TOWARDS A FRAMEWORK FOR DIGITAL DESIGN PROCESS

In terms of CAD/CAM fabrication

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Abstract. This research aims to understand deeply the unique features of the CAD/CAM media tools and their applications, and come up with an initial framework of architectural design and construction process involving the use of CAD/CAM fabrication aids.

1. Introduction

Since the start of the 20th century, computer-aided design (CAD) and computer-aided manufacturing (CAM) have been developing as separate fields following the advancement of computer technology. CAD drawing software such as autocad, 3Dmax, formz, maya, premiere and so on, as well as CAM technology such as computer numerical control (CNC), rapid prototyping (RP), 3D scanner, were mainly used in other fields during the early days. These included industrial design, shipbuilding, aerospace and the movie industries (Mitchell, 1977; Groover and Zimmers, 1984; Callicott, 2001). However, 1992 marks the start of a revolutionary trend in computer-aided technology as CAD/CAM started making waves in the architecture and construction field too. At the time, Frank Gehry applied CAD/CAM digital techniques in the design and construction process of his Barcelona Fish sculpture, in effect digitizing the whole design process (Liu, 1996; Mitchell, 1998; Linsey, 2001). With the aid of CAD/CAM, there is greater freedom and liberty in the design form and the design process is progressively digitized (Rahim, 2000; Kolarevic, 2003).

In recent years, more and more researchers and architects have started probing the ways CAD/CAM technologies are supplementing the design process, culminating in the study of digital fabrication (Kloft, 2001; Wang and Duarte, 2002; Breen et al, 2003 ,Chiu and Chiu 2003; Shih, 2003;

Kolarevic, 2003; Seely, 2004). Currently, a lot of attention is being focused on CAD/CAM fabrication within the architecture field. This is because computer technology not only influenced and changed the design process, but has also impacted the approach and process of building construction (Kolarevic, 2001; Ruby, 2001; Ryder et al, 2002; Simondetti, 2002).

2. Problem and Objective

The aid of CAD/CAM fabrication in architectural designs and constructions has changed the role of the architect in the creative process. In the past, engineers take over the construction when the architect has completed his or her designs. The process of designing and construction are distinct and separate. But with computer-aided technology, the physical form of a building can be more liberal, hence creating more complicated and free form structures. The executions of these designs in turn demand the reliance on various digital tools and technology, starting from the design stage to construction. The digitization of the design process implies architects now play an important role, having to supplement the whole process with large amount of CAD/CAM technologies. The impact of digital design process on the design thinking of architects is clearly illustrated by the proliferation of new digital free form structures and new architecture elements found in the large volumes of digital design cases. This change can be observed at the design conceptual stage, throughout the design process and end results; even construction stage of the buildings. However, the question remains: in the process of applying CAD/CAM technologies, which design methods and steps actually influence the design thinking of the architects? Hence, the goal of this study is to come up with an initial framework of architectural design and construction process involving the use of CAD/CAM fabrication aids. The methodology is to analyze the empirical data of real-life digital design processes and digital design cases. The approaches and various steps involved in the digital design process will be carefully studied and the data gathered consolidated to create a design process that will form the basis for the exploration of design thinking.

3. Methodology and steps

To answer the question raised and achieve the research objective, this research manipulated two main steps: case study and media tools experiment.

3.1. STEP 1: CASE STUDY

The first step is to analyze the digital design process of current real-life cases in order to understand the phenomenon of applying CAD/CAM digital media in the design process. The three case studies selected include works by both international and local architects: Frank Gehry, Greg Lynn, and *Aleppo*ZONE.

3.2. STEP 2: MEDIA TOOLS EXPERIMENT

Even though the case study analyses have provided an understanding of the role of CAD/CAM technology in design aid, that understanding is only superficial. The main aim of this step is to better grasp the uniqueness of these new design tools and how they can better supplement the digital design process. It also allows the designer an opportunity to attempt a creative process with only the help of a single media tool. This step is subdivided into two stages: 1. physical model making by different media tools: CAD/CAM media and handmade; 2. characteristic of laser cutter and rapid prototyping in design process. In the first stage, six architecture graduate students were interviewed after making the physical free form models using different media tools in the design process. Laser cutter and rapid prototyping (FDM) are used as the media tools of CAD/CAM media. While the second stage, a restrictive use of media tools experiment was proceeded. Subjects were asked to use only single tools (laser cutter or rapid prototyping) to aid their design process; there are four architecture graduate students, two of them using only laser cutter and another two students using only rapid prototyping in the whole design process. The CAD software they use is Maya and 3DMax.

