DIGITAL DESIGN AND CONSTRUCTION PROGRESS IN ARCHITECTURE

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ABSTRACT

This paper attempts to compare two design methods between conventional CAD/CAM technique and modern parametric design method. Through the Case Studies, the digital progress from a freeform design process in using CAD/CAM media to a parametric design process in BIM technique is presented. The findings reveal that there are some advantages of BIM thinking. The major one is it integrates conventional design with computational calculation in order to shorten the time of finding out the feasibility of design. It will be good for designers to develop design creativity and design thinking.

KEYWORDS

Computer-aided Design/Computer-aided Manufacture (CAD/CAM) technique, Digital design process, Parametric design, Building information modelling (BIM)

1. INTRODUCTION

Not until the digital era did the digital design media emerge (Mitchell and McCullough, 1995). One of the best-known projects is a fish sculpture, designed by Frank Gehry in 1992, located in front of the Port Olímpic, in Barcelona, Catalonia, Spain. This process where Gehry adopted the CAD/CAM technology to assist the design, or called the digital fabrication, has become a new digital design medium which assists the complicated freeform architectural design and construction process (Ryder et al., 2002; Kilian, 2003; Kocaturk et al., 2003; Kolarevic, 2003; Sass, 2004).

In recent years, there are more and more young designers or design teams, such as Greg Lynn, dECOi, NOX, ONL, Bernard Frankert, and UN Studio, have started to conduct the digital fabrication process to proceed with the architectural design and the construction process. Some researchers also attempts to study and understand deeply the features of CAD/CAM media in the aiding of digital design process and digital manufacture process.

With the assistance of the new media CAD/CAM, digitalizing the design process allows the designers' thoughts to be more freely presented. New concepts of design forms gradually tend be the free forms which are continuity, liquids, folds, blobs, surfaces, dynamic, immaterial, and bionic breed (Lynn, 1995; Zellner, 1999; Leach, 2001; Schmal, 2001; Mori, 2002; Rosa, 2003; Senosiain, 2003). The architecture forms have become increasingly complex. The architects and engineers also face a bigger challenge from concept design process to construction stage.

As the hardware and software of the computer science matures today, the concept of Building Information Modeling (BIM) is taken more widely. BIM is a digital representation of physical and functional characteristics of a facility (National BIM Standard - United States). The resulting building information models become shared knowledge resources to support decision-making about a facility from earliest conceptual stages, through design and construction, through structure design and building performance. It provides cost estimates and well as material tracking and ordering automatically. BIM builds the information models of architecture design in all of the design stages. The models are not only as the computer-aided design tools.

Modern BIM design tools, which are included Revit, EcoTect, Geometric Component, Rhinoceros, Grasshopper, ParaCloud, and etc., define objects parametrically. That is, the objects are defined as parameters and relations to other objects, so that if a

related object changes, this one will also. Parametric objects automatically re-build themselves according to the rules embedded in them (Eastman et al., 2008). BIM technology is far superior to drawings.

2. PROBLEM AND OBJECTIVE

However, in practice there are few design projects totally used BIM technology from the concept design stage to construction nowadays. Because the whole of an architecture project involved in many technologies and experts of different fields, it is hard to communicate with each other in the same digital platform. The implementation of BIM is still difficult. Despite the limitations, the concept of BIM is clearly important for contractors and fabricators to accomplish the complicated free-form designs, but what about architects?

Some cutting edge architects have begun trying to put the concept into their design works, like Norman Forster and Zaha Hadid. It is needed to be verified what is the difference and advantage when CAD/CAM technique and BIM concept apply to the design process for designers. Therefore, this paper attempts to compare two design methods between conventional CAD/CAM technique and modern parametric design using BIM concept based on two case studies in practice.

3. METHOD AND STEPS

This research conducts Case Study to analyse and compare two kinds of digital design process using conventional CAD/CAM techniques and modern parametric tools of BIM concept in one design case of each method. The steps are as follows.

3.1. STEP 1: CASE SELECTION

In the aspect of case selection, this research mainly selects two design projects in practice in Taiwan. They all are free-form designs, which are the similar shape, and have same design procedure.

