STATICS AND DYNAMICS IN THE PROCESS OF CAD/CAM FABRICATION

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Abstract. Through the progress of digital media, dynamic concepts contribute to vivid forms. Nevertheless, these forms still present static space, which cannot reflect the designer's dynamic concept, a shape that changes over time. This is a setback for design and fabrication. Hence many researchers turn to designing dynamic architecture. However, the current development restricted by technical threshold is prone to solve the variation of functions instead of aesthetic-oriented changeable form. It is obvious that the difference between "statics" and "dynamics" becomes a watershed of aesthetics and functions. This research attempts to eliminate the above-mentioned barrier and to suggest a new CAD/CAM fabrication procedure based on aesthetics and reveal key tectonic factors that affect dynamic architecture.

Keywords. CAD/CAM: Statics/Dynamics; Tectonics; Fabrications.

1. Review

1.1 THE DEVELOPING PROCESS OF "STATIC" ARCHITECTURE

The history of architecture development has always been accompanied by a pursuit for nature. Evolving from classic geometry to animated Baroque curves (Zevi, 1957), has gradually imitated nature by the progress of design media. After Frank O'Gehry's completion of the fish sculpture in Barcelona, designers can eventually freely pursued the form of dynamic nature under the assistance of CAD/CAM (Computer-Aided Design/Computer-Aided Manufacturing) without most restrictions in fabrication and procedures in the past (Callicott, 2001; Kolarevic, 2001; Lim, 2006). The technique of CAD/CAM evolves in the short time because of the rising of utilizing rate. This technique is gradually matured in various media forms (Groover and Emory, 1984; Kvan and Kolarevic, 2002) and in the integrated automation of fabrication process (Goldman, and Zdepski, 1990), which provides designers with quite varied swift and pragmatic methods and steps.

New technique makes complex forms possible to build and enables architects to initiate some dynamic concepts like flowing water and particles collision. However, no matter how dynamic the concept is, it is still a static building. Architects design by following physical restrictions to create representations of architecture. For thousands of years, the conflict between static structure and dynamic concept yields the poetic aesthetic of architecture. It is a static CAD/CAM fabrication procedure towards aesthetics.

1.2 THE DEVELOPING PROCESS OF "DYNAMIC" ARCHITECTURE

The history of architecture development is virtually the history of "static" architecture. The reason is not because designers were used to static restriction but they didn't have the capability to make kinetic structures. Consequently, expressing dynamic concepts through static structure become a compromising result. However, all the restrictions have dramatically changed in the digital age. Under the assistance of computing, many designers start to design experimental kinetic architecture (Goulthorpe, 1999; Sterk, 2005) and furthermore to develop Smart Space responds to unpredictable factors such like external environment, bio-context and user mode in order to solve function-oriented architectural problems. Architecture forms transformed by variation of given conditions and finally adapt to the environment in a functional manner. The Smart Space could generate varied dynamic reactions through different conformations like embedded, deployable and dynamic ones and the basic control of artificial intelligence (Fox, 2001; Rusell and Norvig, 2003). This kind of responsive architecture whose fabrication procedure is based on functional variation is regarded as a necessary result under the integration of computing and space (Negroponte, 1975) and has become a direction of fabrication in the CAD/CAM realm.

1.3 THE DEVELOPING PROCESS OF TECTONIC FACTORS

Tectonics is gradually evolving from its significance referred to carpenters and workers in early phases into artistic engineering which involves technology, methods, materials and concepts. It was classified roughly into two categories at first–internal structure and external envelope (Botticher, 1852) then once turned into four elements according to construction method - earthwork, hearth, framework and roof. Furthermore, in this medium term, the importance of joint is fully demonstrated (Semper, 1951). With the advance of technology, people have begun exploring the impact to existing tectonics caused by new technology (Vallhonrat, 1988). In a later period, the significance and necessity of connection integrated regional perspective with prior viewpoints has been established firmly (Frampton, 1995). Tectonics is eventually regarded as some kind of poetics of construction.

