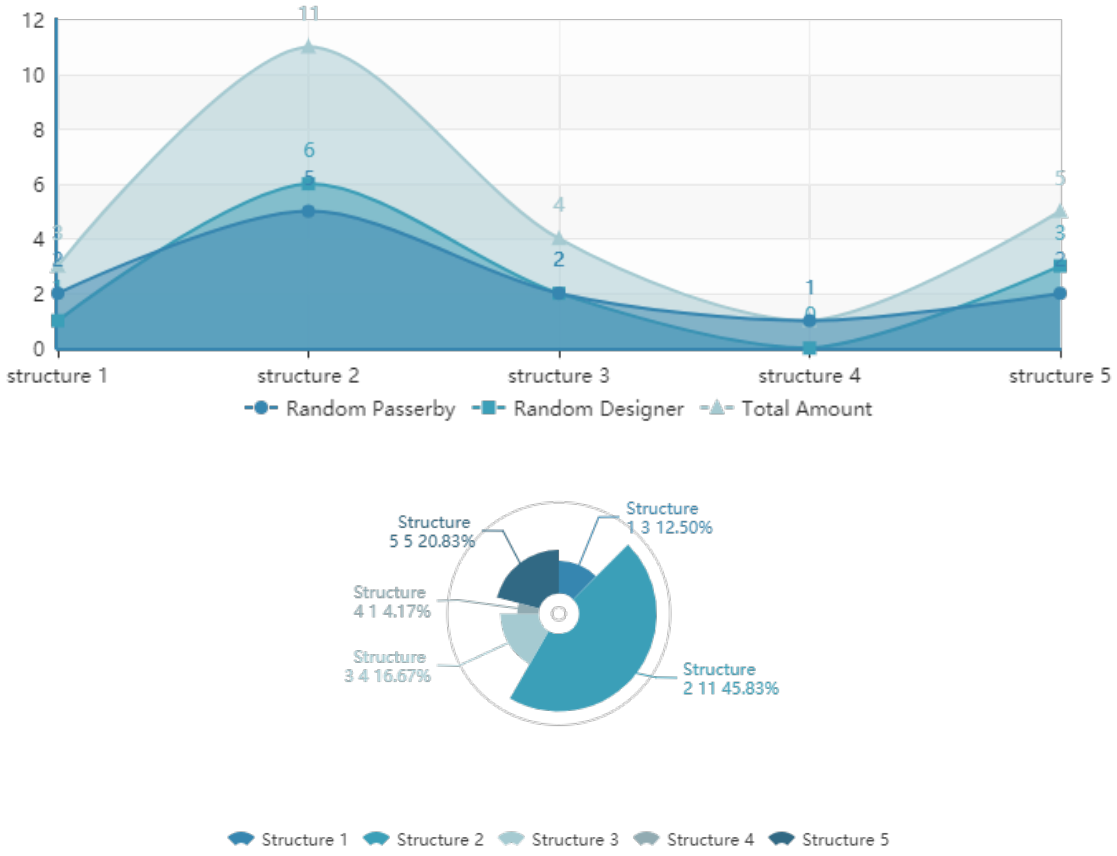


Figure 20: The Result of The Questionnaire

The result of the shape generation experiment is that generative design method can provide more creative and better design ideas. Cellular automata design technique and many other generative design methods have been used for different kinds of architecture design and urban planning **(Herr and Karakiewicz, 2007).** It is obvious through the test that the efficiency of generative design is much greater than the effect of traditional design. Furthermore, generative design methods can calculate a variety of alternative options and multiple options that meet the requirements according to certain parameters. In the different results of the generative design, you can see the design cogitation of the computer in each direction, which is not possible with the traditional design methods. The role of the designer has changed from a traditional designer to a more focused sifter and space demanded. Because there are still some results in the catalogue of the generative design that do not meet the requirements, that requires the designers to filter and select from the results. At the same time, different designers have different aesthetic tendencies, which also

makes the results of generative design more diversified. Therefore, the generative design is not just a simple process of changing the parameters. It requires not only about the designers' subjective filter ability but also a deeper understanding of structure and aesthetics.

