Generative Forms of Historical Architectural Arts – The Example of Caisson in Historical Temple

Yinghsiu Huang

***Abstract*—The Caisson structure with several artworks and sculptures is the most valuable and important art for preservation by using digital technologies. On the other hand, the main function of Caisson structure is supporting the weight of round shape roof, releasing the pressure from structures, and extending the life of the traditional temple buildings. Therefore, the objective of this paper is to construct the "Caisson" system of Taiwan traditional temple structure by generative algorism. Moreover, by modifying some parameters, different style of Caisson will be generated, as well. Consequently, this paper is not only proposing the generative forms of Caisson system, but also simulating the art forms on the system through the generative algorisms.**

***Index Terms*—Generative design, caisson structure, historical temple, parametric design.**

I. Introduction

The invention of computer had changed human life from 1970s, and also accelerated the various fields of study, such as computer-aided, - evaluated, and -manufactured design (CAD / CAE / CAM), which are applied into the latter stages of design process. In these stages, the ideas from designs have been widely simulated, analyzed, and automated-manufactured by computers. Then, lots of research studied on the computer-aided conceptual design (CACD) to help designers integrate the 2D cognition into the 3D cognitive feelings [1]. By doing so, the generated 2D and 3D graphic by computer could represent design ideas using in different design stages.

However, the most imaginative and creative stage in the design process is the conceptive development stage in which designers analyzed design cases and formed a new design concept and shape by their imaginations. These digital technologies also provide highly uncertain dynamic operations for design strategy, which could get rid of the fixed limitation of design ideas. Therefore, the unexpected, uncertain, and varied behavior of design process by utilizing digital technologies makes design process as a "finding of form" process.

On the other hand, by utilizing digital technologies in preserving cultural and historic objects, buildings, streets, arts, and even areas, can be constructed by 3D digital models and represented in the virtual simulations. The culture and heritage preservations are also becoming the important research implement domains in many organizations and countries around the world. Historical building is the most valuable objects to represent culture, atmosphere, and life style of a local area. Thus, temples in Asian countries is not only represent one kinds of religion, but also to preserve one kinds of life-style of local people. In Taiwan, there are many projects of culture and heritage preservation. For example, the "Tien-Hou Temple in Lu-Kang" is considered as the famous Ma-Zu temple in Taiwan and is famous for its complexity of art decoration and "Caisson" structure, which is a system of wood brackets on the top of a column supporting the crossbeam.

The Caisson structure with several artworks and sculptures is the most valuable and important art for preservation by using digital technologies. On the other hand, the main function of Caisson structure is supporting the weight of round shape roof, releasing the pressure from structures, and extending the life of the traditional temple buildings. Therefore, how to utilize the ability of generating 3D derivative model by analyzing historical temple for generating historical arts is the main problem of this research.

In order to investigate the problem of this research, therefore, the objective of this paper is to construct the "Caisson" system of Taiwan traditional temple structure by generative algorism. Moreover, by modifying some parameters, different style of Caisson will be generated, as well. Consequently, this paper is not only proposing the generative forms of Caisson system, but also simulating the art forms on the system through the generative algorisms.

II. Related Works

A. Caisson

The Caisson is an art and historical structure on the top of Chinese architecture, which is up-to-roof of a building, like a hole. The decoration of the walls of Caisson is algae-liked pattern, which is to highlight the main space of the historical building. "Caisson" is a unique ceiling structure and decoration in historical Chinese architecture, especially in the temple building. The location of Caisson is usually chosen to be the most attracted place in the ceiling. It is surrounded by a brackets that are continuously suspended from outer to the center. Looking from bottom is like a well, so called "Algae-like well, or Caisson" (Fig. 1).

The Caisson structure generally composed of multi-layer brackets, continually narrow up from bottom to top. To form an inverted bucket shape, outer-shape of Caisson is square or polygonal, where top-shape is usually circular-like.

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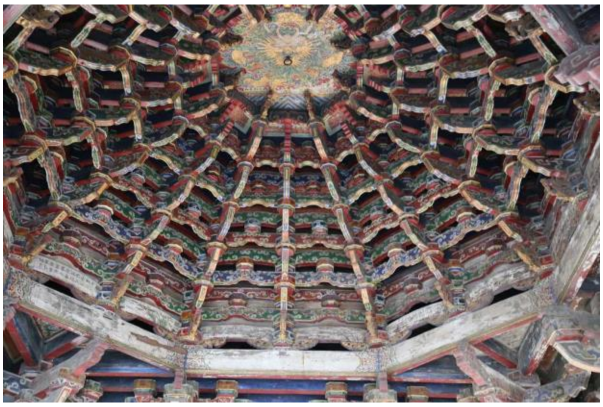

Fig. 1. The Caisson structure of Tien-Hou Temple in Lu-Kang, Taiwan.

