Right Tools for Designing Free-form Geometry

More than Representation and Manipulation

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Abstract: This paper examines what the appropriate strategy for designers to handle the complex object is and how digital and conventional tools are involved in presenting and representing design artefacts for presenting design ideas and deliver design information, particularly in 3D free-form geometry. A series of precedent studies are conducted to examine the argument. The manipulation of digital tools is not merely a technical problem but a strategy about what the right tool for designing geometry is and how design process and principles are innovated. Two demonstrative projects are presented to illustrate how designers can better analyse and define the best choice of medium and design tools, and create a digital design platform to reach the merit of the tools created.

1 INTRODUCTION

The introduction of digital tools including software and hardware into the design process becomes evident in the design professions and education. Recently, free-form architecture is interpreted and designed differently by well-known architects such as Frank Gehry, Peter Eisenman, Asymptote, UN Studio, and Greg Lynn/ Form. The objective of this paper is to investigate what the right tools and strategies are for designing free-form geometry. We then examine the role of digital tools such as CAD/CAM software and rapid prototyping (RP) tools in the design process, and how these tools are involved in representing complex objects, particularly to examine the capability of delivering key design information in the process.

Robbins' study (Robbins 1994), "Why architects draw?" searches for the rationale of the design drawing behaviours. While drawing is an action of producing presentation and representation, sketches are considered as a media of design thinking. Traditionally, tools such as pencils are selected as a media to present design thinking before the design is made. Designers rely on sketches to present design concepts, and represent by plan, elevation, sectional drawings, or scale models to clarify key design information (Laseau 2000). Design presentation is the perception of consolidated design knowledge in mind and representation reflects the perception. However, complex geometry is often simplified or presented as a series

of diagrams because of the limited capability of the traditional tools.

Our argument is that "how digital tools and conventional tools are chosen in the process to present and/or represent the form" and "what the appropriate process and strategy is for designers to handle the complex objects such as free-form" are closely related. Two precedent studies and two demonstrative projects are conducted to examine the argument.

2 STUDIES OF DIGITAL TOOLS AND FREE-FORM

The study is initiated by examining the capacity of digital tools and how these tools are involved in the design process of free-form geometry. We first examine the capacity of digital tools, and then two precedents are selected to examine what key design information are generated by applying digital tools, and then analyse the representations of these precedents through questionnaires.

2.1 Capacity of Digital Tools

The digital tools nowadays are not just a media for drawing and a tool for presentation and representation, but also a powerful assistant for design thinking. Design can be considered as an evolutionary process occurred by interactions between the designer and tools.

In order to study the feasibility of the digital design approach, we first examine the capacity of digital tools including software and hardware, in term of the computability and information management. While different kinds of software (e.g. Form-Z, Rhino, 3DMAX/VIZ, MAYA, and Alias) and hardware (e.g. 3D digitiser, 3D printer, and CNC laser cuts) can be applied in the design process, designers tend to select the tools based on the functional capability, availability, personal experience, and affordability (Chiu et al. 2001).

Our studies indicate that (1) digital design of free-form is highly correlated with computational functions such as solid modelling, NURBS, Metaball, or parametric design, (2) several digital tools have to be applied at the same time for solving the same problems; (3) the tools have to be integrated into the process; (4) complicated geometry require more computational supports; (5) the restriction of file transfers or data conversion will prohibit the uses of digital tools. For example, in 3D free-form design, designers may use digital tools to digitalize the physical model and produce "critical cuts" (sectional projections) for presenting design ideas and deliver key design information.

2.2 Key Information and Conditions Revealed

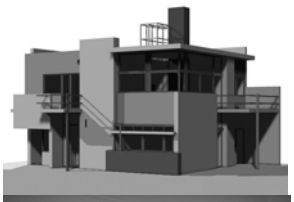
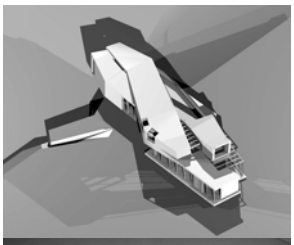
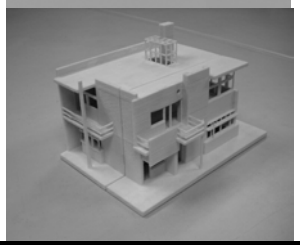
We are concerning what the purpose is for generating the representations of complex objects and how it differs from the conventional approach. In order to reveal how

key information are generated and delivered, two precedents (the Schroder House and the Möbius House) are selected and examined through a reproduction-and-evaluation process by applying CAD/CAM software, and then examine the representations of these precedents through questionnaires.

