RP-aided Design in Architectural Studios

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ABSTRACT

This paper reports on a pedagogical experience at the RP-aided design studios in architecture. RP-aided architectural design is a new method in design pedagogy that acts as an aid to digital architecture. The RP studies in this case were a student "photostudio" project that lasted for six semesters, and ended with encouraging results. Various issues were explored during the course of the project, such as the inter-relationships between images and forms, virtual layout and substantiation, as well as the general design process. RP was used to verify the possible forms in a scaled footprint that shed light on the design development. The RP approach, which also offers a good opportunity for practice with media tools, liberated the dependency on tools, fostering a better interaction with the environment context. A comparison with a typical CAD studio was also made.

Keywords: rapid prototyping (RP), 3D printer, architecture design, pedagogy

1. INTRODUCTION

Digital representation of artifacts has raised new concerns for architectural studio works. When the creation and display of images become the main functions of a space, building form has already been influenced by the way the displays are configured. Cases have been shown of a new trend emerging among teenage students in the photo sticker machines that combine both entertainment and group activity. A photo booth with a camera and printer allows a group of friends to gather inside and pose as desired. These photos have become a sort of record of friendship, and this kind of place has become a standard stopping point on vacations or at weekend get-togethers. The forms that originate from the rise of digital architecture represent a totally different manner of construction and application of media. This new approach actually reveals a controversy in concept substantiation, i.e. the ways of construction and of coping with existing structure or form.

Developments in the photography business have led to the re-consideration of design programs. In the RP-aided design studios, students were asked to design a photo studio in which the client requested that the photo background could be replaced by real architectural objects. These objects were to be interchangeable, in order to permit the maximum amount of variety within a defined space. Up to now, the "Photostudio" project was offered for six semesters, with the first semester focusing on the traditional approach, and the other five on the use of CAD in the studio. Questions were raised in relating photography to architectural design education, in terms of CAD application. These included the modification of the traditional CAD approach to meet students' views of current and x-generation tastes and preferences. The last three studios, conducted in 2002-5, were RP-aided architectural design studios.

2. TOOLS

A rapid prototyping (RP) machine can fabricate 3D models for visual inspection. Applications in architecture are made in the fabrication of building parts and design concepts [3],[5],[7-8],[10],[13],[15], physical models for survey data [9], or CNC generated ornament[12]. Although color-keyed components have been created recently, so that a uniform color can be assigned to a part [2],[4],[6], still, the limited variety of colors cannot provide adequate surface attributes such as the texture that is needed in architecture visualization, whether it is procedure texture (texture allowing for parameter change) or direct image mapping (texture using a predefined image as content). The data used for RP do not have to be the final results of visualization; instead, this stage of application can offer benefits in the early design stages [11]. Similar RP application in the field of art can be seen in the creation of cartoon characters, and in the visual arts [1],[14].

It seems RP has worked well with current modeling processes in a specific and purposely integrated manner. A Z-406, also called a 3D printer (see Fig. 1), was used for layering type output of models, as the only machine that met the studio demands for the outputs allowing color texture mapping. Students were asked for VRML model files, the only files in the machine with color descriptions applicable. Software, Geometric Studio, was used to thicken the surfaces or walls to increase the strength of 3D prints.

Fig. 1. The layering type RP machine (left) and a color printing in process (right).