B. Parametric and Generative Design

Fisher explored symmetry of ignorance, social creativity, and meta-design to provide a conceptual framework for understanding creativity. By comparing multisystem support to the cooperation between several designers, cooperative design creativity can be inspired [2]. Through these systems, users can process, share, and understand one other's works and learn from one another, thereby resolving the problem that computer computation systems based on cognitive science have been considered uncreative or even culpable for reducing people's creativity. These systems are so-called social creativity computer systems. In the meta-design environment, users are like designers, handling new conditions and limitations during a design and development process, and integrating and solving problems. The meta-design environment is a crucial source of social creativity.

Design is change, based on the development of computer, especially the programming software, 3D modelling, 3D simulation…etc. The Parametric modeling also has been changed, which is one of the very first ideas in computer-aided design. Today, the key to both using and making parametric systems could deeply change design works. We can program what we call design. To the human enterprise of design, parametric systems bring fresh and needed new capabilities in adapting to context and contingency and exploring the possibilities inherent in an idea [3]. The potential of the parametric system combines the basic ideas of parametric systems with equally basic ideas from both geometry and computer programing.

Computer-aided design software based on parameter design achieves creativity objectives through parameter adjustment, construction process, and open source. Pro/Engineer and generative components have these functions and use intuitive and nonlinear methods to achieve divergent design and optimize their effects. When Rhinoceros 3D developed the Grasshopper plug-in, the number of logic operators increased and an object-oriented interface was used to write computer programs in combination with modeling instructions. Using elements in a series to compile computer programs allows parametric data flow and treatment to be easily handled and allows model construction processes to be presented. The use of Grasshopper is linked to Arduino and robot controlled entities, is beyond the original modeling purpose, and successfully leads other object-oriented programming languages to emulate Grasshopper (e.g., Nudebox). In recent years, Grasshopper has rapidly developed and has been commonly and widely used in the digital construction sector. Particularly, free-form surfaces and digital construction have been embodied by using the parametric modeling tools.

A computer can perform monotonous huge computation, and is therefore extremely helpful for the digital construction required for handling a huge amount of components with tiny changes. A computer can also perform rapid computation to present real-time changes, and therefore designers can repeatedly use dynamic and nonlinear design methods to present optimal forms and structures.

C. The Application of Digital Generative Forms

Observing, analyzing, utilizing, and learning from natural phenomena are critical for basic modeling training in traditional design education. From both macroscopic and microscopic perspectives, the aesthetic or functional importance of living creatures, nonliving things, and landscapes in nature are highly valuable in design. This is evolving into an independent subject, including design bionics and ergonomics, which are especially closely related to living creatures in nature. The causes of natural phenomena and patterns are complex but can mostly be explained in natural science or engineering. In the work by D'Arcy Thompson in 1917, the development or patterns of various living creatures were described using mathematical expressions. These results have recently been verified and applied using parametric programs and computer graphics (Fig. 2) [4]. However, design education still preferably focuses on the aesthetic characteristics of nature.

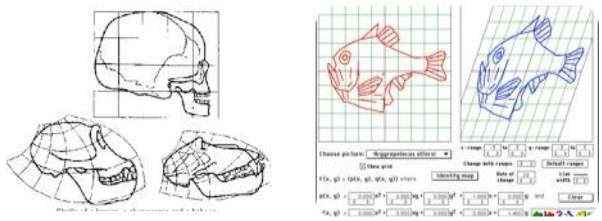

Fig. 2. The development or patterns of living creatures are verified using parametric programs and computer graphics.