4.3 Pattern Generation Design

About the pattern generation part, the result shows that generative design can improve the design more reasonable, structure-reasonable and competitive. In the case of adjusting parameters, generative design can quickly generate a new evolution solution. Meanwhile, the generative design method is also more flexible, efficient and successful on unconventional and non-linear surfaces.

First of all, I put our project surface into the square boxes which generated in the previous steps. The project surface is about hyperboloid with a repeatable unit surface represented by Gyroid geometry. Extract one of the repeating units and start the pattern generation test. The test requires the experimenter to use Gray Scott (Reaction-Diffusion Shader) System **Figure (21 and 22)**, L-System **Figure (23 and 24)**, Diffusion Limited Aggregation (DLA) **Figure (25 and 26)** and Rainflow Simulation Analysis System **Figure (27 and 28)** four different generative design methods to generate patterns on the same repeatable unit surface.

By controlling the density of the generated pattern to control the amount of material. It is also necessary to meet the rationality of the structure and force. The patterns produced by the four generation designs in the same time interval are used as the essential repeating elements to flow on the same surface. At the same time, designers also sketch the pattern on the same unit surface using traditional design method.

Figure 21: Grat Scott Method Generating pattern in the same time interval

Figure 22: Surface pattern generated by Gray Scott (Reaction-Diffusion Shader) system