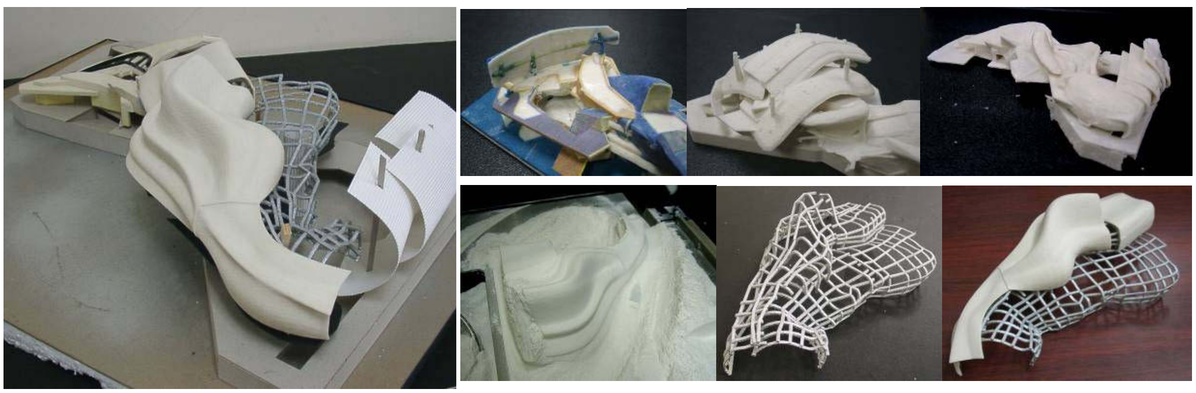


Fig. 2. Final model (left), design alternatives (top-right), and RP output and assembly process (right-bottom).

3. DESIGN PROGRAMMING AND SOLUTIONS IN THE RP STUDIO

Students came up with different solutions to meet the design requirements. Observations showed that the design programs developed along with design development, as the work done with forms and images usually raised new design possibilities that forced students, after the RP outputs were shown, to go back to the “gray area” of their programs for clarification. Each semester, students were asked to select a site for the project as part of their design programs.

Examples can be seen in the following cases. One of the students created a curve (Fig. 2) flowing from the front to the back, where an object was needed to conclude the design theme and to separate it from the existing apartments next to the site. The docking metaphor being used led to such design possibilities as sails or shells. The form was gradually developed. The RP study models were usually output in one piece so that students could control the design as a whole, with proportion and mass being of concern. The final model was printed piece by piece, as the dimensions were enlarged to almost twice the original size. Technically, an RP model shrinks a little after it has dried. The fitting process, which required effort and skill, ended with satisfactory results.

Another study model was printed as a whole for an easier identification of inter-relationships (Fig. 3). What drew our attention was that the building proposed in the design development stage was over-scaled. As seen in the RP output, the enlarged building parts reflected inappropriate control of form that resulted in an over-exaggerated demand for space as compared to the size of the site. After an intensive design communication session, the student modified the program in a more concise and focused manner. As shown in the model, there are large surface areas created by the building enclosure. These surfaces were to be used for projection purposes, the curvature enabling versatile viewing angles of projections exposed to pedestrians and traffic. The free-form enclosures with projections seem to make the surface areas extend beyond their physical boundaries to generate an interlacing effect of interiors and exteriors.

The design emphasis in this project was an image corridor that allowed for changes in appearance on the inner and outer surfaces. Images were applied to both the preliminary and the final model (Fig. 4). In comparison, another design used a model printed on a smaller scale, but of a rather better shape (Fig. 5). Observation showed that the student intended to depend totally on the 3D printer to accomplish the whole modeling task.

Although the RP process saved effort in making the exquisite parts, adding unprinted parts within existing output was still a delicate assembly process. The instructor considers this is also a good exercise in becoming more familiar with spaces and the ways in which they are constructed in the studio practice.