4. Analysis

4.1. CASE STUDY

Some phenomenon of using CAD/CAM fabrication aids can be identified:

Gehry's digital design process: Gehry utilizes 3D scanner to digitalize the handmade concept models. CNC are highly used in the free form construction process. He also initiates a standard design and construction process aid by CAD/CAM media, called Digital Gehry (Figure 1a).

Greg Lynn's digital design process: Greg Lynn utilizes rapid prototyping to produce the physical model and mock-up from the CAD generation design form. Figure 1b shows the RP models of design project of Predator, Eyebeam Museum, St. Gallen Kunstmuseum and Artists Space.

*AleppoZONE's digital design process: Aleppo*ZONE is a digital design team in NCTU, Taiwan. From the real life free form projects, BCOM lobby, GreatLink, and some small-scale projects, CNC milling and laser cutter is used to produce the elements of structure and skin (Figure 1c).

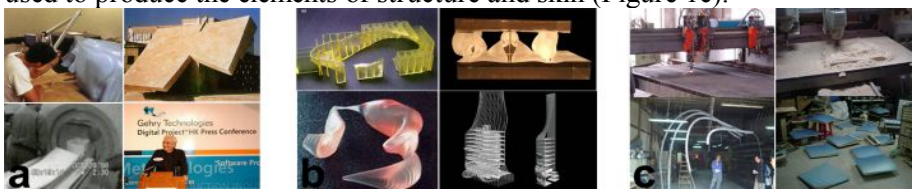

Figure 1. Phenomenon of using CAD/CAM fabrication aids.

4.2. MEDIA TOOLS EXPERIMENT

4.2.1. Physical model making by different media tools: CAD/CAM media and handmade

CAD/CAM fabrication is a digitalized physical model making process and new construction method in digital design process. In order to understand deeply the operation and method of this new media tools, this stage analyzed the difference of CAD/CAM media and handmade model making process after interviewing the six subjects. This research concludes some phenomena as below:

1. **Difficulty**: Handmade process has more difficulty compare to CAD/CAM fabrication process in making the complicated and free form model.
2. **Time**: CAD/CAM fabrication process save more time to produce free form models.
3. **Accuracy**: CAD/CAM fabrication process can produce more accurate free form models.
4. **Materiality**: Handmade process provides more materiality while CAD/CAM fabrication process has the restrictions on it.
5. **Scale**: CAD/CAM fabrication process provides more accurate scale and dimension of models.
6. **Design abstraction**: Handmade process provides more abstract design thinking when designers test and modify the models by hand. However CAD/CAM fabrication process has less abstraction in the making process.
7. **Structure**: Handmade process provides more possibility of structure method as the using of different materials. However the structure methods are not realistic compare to CAD/CAM fabrication process because designers using glue to integrate all different materials.
8. **Spatiality**: The operation of spatiality representation in handmade process is from 2D material sheet (cardboard, etc) to 3D assembly model.

However in CAD/CAM fabrication process, especially using laser cutter, is from 3D CAD model, then decompose to 2D elements (digital file), and after the physical elements are output by CAD/CAM media, a 3D model is assembled.

4.2.2. Characteristic of laser cutter and rapid prototyping in aiding design process

All subjects produce free form design (Figure 2). From the analysis, this research find out some specific characteristics and new methods of using CAD/CAM media tools (laser cutter and rapid prototyping) in design process. The characteristics of these new media in aiding design process are concluded as below:

Laser cutter: The fabrication of physical model is based on 2D cutting process. A complicated or free form 3D CAD model is decomposed to 2D skin and structure elements which can fabricate by laser cutter. Then, the output physical elements are assembled to a complete model. The process is digitalized and accurate. It is more realistic to the real life construction method. It is able to facilitate the design thinking of structure.