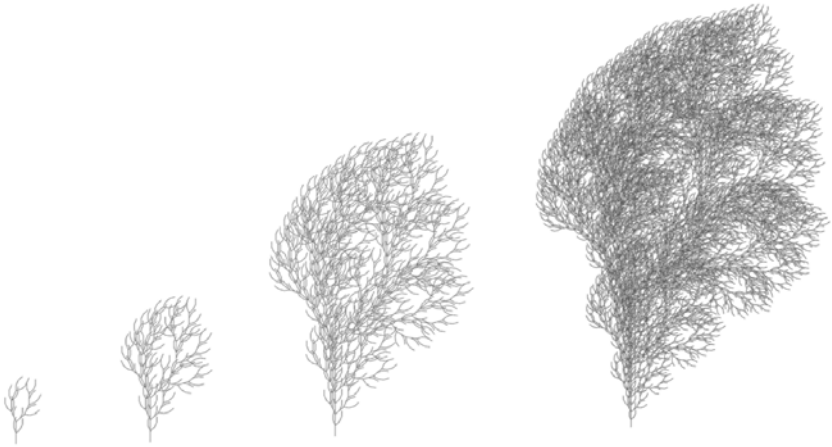


Figure 23: L-System branches generation in same time interval

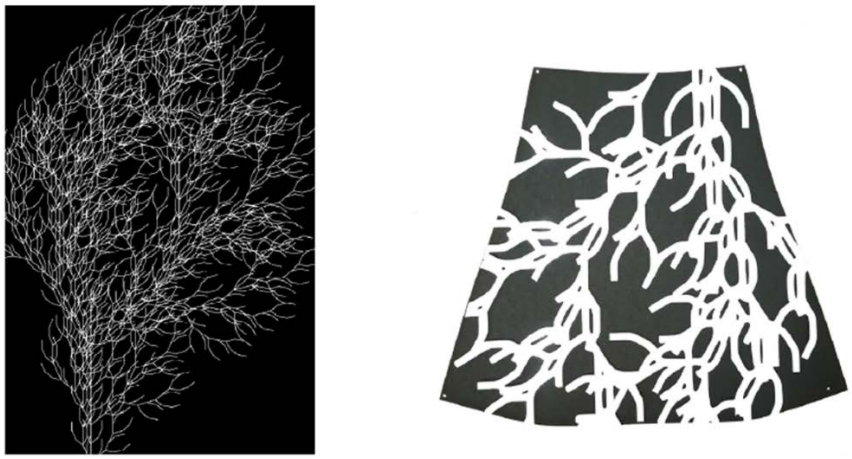


Figure 24: Surface pattern generated by L-System

Figure 25: Diffusion Limited Aggregation (DLA) generation in same time interval

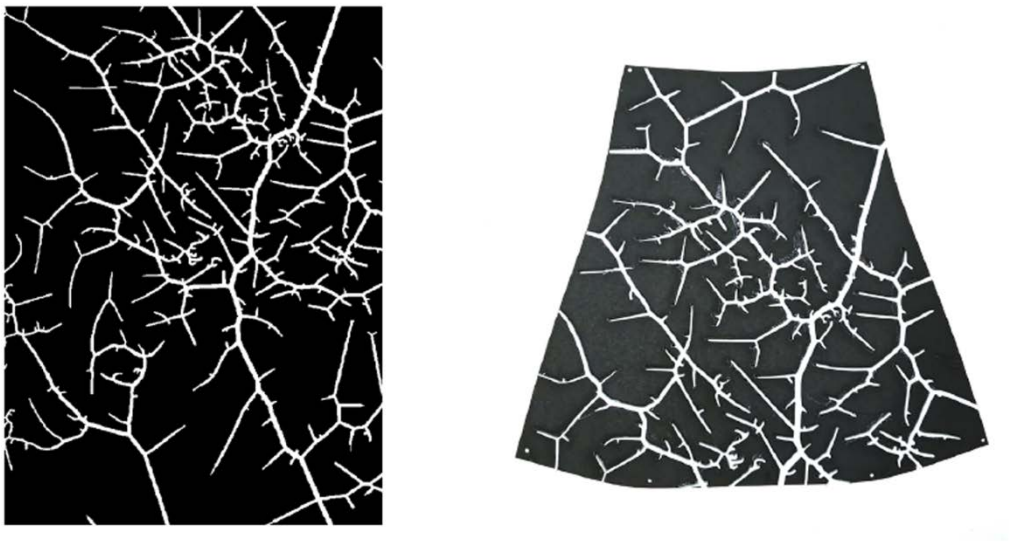


Figure 26: Surface pattern generated by Diffusion Limited Aggregation (DLA)

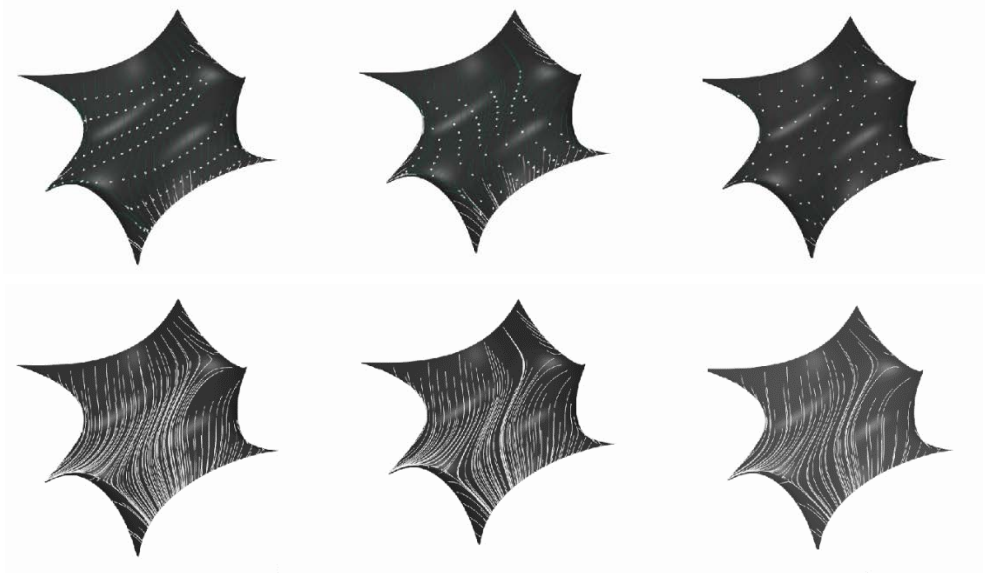
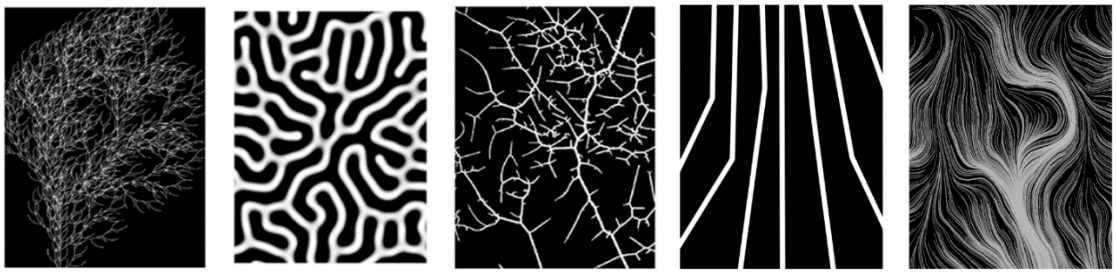


