Integrating Scientific Simulation with Rapid-Prototyping Modeling for Design Curriculum Development

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Although Computer-Aided Architectural Design tools have been introduced to studios for design visualization and communication, tangible models constructed by cardboard or other modeling materials still play an important role in assisting students on developing their conceptual framework related to spatial organization. A Rapid Prototyping (RP) system could provide a paradigm shift from the existing workflow of hand-made architectural model into an automated computer-aided manufacturing (CAM) environment. The introduction of computer controlled manufacturing technology will not limit the use of current conventional model making, and it will provide new capabilities for precise scaled model making and the possibility to generate free-form surface models for design representation. Because the technical capabilities of RP system could dramatically change the design workflow, the computer-aided manufacturing approach for architectural design has been adopted by overseas and local academic institutions.

In this paper, we report the findings of a pilot study that applied rapid prototyping technology in architectural design education for helping students exploring an automated computer-aided manufacturing environment during early stage of design development.

***Keywords**: Rapid prototyping; free-form modeling; scientific visualization.*

Introduction

Making physical 3D sketch models is critical in the early stages of architectural design. Students often spend much time in making physical models during design development as well as for final presentations. In many cases, new design alternatives require a totally new model. This is very tedious and consumes a lot of valuable time that could be better used for design thinking itself.

Rapid prototyping (RP) consists of various manufacturing processes by which a solid physical model can be made directly from 3D computer-aided architectural design (CAAD) data. A 3D model is sliced into very thin planes by the computer. The cross-sections are sent from the computer to the RP machine, which builds the model layer-by-layer. The process is repeated until the prototype part is completed. The resulting prototype provides a "conceptual model" in physical form for design visualization and provides a solid common platform for discussion between teachers and students. For this pilot study, we adopted a 3D Print technology from Z-Corp to generate physical model for students.

RP model as an integrated representation media

RP system in design studio has always been treated as a technical issue or technical support to design students, instead of the potential provided by the system as an architectural education curriculum issue. Meanwhile, RP modeling system has been mainly highlighted on its capability on representing geometrical information, and its potential on representing non-geometric analytical data has been ignored. With the sophistic scientific simulation applications and RP techniques, opportunity is given to designers to use it as an integrated representation media to examine geometry based design information and non-geometry based design information at the same time.

Overlaying these two types of important design information on a tangible model provides the designers a comprehensive design assessment through cross-examination. In the past, this information overlay process was done by designers mentally. For designing a complicate architectural piece in the hyper dense environment such as Hong Kong, it is often difficult for a designer to observe the interrelationship between design form making and different building sub-systems in the conventional way. The works done in this research is the first step towards using rapid-prototyping model as a media to integrate the two different kinds of design information.

Project implementation

A term project, "Space for Adaptable Use: on-site construction & off-site fabrication – Conducting building composition in physical and virtual setting", was issued to students for an eight weeks exercise. Students were expected to investigate the use of media integration technologies as the exploration tools in building programming and design communication; to understand the role of computer visualization operations that can play in the design process; and to explore the issue of information density and contextual media among computer-based virtual modeling, prototyping-based scale model, and physical scale model.

Eight groups, each of three to four students, were to design a portable architecture which serves as the problem domain. Few sets of design scenario were introduced to the exercise throughout the design process to reveal the potential on using rapid prototyping system in the design education. These scenarios has been grouped by different basic design related considerations such as scale, proportion, spatial hierarchy, visual organization, environmental design strategies, and details. Based on the outcomes of another project on scientific visualization and Computational Fluid Dynamic (CFD), technical support has been provided by the research team

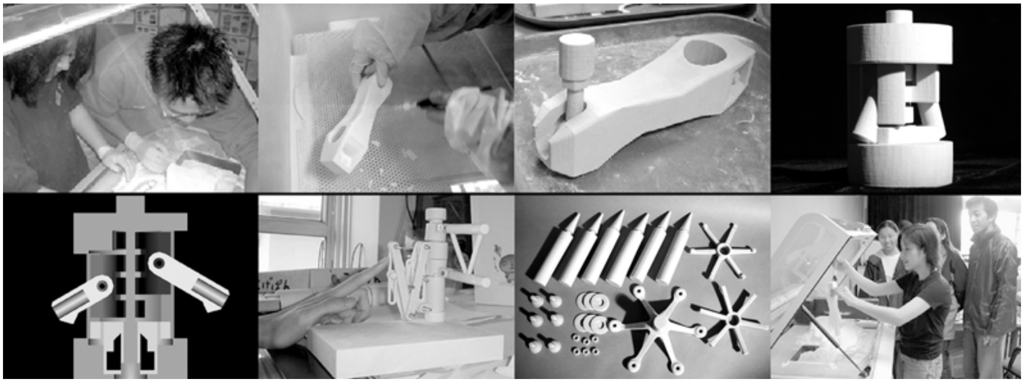

Figure 1. Some of the output models from the rapid prototyping pilot study.

	Tradition model making	Rapid prototyping
Free-form curved surface	Very difficult	Possible
Precision	Fair	Close to 0.25 mm
Interlocking components	Rare	Possible
Complex 3D joint design	Fair	Possible
Model dimension	Flexible	Limited by build volume
Cost	Reasonable	Around USD 100 per model

Table 1. Comparison between traditional model making and rapid prototyping technology

to assist students to integrate environmental simulation data with their rapid prototyping models.