In order to reveal those essential digital factors in the process of design and fabrication and locate the position of classical design and structure thinking in digital era, varied theories have been proposed in recent years. Information is considered one kind of tectonic material (Cache, 2002) and makes the traditional rigid tectonic procedures more flexible (Spuybroek, 2003). Scholars have attempted to probe some phenomena of digital tectonics by analyzing many existing groups focus on digital tectonics (Gao, 2004). Up-to-date techniques make the architectural forms be more in response to spatial context (Giedion, 1967). The spatial forms merged designers' thinking conveys the logic of whole conformation and evolves into a new sort of knowledge of tectonics, which cannot be estimated by past thinking (Mitchell, 1998). In the light of its characteristics, researchers analyzed many new architectural elements which differentiated from conventional ones and suggested the concept of "new tectonics" (Liu, and Lim, 2006). Apart from traditional seven factors–joint, detail, material, object, structure, construction and interaction, they concluded another four factors:

1. Motion: a continuous process under the development of design concept and shaping. 2. Information: the new expression material on the surface of any architecture. 3. Generation: a method generates form or concept through the aid of automation computing system. 4. Fabrication: the procedure of modules designed by the aid of CAD/CAM media. Most of these new tectonic factors are the conclusions under analyzing the present design cases led by static CAD/CAM fabrication procedures and thus are the common phenomena in digital tectonic era.

2. Problem

As space concept tends to be more copious and more vivid, however, there are two different fabrication methods exist in the CAD/CAM techniques. The aesthetic-oriented static structure is prone to cause conflict with kinetic construction during the design process. With regards for moving mechanism, the design is bond to compromise with machinery operation (Fox, 1996), which will greatly restrict the freedom of form. Take two cases for example, in the "Aegis Hypo-surface" (Goulthorpe, 1999), although the need for dynamic behavior of transformation is satisfied, it is still attached to a static plane. And though the performance is dramatic, the avant-garde creation restricted by machinery is only a vivid skin instead of space. The other case is "The simplest actuate unit of a tensegrity structure" (Sterk, 2005). Its transformable structure can create mobile space that pulls away from two-dimensional restrictions but at the same time it destroys the purity of form. The complex structure influences with its outer form and possible state, which makes aesthetics collide with functions thus. Nineteenth-century German aesthetician F. W. J. Schelling once said "Architecture in general is frozen music", which expressed that architecture could let people experience rich variations in static space. This notion is not enough yet by the rapid development of technology. More and more designers involve in the field of dynamic expression of architecture. Architecture evolves progressively into dynamic aesthetics rather than static art. It becomes a vital issue that how to make designers lucidly comprehend the characteristics of dynamic fabrication and thereby create dynamic architecture without any mechanical restrictions.

3. Objective

This research focuses on the design and fabrication of a dynamic free-form construction and its tectonic analysis. In design and fabrication, hope to create a new fabrication method based on aesthetics that will at the same time successfully give consideration to form and movement and furthermore, to also develop a prototype for kinetic structures. In tectonic analysis, the new method will be compared with traditional methods, with an aim to conclude key tectonic factors that affect dynamic architecture.

4. Methodology and Steps

4.1. CASES STUDY

In order to create a dynamic bone structure, analysis was made on four subjects to find related characteristics between aesthetics and function, in the hope of finding inspiration for a new construction method.

4.1.1 Analysis on Static Cases

CASE [1] —Wave Pavilion / Bernard Franken

The main concept of this subject is to reflect the non-revealing dynamic energy through change of form. Using inspiration from "waves", it takes form in exhibition space, using computer aided methods in parametric design and stimulating dynamic characteristics of light and water. The stimulated form is freezed and takes shape at the point the designer is most satisfied. The designer has no idea of the final form; instead, the final form emerges through computer simulation and is controlled by individual parameters. When the design is complete, curved tubes are weld to push to a closure close to the free-form shape.

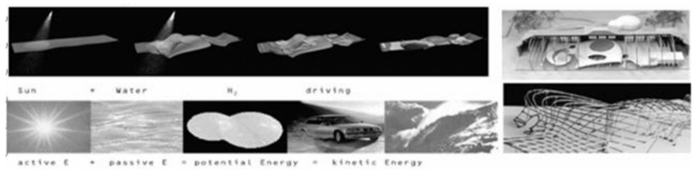

Figure 1. Wave pavilion.

CASE [2] —Dynaform Pavilion / Bernard Franken

Holds a similar notion to the Wave Pavilion, the Dynaform Pavilion tends to express stimulated dynamic energy through form. By using stimulated perturbation air current as a dynamic parameter for the frame of the shape, parameter of force is expressed through a shape. When the final form is decided, vertical and horizontal sections are sliced, creating a bone structure different from before. This captures a precise outline of the form which will then emerge to become the final appearance.

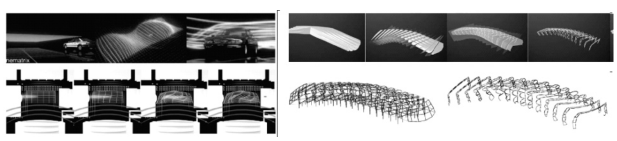

Figure 2. Dynaform pavilion.