Figure 27: Rain-flow simulation test in different density

Figure 28: Surface pattern generated by Rain-flow simulation system

The result is that generative design can give us more complex and diverse options, especially in some unconventional and non-linear surface projects. It is really challenging for designers to sketch the patterns on that. The goal of this research study is to translate the mathematically conceptual elements generates by the rules into the basic design language elements of architectural design **(Krawczyk, 2002).** Generative design can give us more inspired and useful design language elements.

Afterwards, I print out the patterns generated by the traditional way and the generative design methods on the questionnaire. Distributed them to twelve passers-by and twelve designers in the studio randomly. Let the participants choose the option that is considered to be the most flexible option on the non-original and non-linear surface, see the picture **Figure 29(Pattern 4 is made by traditional method)**.



Pattern 1 Pattern 2 Pattern 3 Pattern 4 Pattern 5

Figure 29: mess up the order of patterns generated by five methods

As a result, 85 per cent of the passers-by believed that the pattern produced by the generative design method is the most flexible and inspired only 15 per cent of the

passers-by chose the pattern created by the traditional method. Similarly, 90 per cent of the designers thought that the pattern generated by the generative design method is the most meaningful only 10 per cent of the designers considered the pattern produced by the traditional method, see the picture **Figure 30**. Generative design can give us more inspired and useful design language elements in some unique projects.