The selected case using CAD/CAM techniques is a “Calligraphic House” project, which is one of the cases in “Next-Gene 20: Ao-Di Housing Project in Taiwan” carried out in Taiwan since 2007. The project is proposed by *Aleppo*ZONE, a design team led by *Graduate Institute of Architecture, NCTU*. One of the authors is the chief designer of the team. The selected case using modern parametric tools of BIM concept is “Freedom” space furniture, which is invited to be on display at Taipei World Design Expo 2011 with the theme of “Green and Sustainability”. The project is proposed by *CHU-studio*. One of the authors is the chief designer of the team. As a result, two of the cases can be analyzed with familiar and large quantities of design data.

3.2. STEP 2: CASE SELECTION

The study attempts to compare conventional CAD/CAM design with modern parametric design using BIM concept in the digital design process, and provide the different thinking and procedure for designers. The analysis structure focuses in three digital design and construction stages: 1. Form-finding; 2. 3D digital model; 3. CAM physical model/mock-up.

4. CASE STUDY

Take two of the selected projects as the case study, and analyse the design process in the three digital design and construction stages.

4.1. CASE 1: CONVENTIOANL CAD/CAM DESIGN

4.1.1. Form-finding

The design concepts are adopted from calligraphic ink monochrome paintings. In the process of the concept development, the relationship between the written strokes of cursive scripts created by Huaisu in the Tang dynasty and the lines is analyzed first (Figure-1a), and then the digital tool is utilized to operate the “form-finding” process.

The method to operate the “form-finding” is to derive the design form by means of three-dimensional dynamic simulation function in MAYA. First, start with two-dimensional strokes done with Chinese calligraphy within the range of the site. Then, transform the tracks made by the calligraphic ink strokes on the paper into three-dimensional strokes by utilizing three-dimensional dynamic simulation software (Figure-1b). And then, by using the “edit surface” function of the three-dimensional parameter software, create the spatial strokes with the previous calligraphic strokes and the analysis of the lines, forming the curves which are continual and comprise the calligraphic lines, and then construct the curved surface form with these curves (Figure-1c).

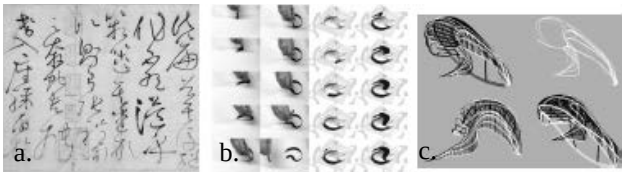

Figure 1 – a. Calligraphy; b. 2D to 3D simulation; c. Form-finding

The physical model of the “final-form” constructed with the design concept is output with

RP to examine the design form. It presents the momentum and the verve of Chinese calligraphy no matter it is in the two-dimensional, elevation or perspective spaces (Figure-2).

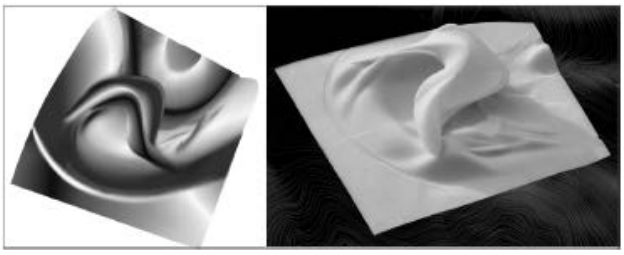

Figure 2 – Final-form RP model

4.1.2. 3D master model

Once the master form is finalized, smooth the curved surface form and divide the frame and the skin. In order to accommodate the free curves of the design form, the structure system adopts the cylindrical tube framework system. The data of divided framework design is submitted to the structure technicians to proceed with the drawing analysis and to calculate both the FEA structural analysis of the framework and the structural analysis of the curve floor load (Figure-3). In the meantime, the roof surface is also analyzed with the Gaussian curvature, and then the form is adjusted to a reasonable degree according to the structure and curved surface analyzed with the drawings. Besides, as for the division of the curved glass in the design form, during the process, cooperate with the technicians of Bentley Microstation to do the research on the automation division of the curved glass. The main purpose is to hope that the glass can be divided in a standardized and rationalized way in order to reduce the manufacturing cost of the curved glass. After the frame and the skin are rationalized with the drawing analysis, revise them to be the "3D master model" (Figure-4). This model is the master model of the finalized design. It is the reference for the acquisition of the drawing data in the next stage of construction plan.