In the first step, the Schroder House (completed in 1924 and designed by Gerrit Rietveld) and the Möbius House (completed in 1997, and designed by UN Studio/ Ben van Berkel) are selected, Table 1. These houses present two different design methodologies and characteristics, and consequently require different 3D manipulation conditions. Various kinds of representations of these two houses like drawings, sketches, and photographs are collected and analysed for determining what key information are needed for reconstructing the 3D digital model. After generating these models, we then verify the capability to generate these representations from the 3D model.

In order to compare the difference between computer models and scale models, we then produced scale models of these two houses by applying the rapid prototyping technique as an alternative representation of buildings. Without the digital tools, the free-form is more difficult to reproduce and evaluate. We found that both models are more critical needed in the free-form geometry (i.e. the Möbius House) than the conventional one (i.e. the Schroder House).

Table 1 Case Studies of Schroder House and Möbius House

	Schroder House	**Möbius House**
Design Characteristics	Orthographic configuration with 2D manipulation, and interior and exterior space separated by components.	Non-orthographic configuration with 3D manipulation, and outside and inside spaces are mixed.
Digital Model and Representations		
Scale Model (Generated by Rapid Prototyping)		

In the second step, various kinds of representation of the complex object like drawings, sketches and images are provided and analysed in order to determine what key information are and verify the capability to generate these representations. Then a questionnaire survey is conducted for examining how the representations differ between two buildings. 20 undergraduate and 15 graduate students participate the survey, and the results are similar. The findings include: (1) the diagrams are helpful for understanding the design rationale; (2) drawings like plans, elevations, sections are useful in the case of Schroder House but are not adequate for the Möbius House; (3) perspective drawings, pictures, scale models and videos help people realize the Möbius House but not necessary for Schroder House; (4) sectional projections are more important than the plan or elevation information; and (5) scale models are useful for evaluation than computer models.

3 TWO FREE-FORM PROJECTS

The above studies reveal that digital tools can visualise our studies, and effectively presents and represents the free-form. The conventional thought of delivering design information from sketches, models to drawings should be reconsidered and the importance of information management reveals. The necessary design documentation is selected from the archive for constructing both models, but the number of images for Möbius House is most twice than the Schroder House. In order to examine the digital design approaches and the feasibility of the process, we implemented two demonstrative projects, the free-form facade project and a library roof project. In additional to transform digital design concepts into real objects, we further explore the assistance of digital tools in digital fabrication. Two approaches are developed and applied to each project, Figure 1.

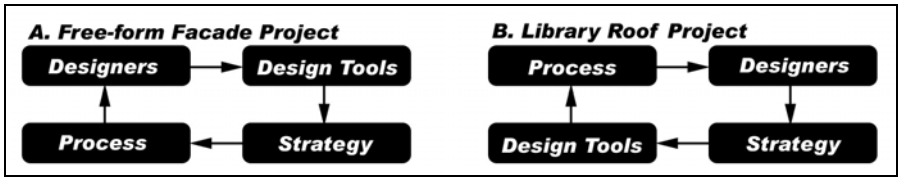


Figure 1 Two Approaches of Developing Design Strategies

3.1 The Free-form Facade Project

A new facade of the computer laboratory at NCKU is simulated and built by a digital design process. The curve is proposed to be a metaphor of information hub as a human body's "heart" and presented as the twisted skin of the computer laboratory. Different tools are supposed to be involved in design conception, the design development, and fabrication. The critical task is to build a digital design platform for constructing the digital model, scale model, the mock-ups, and

fabrication.

1) Digital modelling: Because of its characteristic of non-orthographic geometry and gradual changes, it seems digital tools have more advantage over traditional ones. In the initial state of the design process, the form is studied and produced by operational functions like “CV curves” and “loft” in Rhino.
2) Scale models and mock-ups: The transformation process can convert the free from into structural components, Figure 2. The frame is produced from vertical and horizontal equidistant sections in Form-Z and then the surface can be decomposed into small components. Different materials such as timber or steel are selected to build the skeleton.
3) Digital fabrication: At the final stage, we use the unfold function to study the surface after the skeleton of free-form facade is constructed.