Expectation for RP technology

Before the pilot study, the team expected 3D Print RP machine is easy to use, very accurate and precise, and innovative compared to traditional physical model making approach. Though the concurrent running cost would be higher due to machine cost and model materials the quality of the output model and the streamline of the manufacturing process would compensate the shortage.

Opportunities

The RP technology provides designers a new approach to realize a complex three-dimensional geometric form. For example, the three-dimensional curve shape is very difficult to be envisaged without a 3D model in a physical space. Interlocking of elements are almost impossible to built up by traditional model making method. It can also demonstrate the making of foldable elements and its anchorage to the structures.

Variations and design alternatives of repeated components are easily generated and modified in the CAD environment. The computer aided manufacturing enable students to explore more possibilities in the design process. They could generate large amount of identical products in a short period of time with the minor variation and design alternatives.

A hybrid approach which combines CAM and conventional model making, may be able to balance the shortcoming of the RP technology. Some students used a hybrid approach to solve their problems. For example, as the “bots and nuts” of the output model are too small and fragile to be printed using RP, real screws and nuts were used to replace the broken RP components. At the end, it is a physical model mixed with RP technology and conventional model making technique.

Student’s comments

In general, the students appreciated using computer-aided manufacturing process in the design process. They used the RP machine to generate scaled models with desired curve profile and joints can move freely as expected. Though the material is lack of stiffness even after the waxing process, it is good to explore the complex curved surface conceptual model in physical form Nevertheless, the broken small components made the students quite discouraging in fact.

Although there is shortcoming of the 3D printer, it enables students to experience the form physically. Students also found it very interesting to imagine how the structural detail works comparing to the virtual reality computer animation.

Students have been posed to such challenge in such a limited period of time and the end product is not as marvelous as they expected, but they learned a lot in terms of the integration of different technologies in a design process. They experienced an innovative design method, which was not conventional. They think that all the works are precious to them and what they have learned would help them definitely in the coming future in terms of the exploration of new rapid prototyping technology.

When dealing with the complex 3D Boolean operation, the CAD package, 3D Studio VIZ made the students very frustrated sometime on its unexpected end result. After a series of solid subtractions, the software just cannot perform the operations anymore. The model was ruined and cannot be recovered.

Challenges

The size of the output model is confined by the build volume of the RP machine. It is limited to no more than 8 inches (W) x 8 inches (L) x 10 inches (H). Students may require to scale down their model in order to fit the build volume. When students scaled down their models, for example 1:10, some components may be too small to be built. At the end, some parts may be too small, fragile and broken into pieces during the waxing process.

Moreover, it will take three to eight hours printing time for each model, depending on the build volume and geometrical shape. The output model was not as accurate as expected due to the model material's physical property. For example, some of the movable components were expanded and merged together.

One of the biggest challenges on applying 3D Print technology for a joint design is considering the space tolerance between movable components. If the gap is too small, the output model would probably become unmovable due to the considerable amount of lime power trapped in the gaps and the layer of wax applied for strengthening in the later stage. If the gap is too big, the output model would be very different from the expected physical dimensions. At the end, recursive trail and error approach were required to test the tolerance of the manufacturing process, which is extremely time consuming. In the future, accumulated experience on the machine usage would help to solve the issue.

Level of abstraction is also one of the problems need to be well planned before using the RP machine. Because of the limitation of the RP machine and the constraints of the current CAAD package, students were required to refine the design again and again, in order to getting rid of less important details for CAD/CAM process.

The design of CAAD software packages is always optimized for certain range of tasks only. Students may generate very good-looking 3D visualization of their design on screen, which may not necessary mean the model could be manufactured by RP. At the first stage, we decided to keep on using existing CAD packages for students to facilitate the RP process, such as AutoCAD and 3D Studio VIZ. In that case, students were not required to spend extra time for the new modeling environment. The RP was integrated into the curriculum without additional CAD tutorials to the students. After the exercise, we found that the conventional CAAD packages were no longer sufficient to facilitate the new challenge, in terms of high degree of accuracy, flexibility of data structure, and comprehensive data integrity check. The STL and VRML file formats are currently deployed to facilitate the CAD data exchange. In the future, there may be a need to introduce more sophisticated solid modeling package such as Pro/ENGINEER, Autodesk's Open Inventor, SolidWorks or CATIA, to students to facilitate more on the complex Boolean operations, Non-Uniform Rational B-spines (NURBS) and parametric 3D modeling.

References

Chiu, M.L. et al. "Teaching Rapid Prototyping in CAD Studios for Creative Design", Proceedings of the 6th CAADRIA. University of Sydney, Australia, 2001.

Kurrent, F. Scale Models – Houses of the 20th Century, Birkhauser, Berlin, 1999

Neuckermans, H. Computers in Design Studio Teaching, Proceedings of the EAAE-eCAADe International Workshop, Leuven, Belgium, 1999

Robbins, E. Why Architects Draw, The MIT Press, Cambridge, Massachusetts, 1994