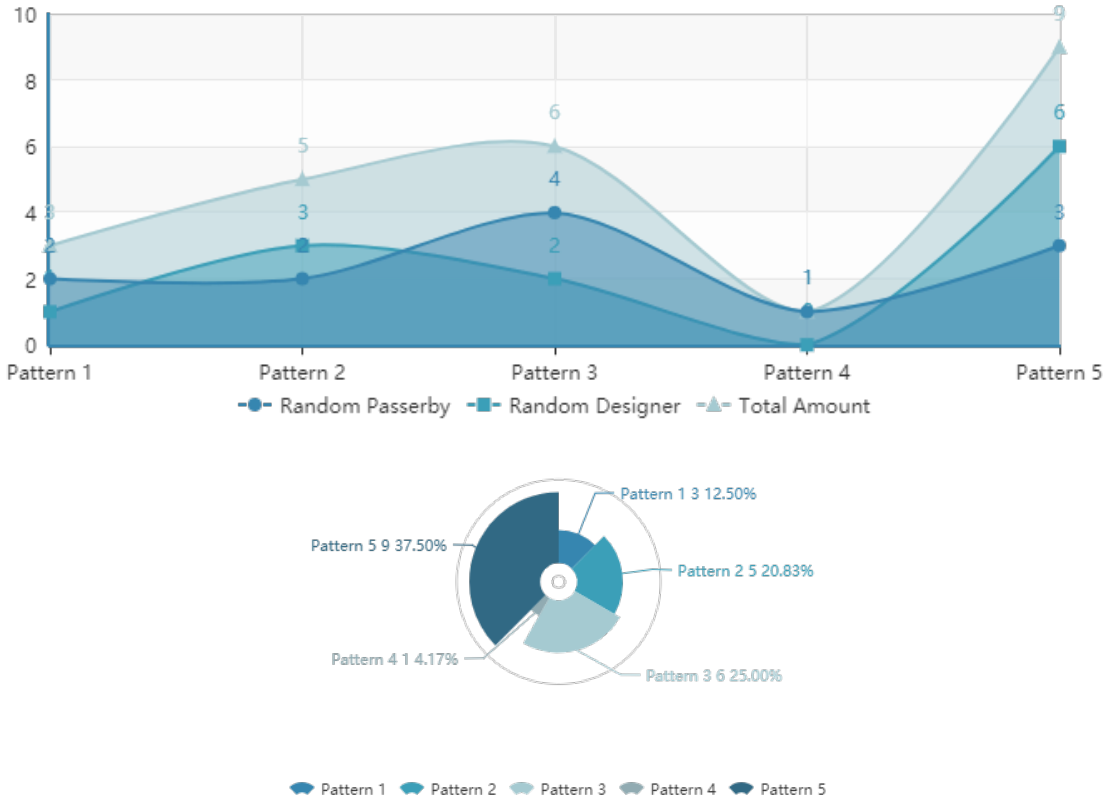


Figure 30: The Result of The Questionnaire

Finally, the experiment needs to perform the anti-stress test on the surface after generating this patterns, see the picture **Figure 31**. During the same time interval, applied the pressure to the test object gradually from zero and recorded the corresponding test pressure value when the structure of the object is broken.

As a result, the first surface that was destroyed in the structure is the pattern generated by the Diffusion Limited Aggregation (DLA) method. Following this, the pattern sketched by traditional method was broken and then the pattern generated by L-System and Gray Scott (Reaction-Diffusion Shader) System method. The most structural rationality

one is the pattern generated by the Rainflow Simulation Analysis System method. Due to the parameters of the generative design method have the strong rationality with mathematical logic, the pressure resistance of the generative design surface is much stronger than that of the traditional design, see the picture **Figure 32**. Traditional designers cannot achieve the accuracy of computer-generated design because they only rely on sketching and simple space imagination. It is difficult for them to handling complex spatial structure space in a short time. Compared with traditional, generative design can improve the design more reasonable, structure-reasonable and competitive.