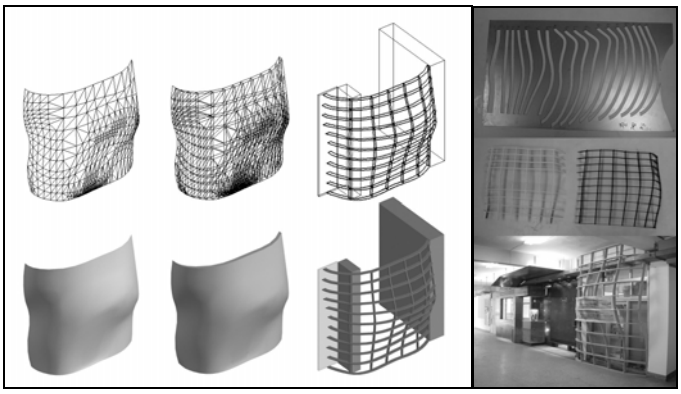


Figure 2 The Modelling Process, Mock-ups and Final Product

3.2 The Library Roof Project

The library roof project is in collaboration with remote architects and clients for studying the free-form by digital technology and process. On the top of the library is a greenery open space, a part of the informal reading room. We generate the roof as a symbol of the library that can host people for exchanging information and social activities. Both conventional and digital tools are selected and examined to see how distinct kinds of strategy influences the design proposal. To fulfil the requirement, a process of emerging different participants and proposals are created.

1) Participants and Process: Designers in different backgrounds chose different tools and methodologies to define the shape/form and found the advantages and limits of their familiar way of designing complex forms. The followings demonstrate the transformations of the project in each phase and distinct proposal generated by different tools, Table 2. The

architect (A) began to design the shape from sketches and visualised it by models and then found the limits of traditional tools. The roof shape has some difficulties to modulate, measure and duplicate even the roof shape can be foreseen by sketches.

2) Modelling: To support the concept initiated by the architect (A), designers (B, C, D) studied the concept and proposed different solution by various tools. For example, designer B chose 3DS Max to study folding of the single surface, so that the shape changed resting on the variation of quantities and types of the forces. The designer C tried to bend wire meshes directly and then transformed it into digital models by 3D scanner. The advantage is that the designer can depend on his intuition to grasp the shape and the inter points on the mesh helps the complicate operation of digitisation easier. The designer D manipulated the NURBS tool in Rhino and the ability of solid modelling in Form-Z in different phases. Rhino helps to generate the NURBS surface and modulate the shape by moving the position of control points and then the surface can be operated in form-Z to study the possibilities of the structure system.

3) Synthesis: In the roof design of the library project, the tools and process are integrated. More importantly, various design proposals supported by different participants and tools are emerged in the process, Figure 3.

Table 2 Tools and Approaches Involved in the Library Roof Project

Participants	Tools		Process	Approach and Tasks
A	Sketches Form-Z	AutoCAD Scale Model	Forward	Sketches as studies of the roof shape. Physical and digital models as a way for visualisation
B	3D Max		Forward	Generating forms in the software.
C	Scale Model 3D digitiser		Reverse	Studying shapes and forms by physical models, then digitising and modelling the geometry.
D	Rhino Maya CNC	Form-Z 3D digitiser	Forward and Reverse	Generating the forms according to the sketches, and illustrating the images in different software.

Notes: A (architect), B, C, D (CAAD designer)