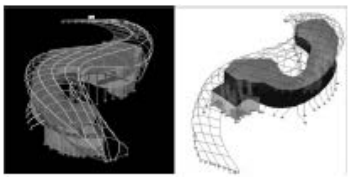

Figure 3 – Structural analysis

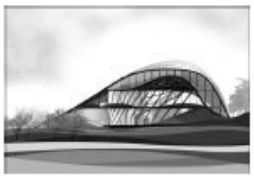

Figure 4 – 3D master model

4.1.3. CAM physical model

In addition to rationalizing the frame division model, the divided frame is cut in a one-meter unit to manufacture 2D unit drawing. The CAM equipment laser cutter is then utilized to cut the unit, and finally the physical model of the frame is assembled to discuss the structured form and its rationality (Figure-5a). In addition, the skin model of the form is also manufactured by using the RP equipment to discuss the curved surfaces of the design in the early stage of design development (Figures-5b). After the design revision and adjustment, the data of the finalized "3D master model" are delivered to the professional factory to manufacture the design form of which the curved terrain is made of CNC wood material and of which the materials are resin and RP output. The finalized CAM physical model is in the complete proportion 1:100 (Figure-5c).

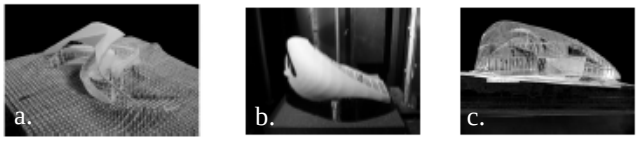

Figure 5 – a. Laser cut frame model; b. RP skin model; c. CAM final model

The detailed design and the shop-drawing of the design form of "Calligraphic House" must be based on the "3D master model" in order to get the 2D drawing data of the design unit. In addition to drawing the 2D drawings, this freeform design must also be presented with the multi-angle 3D perspective presentation. This is different from the collection of traditional 2D shop-drawings. The main reason is that even though plenty of floor plans, elevations or sections have been drawn to express various spaces in the 2D drawings, it is still insufficient in the design presentation of forms. Therefore, 3D models must be utilized as assistance so that the spatial relationship of any elevation of the form can be obtained at any time.

4.2. CASE 2: PARAMETRIC DESIGN USING BIM

4.2.1. Form-finding

The design concepts are adopted from the chair image of Chinese and Buddhism in the past. History shows that in early period, woven mats, which sometimes accompanied by arm rests or low tables, were commonly used by ancient Chinese to sit on floors. The raised platform evolved as an honorific seat for special guests or officials, and longer version of mats were used for reclining and evolved into bench, daybed and bed with multiplex functions (Figures-6a).

The method to operate the "form-finding" is to derive the design form by means of 3D MAX. The figure was designed and adjusted from CAD/CAM

program based on several defined postures and dimensions (Figures-6b).

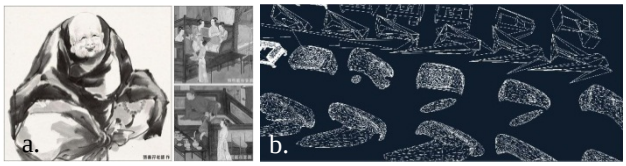

Figure 6 – a. Chinese paintings; b. Form-finding

Rapid prototyping technique was used to read in the "temporary final-form" constructed with the design concept from the CAD/CAM drawings to produce physical models (Figures-7).