4.1.2 Analysis on Dynamic Cases

CASE [1]—The simplest actuate unit of a tensegrity structure/Tristan d'Estree Sterk

This subject is made of several unique units. These units are made from shafts and cable which allows it to endure both tension and compression. By duplicating the unit in great numbers, an outer structural skeleton takes form. The dynamic concept of this subject is shown in two aspects: One, when spatial need is changed, space can be shifted according to user need. As spatial usage changes with time, unused space in one room can shifted to another. Two, when environmental factors hit the building, change of form may help buffer such impacts. For instance, high-story buildings are easily influenced by wind pressure which raises the risk of a trembling building, which will later result in damage to the wall or structural. Through the change of form, diversion of wind pressure will be shown thus extending the lifespan of the building. The main feature of this subject is on the movement of its structural skeleton while little was mention on how the skin is handled.

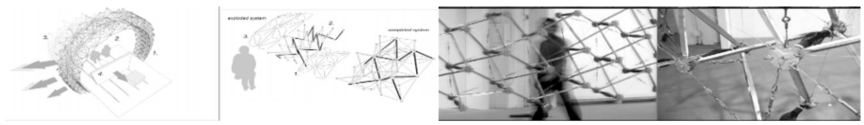

Figure 3. The simplest actuate unit of a tensegrity structure.

CASE [2]—Topotransegrity / 5Subzero

This framework system is accompanied by pressure sensors which detect user movements. Signals detected are sent to the computer for further operation. By adjusting length of the shaft, the form is opened, raised and reflects user status in real time. Space is remotely reshaped to meet the needs of such conditions. There are two methods to how form changes: the first kind is with the system reacting to environmental change; the other is with the form changing through computer operating. Likewise, by change of the structural skeleton, a change of form is generated. As to how a skin is to be placed on this structural skeleton, nothing was mentioned. This was not part of the research, therefore this is considered an experimental stimulation.

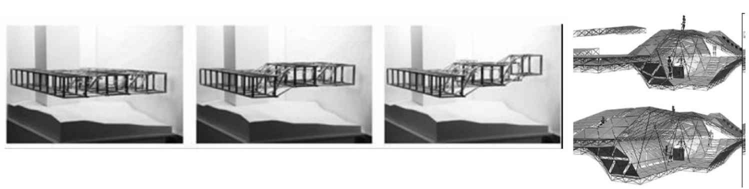

Figure 4. Topotransegrity.

4.1.3 Minor conclusion

Static subjects are aesthetic-driven cases on how CAD/CAM methods are used. They tend to slice form vertically and horizontally into sections and then putting them together constructing a precise representation of the form. However, each joint is fixed and each frame is unique. The architectural skin can be fully wrapped. This is a division execution method. Dynamic cases are a functional-driven CAD/CAM execution method. They begin with a dynamic unit. Through combining repeating units, a flexible and changeable form is constructed with the ability to change space. At this case, these units which come in great quantity become the critical factor. However, it makes difficult case in how to wrap on the skin. This is a multiple execution method. The new execution method takes advantages from both. First, it has to contain expansion of the multiple execution method. Second, it has to hold the precision of the division method. At the same time it should not affect the way of design, nor restrict or change the way designers think to cause technical thresholds. Meeting these needs a dynamic aesthetic can become an acceptable form of representation.

4.2. PROCEEDING EXPERIMENTS ON DYNAMIC STRUCTURE

This experiment is divided into three steps. According to conclusions to different approaches, we hope to conclude a dynamic structural skeleton.
Stage One: We use expansibility of the multiple execution method as a start point. The first step is to experiment on how to construct different forms with repeating units. The state of the unit is not the focus at this point. Instead, how these units are put together is the aim. The chosen unit is a deltoidal icositetrahedron. Through research, it is concluded that no matter what the unit is, as long as there are enough units, they can form a closure to almost any form. Suppose these units themselves can slightly modulate, it will be possible to create change of form.

Figure 5. Static unit study.

Stage Two: Using precision from the division execution method as an aim status. We observe that present free-form design methods are mostly accompanied by digital media as a design media. Through powerful computer stimulation, all kinds of visual representation on free-form are made possible. However, to the computer, even the smoothest surface is made of different triangles placed in different angles. Changing the angle of the triangles allow precise molding of the shape. Precision of the division is reflected through the size of the triangular face. With this as a base, and conclusions from step one, deltoidal icositetrahedrons will be places on the triangular frame connected at the joint with a ball shape structure. By precisely controlling the length of the frame, different extent of curve can be generated to complete a kinetic model capable of structural skeleton movement with additional skin.