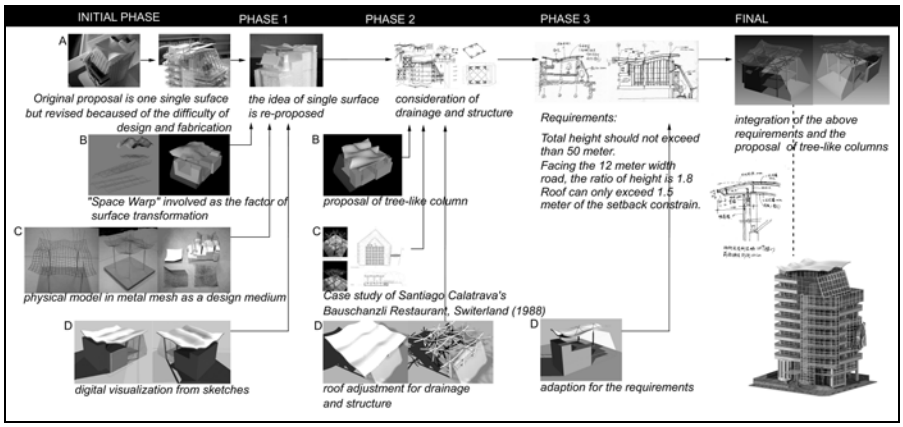


Figure 3 The Digital Design Process Emerging Different Proposals

4 THE INNOVATIVE DESIGN PROCESS

The above projects demonstrate that we can present and manipulate free-form geometry effectively during the design process with the assistance of the digital tools. In both projects, we found that the interactions among the designers, tools, and processes are critical to the completion of projects. More importantly, the design processes are situated and designed in accordance with the understanding of the strength of each tools and the process defined by the designers. Both projects provide the ground for analysing important factors in the innovative process.

4.1 The Design Process is Situated and Designed

Chiu et al. (2001) indicated that both the forward and reversed processes could be applied to digital design. The library project demonstrates that the design process is often situated and redefined to adopt new tools and explore more alternatives, Figure 4. Both the forward process (by designer b & d) and the reverse process (by designer c) are applied parallel to support architect (a) in studying form generation and fabrication. During the design process, several iterations are developed, Figure 5. The roof was changed from symmetric to asymmetric, from stand-alone columns to tree-like columns, and from the orthographic grid to the diagonal grid system. Meanwhile, the structural spans, heights, and proportion are changed accordingly. The result of the library roof project will be significantly different without the digital tools for project modelling, visualisation, design communication, and system integration. The strategy demonstrates to foster better ideas as well as processes.

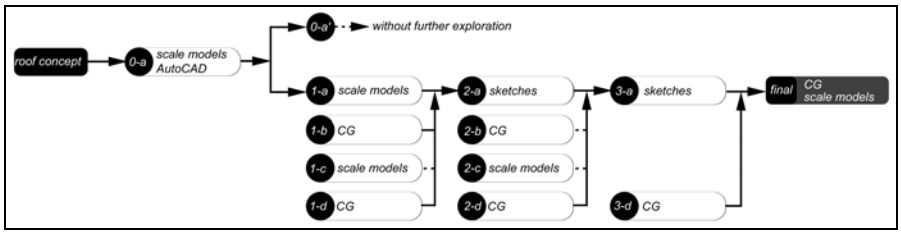


Figure 4 A Situated Design Process

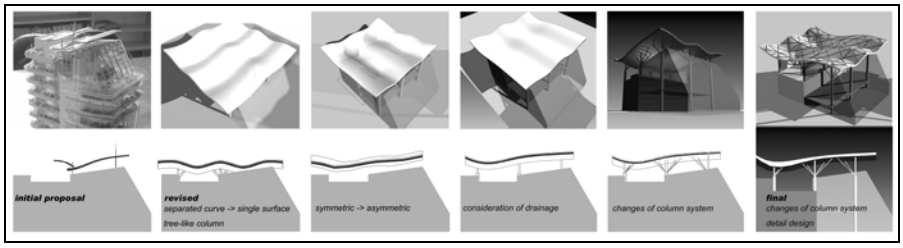


Figure 5 Major Changes in Roof Design Development

4.2 Delivery of Key Information

In the above projects, different tools and processes are selected because design tasks depend on the requirement of key information such as 3D geometrical relationships to support design development. For example, in the library roof project, designers request the computational capacity for delivering key information such as curvilinear forms and sectional views of structural depth in order to produce various roof alternatives through iterations. At least five major alternatives are proposed during the process. Parametric design facilitated the adjustment and decision-making. The levels of details are different from design conception, documentation, to fabrication. Digital tools not only allow the continuity of deliver information, but also integrate the information in the process. In complementary to computer modelling, physical models by RP and CNC also help to visualise and examine the results.