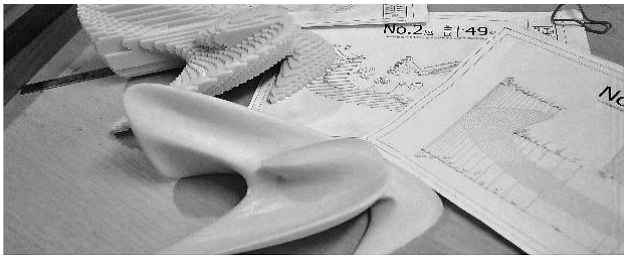

Figure 7 – Final-form RP model

4.2.2. 3D master model

In this case, recycled wood materials were processed appropriately with identical section before re-using and then distributed according to the chair's curve and intensity. After that, it can undertake the layout and fabrication process.

Therefore, first, import the temporary final-form into the BIM design tool, Rhinoceros, and then be cut into modular units by Grasshopper, plug-in of Rhinoceros. The unit was based on the size of recycled wood timber (Figures-8).

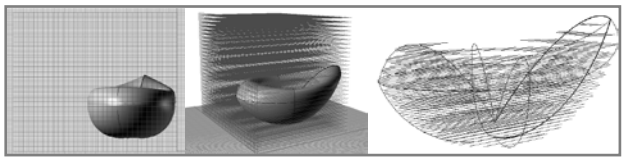

Figure 8 – materials analysis

Next, the layout of the recycled wood timber would be considered for fabrication to confirm the location and length of each timber. The recycled timber needed to be rearranged for based on the different materials and lengths. It was calculated in Grasshopper the same. The construction process had been built with BIM technique and could output fabricating data automatically. Figures-9 is the procedure of BIM concept.

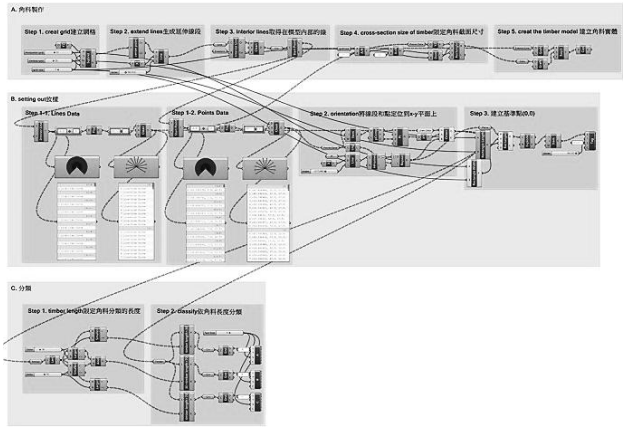

Figure 9 – Grasshopper layout

Finally, use the Scan & Solve software to analyse the security and load-bearing of the design form when people sit on it (Figures-10). The design form would be modified based on the results of structural analysis. The design process had to return to the last step to redefine the final-form. However, the automation of the construction process in Grasshopper has been set up. Designers did not execute the previous process again.

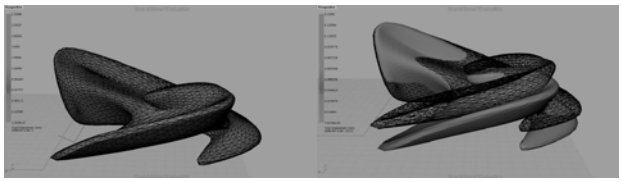

Figure 10 – Structural analysis

4.2.3. CAM physical mock-up

Thanks to the automation of the construction process in Grasshopper, the shop-drawing of the design form of "Freedom" can be outputted automatically without draftsmen. Based on the layouts, constructors can build the free-form directly and quickly. Figure-11 is the process of rough mock-up construction.

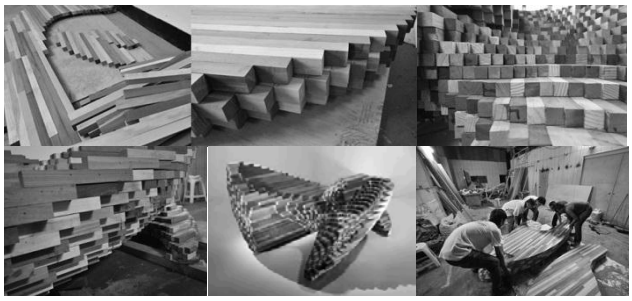

Figure 11 – The process of construction

The computer data was loaded into the Computer Numerical Control (CNC) machines for production based on the 3D master model. The rough mock-up

was milled smoothly with CNC in Figure-12. It significantly reduced the time and cost required to produce a free-form or geometric feature in comparison with the past.