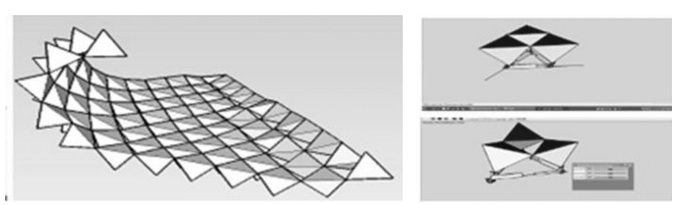

Figure 6. Computer simulation.

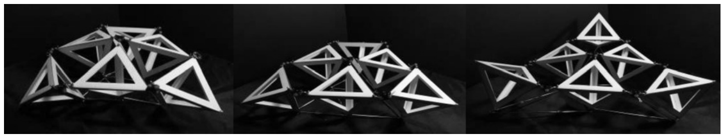

Figure 7. Dynamic model.

Stage three: source in stage three is replaced with a 9 voltage battery. A D.C. motor is used to control the length of the triangular frames while acrylic plates are put through the laser cuter form units. Put together these parts, we conclude a preliminary electric powered dynamic model. The model at this point is controlled by hand. However, no controlling script has been inserted yet. Experiment at the point is to test smoothness of the device and observing force flow within the device.

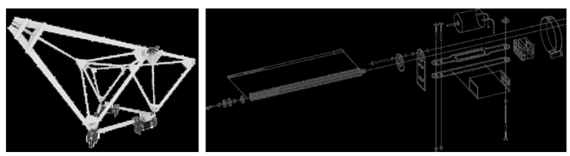

Figure 8. Computer simulation.

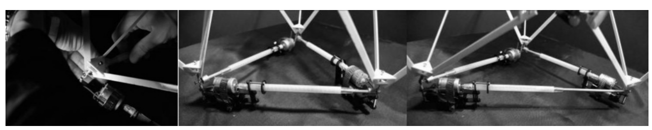

Figure 9. Power dynamic model.

4.3 FRAMEWORK FOR BEHAVIORAL CONTROL

After completing a preliminary model, a controlling script will inserted. A controlling interface will be completed according to aesthetic conceptual representation of the designer, adjustments to environment and user operation. Observation on different characteristics of the three will also take place.

4.4 TECTONIC CHARACTERISTIC ANALYSIS

Due to the fact that the prototype of dynamic component is still under development, precise analyses on possible future new tectonics were unable to be confirmed. But what can be predicted is the exploration on characteristics of dynamic tectonics which will be done according to design progress, mechanical structure, and switch of atmosphere in comparison with traditional CAD/CAM procedures. Using new tectonics (Liu, and Lim, 2006) as a base dynamic and static architectural tectonic feature will be classified.

5. Expected Results and Significance

The research is expected to gain a whole new aesthetics-oriented fabrication method which gives consideration to both form and dynamics. This fabrication method assures that architects could fabricate dynamic modules after forms are decided, without any change of their existing design habits and the aesthetic restriction to architectural forms caused by conformation. It even solves the problem - dynamics due to aesthetics could be only partially accessed. In the near future, architects could bring the forms and tense in their brain into full play and also let those dynamics concepts be clearly conveyed to the public untrained. People could experience vividly the variation of space then comprehend the spatial state architects tried to describe. Frank O'Gehry's establishment of free-form fabrication method led to unlimited imagination and pursuit of free-form architectures. Yet this method has become a restriction and custom. This research attempts to offer new possibilities and alternative directions under existing common digital tectonics phenomena in order to give some support for forming or realization of concepts.

6. Limitation and Future Study

The result of this research might reveal gap between expectation and the real state of fabrication because the main purpose of the study is to develop a fabrication procedure that falls into the experimental category. Due to its experimental characteristic, the realization of materials could merely be simulated in a small scale instead of a scale appropriate to true dwelling units. Besides, the difficulty of fabrication is determined by scale – the new procedure runs facilely in a larger scale rather than in a smaller one. Consequently, it is believed that the result would be more precise and complete if the study and construction were large scale. Furthermore, if this model could be realized, it might shift people's experience in architectural space. Space would be static no longer, which means designers have to take the dialectical relationship between time and form into every single moment. Under this keystone, it could explore the time-variant relation between people and space, which would then evolve into a dynamic relationship, and meets both aesthetics and function in the near future.

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