Design rules obtained from subjective observations but not from system measurement, generalization, and quantification can only be implemented by designers through manual operation and cannot be implemented with the help of digital auxiliary tools. Concurrently, students are limited by time and materials and therefore cannot adequately perform verifications and conduct tests. The reason is that traditional design education is aesthetics-oriented. Although numerous design departments belong to engineering schools, because of insufficient background knowledge regarding manufacturing engineering and technology, concepts of quantitative parameters and programming are not taught in depth for influencing design concepts [5]. In addition, no programming tool suitable for designers has been developed. Because people with design backgrounds are typically resistant to learning mathematics and programming languages, programming languages are still mainly used by professional program developers. From the 1970s to 2000, generative design theories such as shape grammar [6], genetic algorithm [7], parametric design, design rules, evolutionary design, and generative art [8] had developed and become mature. Thus, rules, computations, and parameters were included in design concepts (Fig. 3).

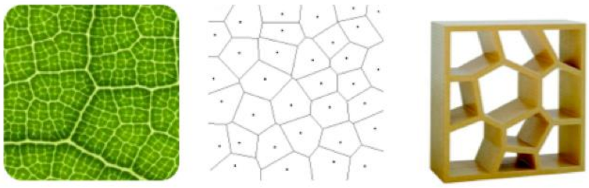

Fig. 3. Transformation of natural forms into products.

Regarding architecture design in the digital age, we should not only consider what to design but also how to consider design challenges. The book "Hybrid Space" by Zellner [9] indicates that architecture itself has become a study related to topology and geometry, a computational and recombined smart product, and an automatically generated and dynamic spatial form. To date, computational design has become an independent technology in architecture education and practice. Numerous architecture schools offer related courses. Architecture firms that are well known for their digital and curved styles have established computation technology departments and related technology databases. Numerous architects possess the capability of computational design (Fig. 4).

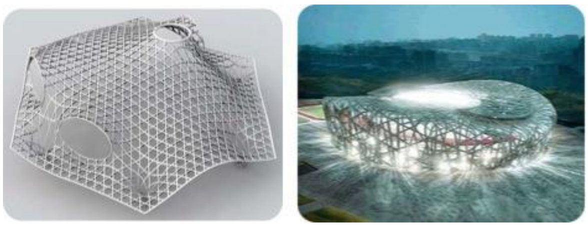

Fig. 4. Forms constructed by architecture firms using computation technology and technology databases.

III. Methodology

In this study, the first step is to analyze the structure of Caisson (Fig. 5); the second is to construct the Caisson framework by using Grasshopper, which is a plug-in of Rhinoceros. And finally, to generate different kinds of Caisson by modifying varies of parameters is to form the historical aesthetics of traditional temple building.

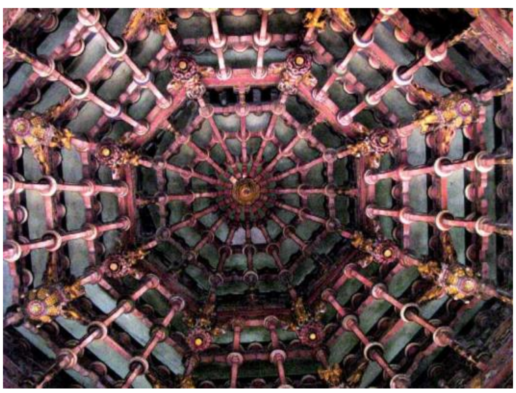

Fig. 5. The bottom to top view of Caisson structure.

A. Analysis of Caisson

1) The basic polygon shape

According to the appearance of the Caisson structure, there are the eight diagrams, round, oval, square, hexagonal… etc. This basic polygon shape is the main factor of traditional Caisson structure (Fig. 6, left).

2) The single-layered radial brackets

After the decision of basic polygon shape, the single-layered Caisson composed by twenty-four Brackets stacked in the surrounding (Fig. 6, right). Each side of basic polygon are three Brackets, which point at the center of the basic polygon.

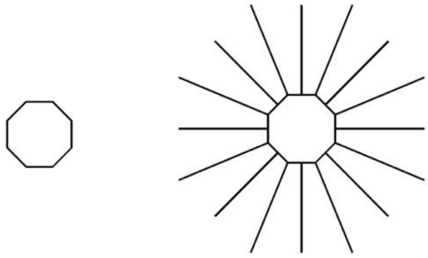

Fig. 6. Left: The basic polygon shape; Right: The radial Brackets.

3) The transverse plate

The transverse plate (Fig. 7, left) is a structure that connects each piece of Brackets with the same shape as the basic polygon.

4) The octagonal pillars

Long octagonal pillars, consistent with the Chinese culture "Bagua" shape, are combining the radial Brackets and the transverse plates (Fig. 7, right). At the forefront of the radial brackets, there is another short octagonal pillar with a shorter height, which is used to support the upper-structure of the ascending Caisson.