There are many advantages of Grasshopper, the major one is it integrates conventional design with computational calculation in order to shorten the time of finding out the feasibility of design. With BIM concept, parametric design process, modular production method and budget control, designers successfully combined waster woods and computerized design process, turning salvage into stunning artwork.

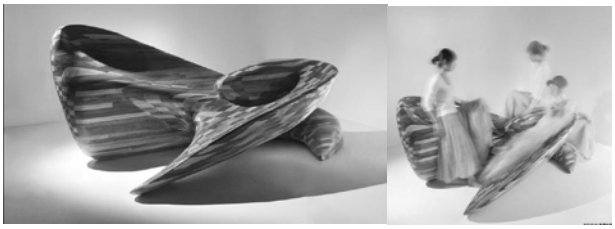

Figure 12 – Final Creation

5. CONCLUSION

This paper compares two design methods between conventional CAD/CAM technique and modern parametric design using BIM concept based on two case studies in practice. A preliminary framework of freeform design process in using digital media concludes this research (Figure 13).

The way to operate two of the designs is also to construct from the free lines and then form a free form of curved surface. The operational mode of "constructing the surface from the lines" in the 3D parameter software in the conventional CAD/CAM media is an advantage to the construction of the free form, and it is easier to edit. On the other hand, it is easy to manufacture the precise physical model of the spatial design, which is complicated and formed with the curved surfaces, by means of digital control with the CAM equipment.

And further, modern parametric design using BIM concept in Case 2 is more flexible for designers than conventional CAD/CAM design owing to the automation of the design and construction process. Designers can think about and modify their designs among the three design phases of concept design, design development, and detailed design repeatedly. In the past, it is hard to jump back concept design to modify the original design form if the shop-drawings have been done under the consideration of cost. BIM technique can cut down the human resource cost.

This would advantage designers to reach the fluency of creative thinking (Torrance, 1974), and it would be more similar to the creativity process (Wallas, 1962; Weisberg, 1986). Based on the Schön's seeing-moving-seeing model, moreover, the use of BIM technique is also suitable for architects' design thinking and process (Schön and Wiggins, 1992).

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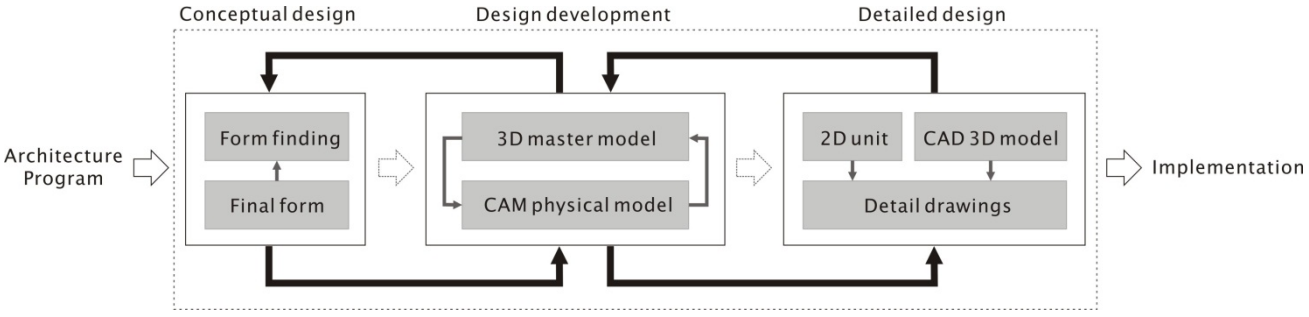

Figure 13–A preliminary framework of freeform design process in using digital media

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