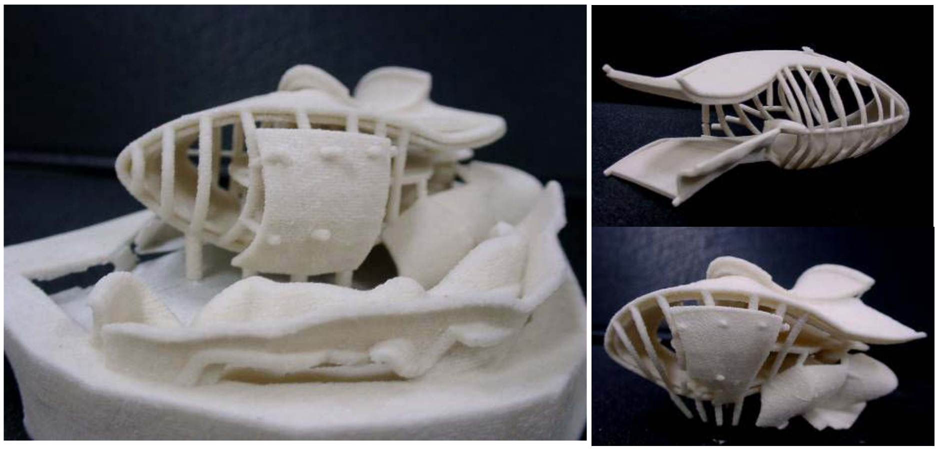


Fig. 3 Design interpretation (left) and RP parts (right).

Fig. 4. The final model (left) and the alternatives for the image corridor (right).

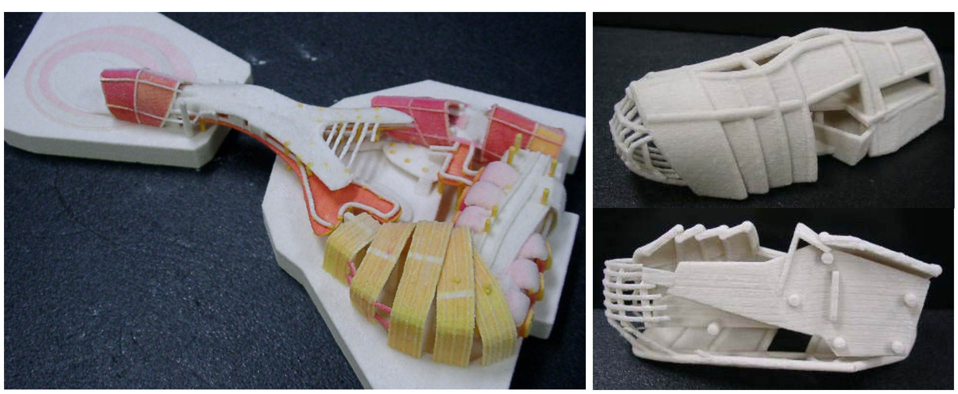


Fig. 5. Final model (left) and study models (right).

4. LEVELS OF APPLICATIONS

The observations show that the three levels of applications came with different requirements for output appearance.

- Level I - RP as a reproduction of design forms: Original forms were fabricated without surface attributes being added (Fig. 6). The presentation of physical models is used to deliver the shape only of design concept.
- Level II - RP as an extension to design alternatives: Original forms were printed with surface attributes like colors or image mappings (Fig. 7). The presence of features is frequently used in design development.
- Level III - RP as a kind of media to interact with design: Interaction occurs between original forms and surface attributes (Fig. 8), so that the change of shapes creates new needs for images, and vice versa.