Figure 31: The Anti-Stress Test of Different Pattern Surfaces

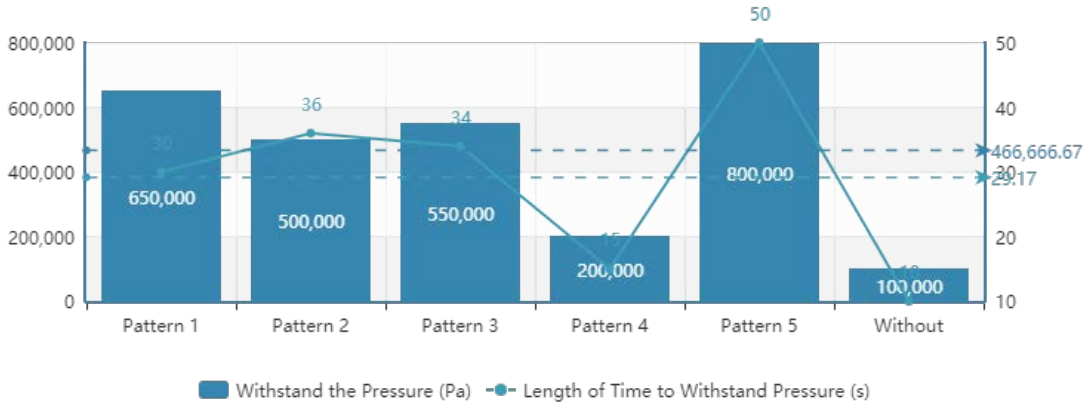


Figure 32: The Result of The Anti-Stress Test

The result of the pattern generation experiment is that generative design can quickly generate a new evolution solution and this method is also more flexible, efficient and successful on unconventional and non-linear surfaces. As for the complex spatial structure, generative design method can give many solutions quickly according to the specific generative parameter logic. The designers can observe the changes in the shape of

the program in real time while changing the related parameters. But the traditional design approach requires the designers to participate in fully. The results of the program will go through many processes, such as sketching and modification and will not get a new solution quickly in a short time especially for the complex spaces. The generative design makes the design more reasonable, including reasonable structure, more optimized materials and more competitive. In traditional design methods, considering the number of design factors is complicated and time-consuming. However, it is different in generative design. It can quickly generate a preferred solution using the given parameters and rules.

4.4 Conclusion

Generate design imitates natural design evolution methods. Designers can input the design goals into the generative design software, along with parameters such as materials, manufacturing methods and cost constraints.

Designers use genetic language to describe the rules program and generate code scripts for the corresponding instructions. This method is used to build and identify basic design rules that are difficult to adapt to common geometries, transforming conceptual designs into structural descriptions. The generate design method provides different forms of selection options according to the corresponding parameter requirements. The traditional design process cannot achieve this morphological structure. **(Branko Kolarevic and Ali Malkawi, 2005)**

From the above test results, designers can use some fixed rule algorithms to achieve their required planner layouts and spatial compositions. The spatiality of architectural design and the geometry of computer algorithms will appear to some extent to the unity and coincidence of requirements. Designers can use this commonality to allow computer algorithms or bionics to generate fixed algorithms to assist them in designing.

Furthermore, generative design can make designers more creative. It can provide designers with a variety of options efficiently under the certain rules and parameters. Even though there are still some options that do not conform to conventional phenomena and physics logic as in the above experimental process generated by the method. At this time,

designers are required to select out the logical solutions through the generated design results. The role of designers has changed from design to selecting but selecting is not blindly choosing. It also requires the designer's professionalism and aesthetic requirements. Similarly, designers can focus more on the developing and formulate the generative design rules. It will help the designers to complete the part of the generation more efficiently. Generative design can make the solution more rational including optimizing structure, reducing material usage and increasing overall competitiveness. These conclusions are answered in the various experimental tests above and the results of the test also explain a series of questions raised in the hypothesis.

Nowadays, digital technology is developing at a high speed, the development speed of the generated design has also been rapidly improved. To what extent does the generation design replace the work of traditional designers? Can this short-cycle designed solution withstand all aspects of comprehensive testing? How long will the life and freshness of the generative design last? These questions are also worth studying and answering.

5.0 Conclusion and Further Work

5.1 Conclusion

This essay is target about the following questions that can generative design make designers more creative? Can generative design improve design more reasonable, structure-reasonable and competitive? Does the designer need subjective participation in the process of generating the design? What role does the designer play in generating the design? The purpose is about experimenting with the questions and exploring the results. To result in more convincing and accurate experimental conclusions, we use data and facts to answer and solve the above issues in hypothesis.

Generative design is oriented to architectural disciplines and other emerging cross-disciplinary areas. These design methods need the actual data and objectivity to start imitating the prototype system. They have the following standard features:

A) Multiple elements interact directly or indirectly. The generative design uses multi-element as its essential characteristics and the model mainly explore the various elements of the system relationship directly or indirectly. This interaction is non-linear features and the interaction of elements cannot be linearly overlaid simply.

B) Dynamic research feature. Generative design system requires dynamic research ideas, which is corresponded to the genetic algorithms, multi-intelligent system and artificial intelligence method.