4.3 The Interaction Among Designers and Tools

Although digital tools have made a great progress and are widely applied in recent years, they are not merely a tool for visualisation but exploration of alternatives. The studies and the projects explore the power of digital tools and how they involved in the discussion and design process. Though the imagination and creativity is infinite, it should not be limited or over-simplified. The manipulation of digital tools may be an alternative way and the importance of selecting the right strategy should be

emphasized.

We have compared two developed approaches for studying the effectiveness of design exploration. In the first approach, designers can examine different software functions to define the free-form modelling capability, and some designers may foresee the benefits of certain tools and develop the strategy to incorporate the tools into the process. For example, Rhino and Maya can create, edit, and translate NURBS (Non-Uniform Rational Basic Spline) curves, surfaces, and solids.

In the second approach, designers in the process define the strategy then choose the design tools. Normally, designers have to evaluate their strength and restrictions before utilizing different software and hardware. For instance, when certain functions such as NURBS are applied, parallel sectional projections and subdivision become the impetus for design conception. Consequently, a RP model is more useful than many visual images. It can present designer's idea in an accurate way and helps the designer to make evaluation.

5 DISCUSSION

The question "what the right tool/strategy is for designing?" brings our intention into the discussion on the digital design approaches in the practice and education as the below.

5.1 Creating a Digital Design Platform

The above projects and analysis demonstrate the choices of tools are depending on the combination of the process and the users for solving specific purposes. It is clear that the designers are demanding the power of depicting free-form or complex geometry in the near future, the design control ability in terms of manipulation of objects increases because of the involvement of the digital tools which will better present and represent design ideas. The result of the analysis does not mean the traditional presentation and representation methods such as sketches and projection drawings is useless but points out its limits, the new method about the manipulation of digital tools amplifies the scope of the possibilities and better represents the idea. Therefore, the discussion about digital tools is not merely a technical problem but a query about what the right strategy for designing geometry is and how we choose the right tool. This research will enable designers to better analyse and judge the best choice of medium and design tools, and the results and analysis of the experiment will help designers familiarize the tools and reach the merit of the tools created.

5.2 Exploring Form Generation

Most people use computers as powerful computational tools. Some of them take computational logic to design thinking. Designers can redefine the architecture and space through the implementation of design computation. The formation of free-

form is possibly initiated by an innovative process such as Gaudi's Temple Sagrada Familia (Miracle 2001). It is well known that Gaudi was inspired by the nature but had no appropriate tool for construction so he found the laws through anti-funicular models and transformed them into architecture. Following this process, designers can explore form, and the relationship between space, geometry, structure and construction. The difference is we may be inspired by the nature but better equipped with digital tools for realizing innovative ideas.

5.3 Redefining Digital Design Studio

The digital design studios are undertaken around some well-known institutions such as MIT, UCLA, U. Penn, Columbia U., ETH Zurich, etc. The goal is normally to familiarize the digital tools and formulate an innovative process for integrating the tools. For example, the graduate course "Digital Morphogensis" and "Digital Fabrication" are proposed to integrate CAD/CAM techniques (Kolarevic 2002). A similar approach is applied to our institution. Therefore, the knowledge of using digital tools is gradually built upon the previous experience.

In the future design studios, students are not merely equipped and trained to use the tools, but better understand the innovative process and strategies for utilizing the tools. More importantly, designers not only understand the design principle but also the engineering and construction of free-form space. Eventually, the designers and specialists in the A/E/C industry can work together better to support innovative design concepts and projects.

6 CONCLUSION

Digital design of free-form geometry is a challenge for the conventional thought of design process and fabrication. It is a catalyst enables us to re-consider the familiar design process and even the design principles. This study indicates that designers have to be sensitive of design tools and strategies for developing an innovative process as well as ideas. Two conducted projects demonstrates how new ideas can be explored from the interaction of different design tools while each has its uniqueness and restrictions. The choice of "right tools" is based on its effectiveness on manipulation, representation, and integration, while it is often subject to the complexity and design intentions of the projects. Furthermore, a "right strategy" can not only integrate design tasks, processes, and manage the information for A/E/C, but also foster innovative ideas with the assistance of right tools. In the future design studio, students can learn the process of integrating technology, material, and ideas. These empirical experiences will foster new possibilities of innovative design.

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