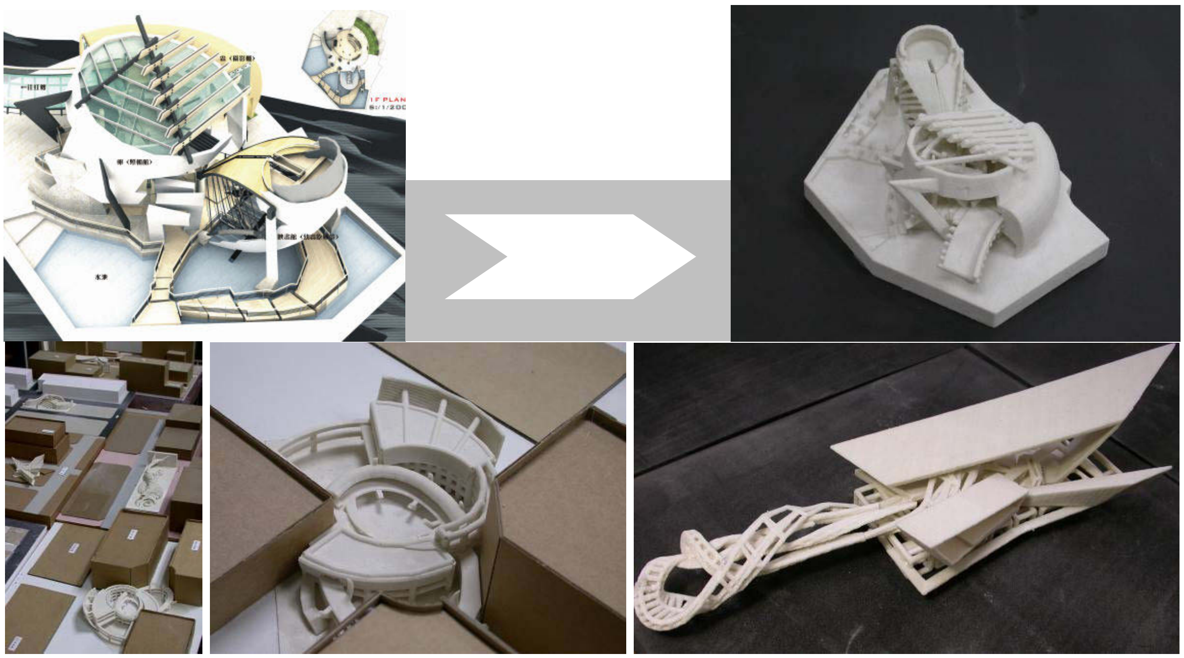
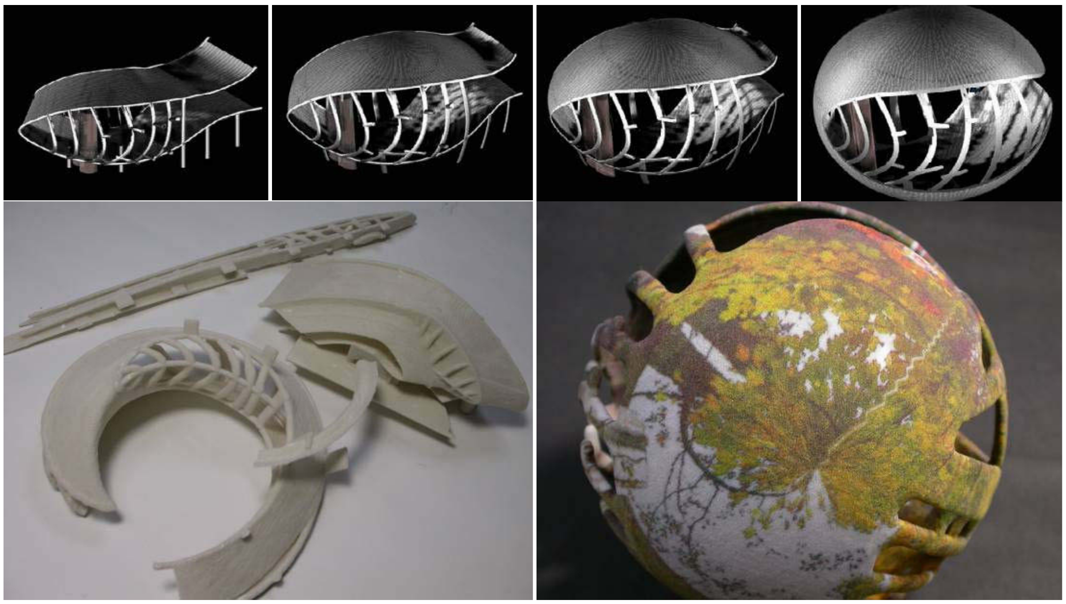


Fig. 6. Level I application: computer model and RP output (top); student works (bottom).

Fig. 7. Level II application: computer model and RP output (top); student works (bottom).

Three levels of applications were achieved with different requirements of preparation before output. As indicated in level III, the interaction, which is a typical design process, was enlightening in respect to the creation of a series of models. The models, along with surface attributes, represented a collection of efforts that involved the preparation of design-oriented images, the transformation of original models, and image mapping manners. The original purpose of the model in Fig. 8 was to design a building suitable for panoramic projection. The shapes of bridge, snake, circle, and ball were solutions that were developed from the original design configuration. Frames of animation show the process of transition in meeting design need. The linearly lengthened bridge did not display panoramic view as well as did the organic form and the symmetric geometry. The ball, like a bubble, was projected using spherical mapping function as specified in the design proposal as an ideal setting of building enclosure.