C) The parameters in the generative design system are affected by the state of the process and present random outcomes.

D) The constituent elements in the system have a hierarchy structure, each element has a variety of attributes and active adaptabilities.

There are obvious differences between digital design methods and traditional paper design thought. Digital design has greater interactive potential because it supports reflective practice and interactive information exchange. Different types of digital design models have different goals and attributes. **(Singh and Gu, 2012)** Generate design system

is a design method that uses different parameters to support design explorations. Most of the existing generate design system are based on a generative design technique. They tend to follow a design approach to generate routes rather than exploring different design perspectives. It is the reason why I have to choose four generative methods to achieve my goal and use four generative design outcomes to test for the best choice. It is in contrast to the creative approach to divergence. Therefore, it is necessary to generate composite models of design systems that can support multiple generations of design techniques and promote more flexible design exploration in different directions.

Consequently, to experiment with the possibility of an integrated framework and determine the technical and conceptual requirements, some empirical work has been advanced with sample design scenes. It is needed in the future work to refine and implement the process framework. The development of the integrated generative design system based on the framework is prospected to be the iterative process. The improvement is much like other design behavior, where the rule setters, the tool builders and the designers, think about the unexpected challenges, mostly varying parameters and opportunities as new regulations are determined and integrated into the generative design method system.

5.2 Further Work

Regarding the further work, I continue to use the generative design method to create the project shape to verify further the issues mentioned in the hypothesis. Another control parameter is added based on the method of continuing to use Cellular Automata method to generate the shape. Draw a curve in the space and generate another shape alone that curve according to the principle that the radius of the starting point is the smallest and the range of the centre point is the largest. The two shapes cut from each other to get the intersection part as the basic shape for further design development, see the picture **Figure 33 and 34**.

It not only increases the complexity and diversity of the project but also avoids the characteristics of the edge being too rigid, dull and monotonous effectively. After

repeated modification and selection, designers determine the final shape. Finally, the Rain-flow Simulation Analysis System method is used to generate the pattern to provide structural support for the design.