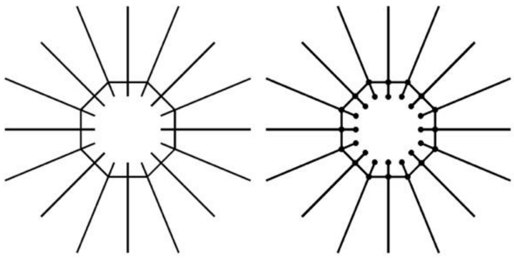

Fig. 7. Left: The transverse plate; Right: The octagonal pillars.

5) The ascending structure

There are 3 to 4 layers of the Caisson structure. Each layer is ascending based on the bottom layer, supported by the short octagonal pillars (Fig. 8, left).

6) Ascending and rotating structure

In each ascending layer, if each layer is rotated, it formed a spiral Caisson (Fig. 8, right).

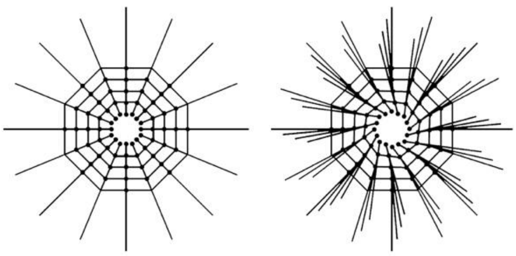

Fig. 8. Left: The ascending structure; Right: The Ascending and rotating structure.

B. Generative Modeling

In this study, by using Grasshopper, which is a plug-in of

Rhinoceros, generative modeling program of Caisson had been constructed by following six stages of analysis in previous section.

1) The basic polygon shape

In the basic polygon parameters, this variable not only can change the number of edges of basic polygon, from 4 to 16 edges, or even similar to circle; but also can control the diameters of basic polygon for generating different sizes of Caisson (Fig. 9, left).

2) The radial brackets

The Radial Brackets is based on the edges of basic polygon, directed to the center of basic polygon. Parameters of radial Brackets not only can control the length of the radial brackets, but also control the ratio of the upward layer (Fig. 9, right).

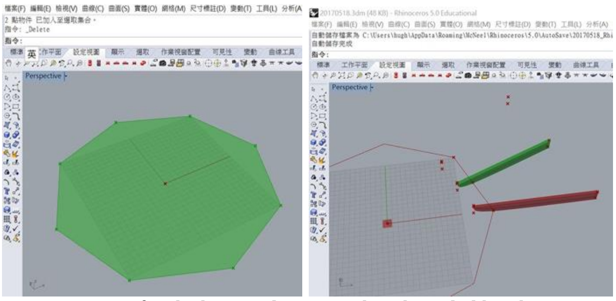

Fig. 9. Left: The basic polygon; Right: The radial brackets.

3) The transverse plate

The transverse plate (Fig. 10, left) is connecting the radial Brackets, followed by the shape and size of the basic polygon, and the shape of Caisson is the same as the basic polygon.

4) The octagonal pillars

Long octagonal pillars: the function of long octagonal pillars is to combine the radial brackets and transverse plate structure, and the height is consistent to plate consistent. Short octagonal pillars: the short octagonal pillars at the forefront of radial brackets is to support the structure of the upward layer of Caisson (Fig. 10, right).

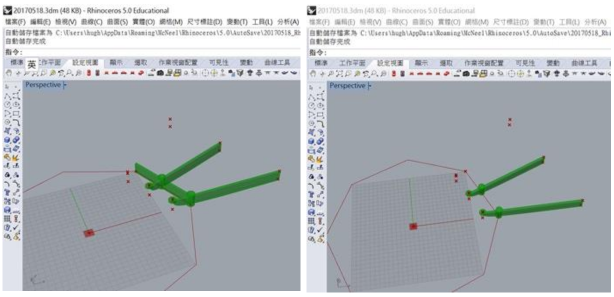

Fig. 10. Left: The transverse plate; Right: The octagonal pillars.

5) The ascending structure

Each layer of Caisson structure is including the radial brackets, transverse plate, and octagonal pillars. when stacking up, the short octagonal pillars of down-layer is to support the long octagonal pillars of upper-layer layer to form the ascending structure of Caisson, which will have 3 to 5 ascending layers (Fig. 11, left).