Rapid prototyping: The fabrication of physical model is based on 3D manufacture process. A complicated or free form 3D CAD model is produce directly to a complete 3D physical model layer by layer. The process is digitalized and accurate. Designer need not worry about the difficulty of making the complicated forms. Therefore, design form can be more liberal and free. It is able to facilitate the design thinking of form.

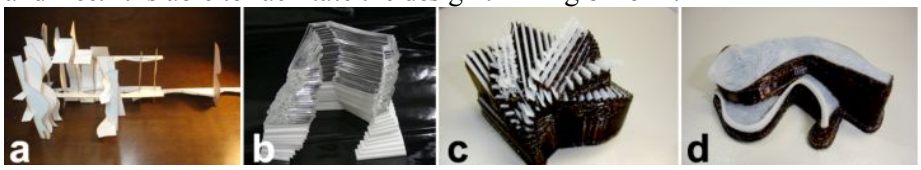

Figure 2. Physical models produced by CAD/CAM media (laser cutter & rapid prototyping).

Meanwhile, the restrictive use of media tools prompts designers to look for a better and creative way of using new media tools. Some new methods are elaborated by designers to get over the drawbacks, such as complicated steps and operation of data transform or limitation in using CAD/CAM media tools:

1. **Operation process**: Subject A (using laser cutter) adopted a 2-dimension to 3D method in designing the CAD model in order to simplify the operation of decompose the model. First, he drew the flat sheets and then assembled them in CAD environment (Figure 2a). Therefore he can overcome the complicated operation in transferring 3D data to 2D data.

2. **Representation of model**: Subject B (using laser cutter) change the general representation free form model, skeleton or structure model, produce by laser cutter. She stacked the cut sheet (transparent acrylic) to represent a design volume. Hence, she can study the design form by the stacked model (Figure 2b).
3. **Form finding**: Subject C (using rapid prototyping) used Maya generative function to produce complicated design forms in CAD. He had the opportunity to do so because he can easily produce accurate physical models by rapid prototyping (Figure 2c).
4. **Unexpected discovery**: Subject D (using rapid prototyping) discovered that the support material (self generated by the software of FDM) of the output model by rapid prototyping act as a good stimulate factor for him while study the model (Figure 2d).

5. Conclusion

Certain phenomenon of using CAD/CAM fabrication aids can be identified based on the case studies analysis in the first step. These included the changes in design concepts, digital design approaches and special characteristics of the using of CAD/CAM media tools. During the second step, experiments with various CAD/CAM tools provided information of the unique features, weaknesses and strengths of each tool in the design process. Consequently, an initial framework for digital design process is concluded (Figure 3):

1. CAD/CAM media able to implement and facilitate the free form design.
2. The design and construction process of free form design difference with traditional geometric design, therefore CAD/CAM fabrication become a new digital approach and stage in the whole digital design process.
3. Free form CAD model need to decompose to skin and structure elements in order to implement. Laser cutter plays an important role for this implementation. This process becomes an essential stage before the construction stage. So, a new stage, "fabrication stage" evolves in the digital design process.
4. Rapid prototyping able to produce 3D physical model directly from the 3D data in CAD model. Designers can utilize the generative CAD system to generate design forms liberally. It helps designer in form finding especially in conceptual stage and design development stage.

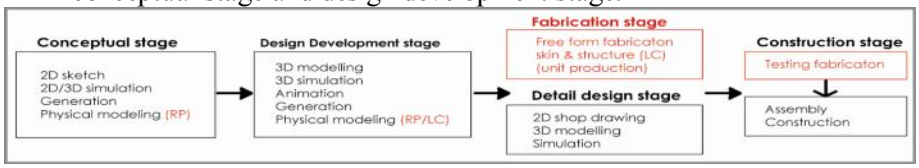

Figure 3. A framework of digital design process in terms of CAD/CAM fabrication

6. Significant and future studies

This study has identified the appropriate applications and supplementary usage of various CAD/CAM tools within the design process. These insights offer a blueprint for the development of digital design programs within the architecture design curriculum. In addition, the integrated digital design process framework can also be a helpful reference for both educators and practicing architects working on digital designs, making it easier for them to use digital tools to create brand new architecture structures as well as spatial designs.

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