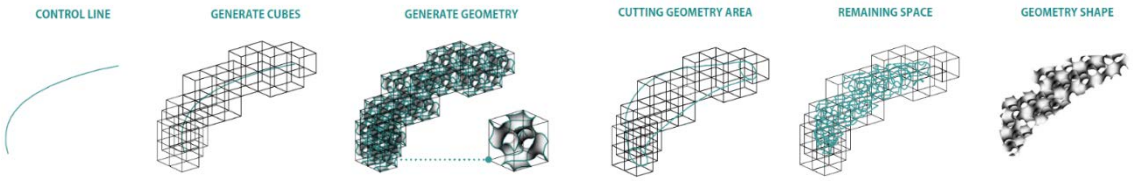


Figure 33: The Evolutionary Generative Design Method

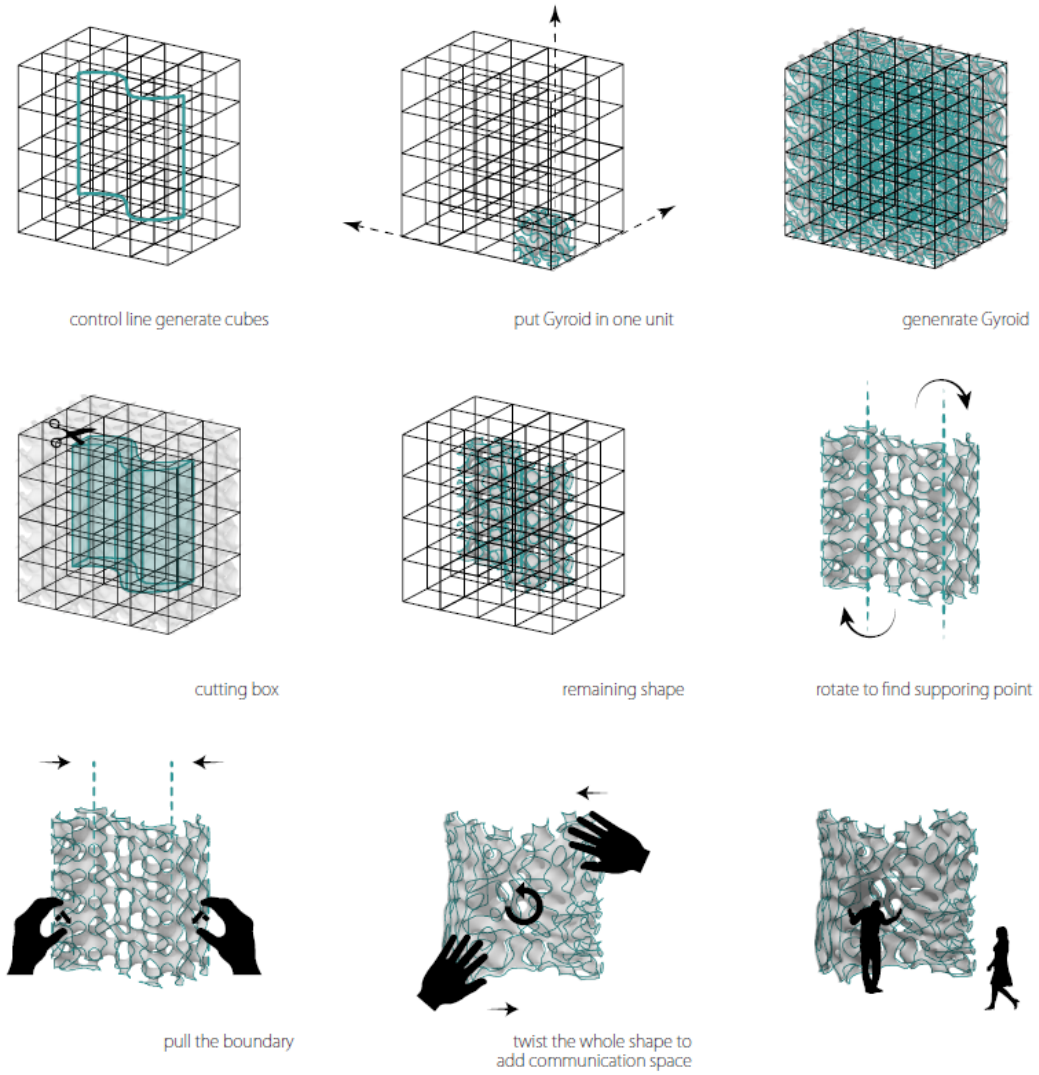


Figure 34: The Evolutionary Generative Design Method

As a result, this project further proves that generative design can make designers more creative. It is a challenge for traditional design method to design such a structure. Because traditional design methods consume a lot of time for complex shapes and the traditional design may not be very accurate for the cutting edges of the two shapes. But the generative design is different. Based on changes in the parameters, the designer can see the real-time changes in the new shaped option and the intersection between the two shapes will be calculated at the same time which improves the accuracy and efficiency of the project significantly. About pattern generation, this project further demonstrates that generating designs can give more reasonable options in complex spatial and hyperbolic structures and also increasing design efficiency and quality significantly.

In conclusion, from sketch design to computer-aided design to current generation design, designers seem to participate in fewer and fewer roles. Previously, designers used drafting and manuscripts to express their design intent to the functional arrangement. After that, designers made precise implementation of design and functional requirements with the help of computer-aided design. Until now, the design way changes dramatically, the complex body generation requirements are fully input into the computer to generate the design and designers choose one they like.

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List of Figures

Author: Yang Song
Program: March Architectural Design
Theory Tutor: Abel Maciel
Cluster: RC9
Student Number: 17050210
Student E-mail: ucqbys4@ucl.ac.uk
Address: The Bartlett UCL, 22 Gordon St,
Bloomsbury, London WC1H 0QB
Date of Submission: 13.07.2018