6) The ascending spiral structure

During stacking the ascending layers by a fix rotation angle of radial brackets and the transverse plate, that will become the structure of a spiral Caisson. This parameter can adjust the angle of rotation in order to form different degrees of the spiral Caisson (Fig. 11, right).

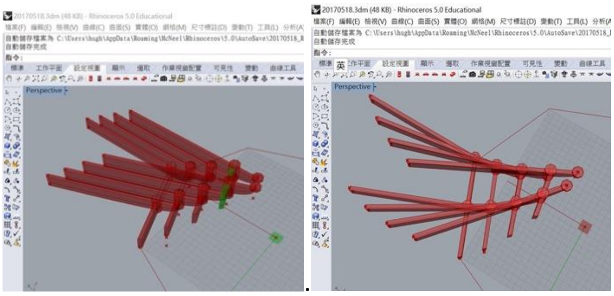

Fig. 11. Left: The ascending structure; Right: The ascending spiral structure.

C. Generative Caisson and Aesthetic

1) The ascending structure

The outcome of this research is to simulate historical art of Caisson structure by using generative program. Fig. 12 is the simulation by following previous steps with eight diagrams, and stacked 4-ascending layers. Fig. 13 is another simulation with 16-edges polygon, and stacked 4-ascending layers.

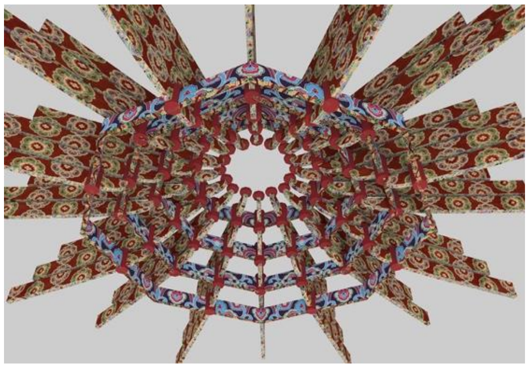

Fig. 12. The ascending structure with eight diagrams.

Fig. 13. The ascending structure with eight diagrams.

2) The ascending spiral structure

In the simulation of ascending spiral structure, Fig. 14 and 15 shown different angles of rotation degrees with 10 and 20 degrees, respectively.

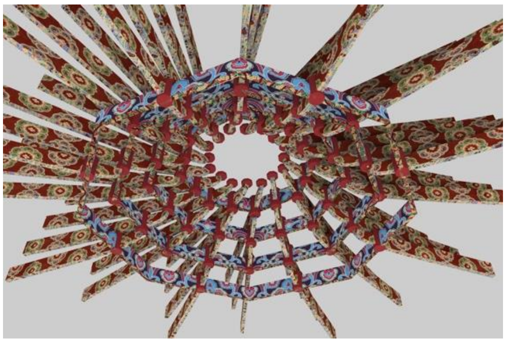

Fig. 14. The ascending spiral structure with 10 degrees.

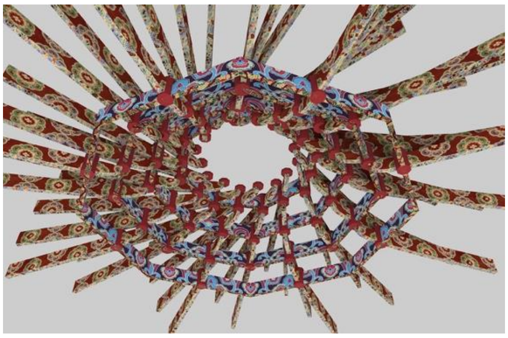

Fig. 15. The ascending spiral structure with 20 degrees.

IV. Conclusions and Suggestions

The objective of this study is to generate the most important and complex Caisson structure of the traditional and historical temple by using computer programming. In order to do that, the analysis, decomposition, and simulation of the historical Caisson structure have already been completed in this paper.

Parameters in each stage of digitally composing the Caisson structure are to control different variables, including numbers, diameters, lengths, angles, number of layers...etc. Similar to the DNA of Caisson structure, these parameters can be derived from the traditional Chinese art and historical buildings.

The ability for computers to derive traditional aesthetics buildings is not to replace the architects' works, but, in contrast, is to provide much more designs for architects or designers. Therefore, how to define the parameters, derived from nature, arts, and historical objects, will be the critical factors of producing generative designs.

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