Alternatives in bridge, snake and circle shape Final shape of the main building

Fig. 8. Level III application.

Fig. 9. Design communication and the final jury.

5. COPING WITH THE DELIVERY OF DESIGN CONCEPTS

The RP models, along with the application of a notebook computer, a touch panel and 3D browsing software, were used by the students and the instructor to communicate their design concepts (see Fig. 9 left). A final design jury was held at the end of the semester (see Fig. 9 right). Three semesters' of RP-aided design have led to the following findings regarding the delivery of design concepts.

- Details: Structural and visual details are differentiated. Since a number of scenes have to be provided to meet the demands of variety, structural detail that depends on the number of objects created to reveal the reality of a scene may no longer be satisfied by the students. Instead, the visual details that arise from the contents of images were applied in order to create scenes of variety. The visualization manner of the design encouraged a deeper inspection and discussion of details and broadened the pedagogical perspective in student-instructor communication.

Color binder printed on layers of powder (Z102) is far different from the effect of prints made on sheets of paper. The resolution of image applied to the RP prints was the same as the contrast. Image brightness and contrast were adjusted before use. The model in Fig. 7 illustrates a possible resolution of appearance on surface through Chinese characters with identifiable strokes. The same proof is also shown in the balls of the model (Fig. 8) in which branches of a tree can be seen.

The effort for file preparation was also a process for the feasibility study of the structural details. The restriction of the strength provided by powder-based RP materials limited the strength of building components. In addition to looking forward to new materials, empirical application led to a positive consideration that students should learn that the building structure should be checked beforehand. This checking procedure became very important when a current trend of digital architecture usually creates an anti-gravity design of objects in the air.

- Image-oriented space management: The approach of switching space and image changes the process in which an image usually comes after a space is designed. The reversed process lets students determine how a scene would be formed and how it would relate to other possibilities within the same space. The RP process not only reversed the space-image process in the manner of space visualization, but also verified the images in a solid form to fulfill the design criteria.
- Environment or design domination: The interaction between environment and design has become more versatile. Instead of an enriched visual impact, the social context, including cultural influences, has been enlightening in design development. The RP approach, which also provides good practice in using media tools, liberated the dependency on tools and perspective renderings for a better interaction with the environment context.
- Exterior- and interior-oriented design scheme: The building enclosure, inside and outside, became an important part of the design scheme in that its existence and manner of display actually redefined the greater part of the program. A virtual design, later turned into a clearer level of reality, became a good opportunity for studying the inter-relationships among building parts.

6. EVALUATION

The application of color-texture-mapped RP expanded the experience in 3D modeling. This section will present the observations that are followed by quantitative evaluation and qualitative evaluation.

6.1 Quantitative Evaluation

The Tab. 1 is classified by the statistics into two types. Type 1 data are made of records like printing time of RP, number of parts, number of pixels, scales, or monochrome/color. Type 2 data are made according to the size of all RP-related auxiliary files, to show the effort, in terms of student's work, RP output (instructor, in this case), file transfer, and model format. Type 1 data show that the more models printed, the more time was saved, even when all the models were made as a combination of hand-made cardboard models and RP models. In fact, the time saved from RP output should not be measured in the same way as cardboard models were constructed, because the curvature of free form was very difficult to make manually to match original 3D digital design. The longest period of output came from a design that separated frames and building enclosures into 6 parts. The least modeling time in total, which was about 3 hour 28 minutes, came from the output of a 1/400-scaled model and that was the only physical model being made by that student in the latest semester.

Each output case represented a benchmark of its own, just as each student’s solution to the architecture design project was unique. Most of the models were made in a 1/200 scale. A color model of about 11cm*12cm*9cm would take 6 hours to print. In general, a monochrome output would require only half the time. In the earlier semester, all the models were printed with manual/print ration 0 in a smaller scale. The advantage was less model effort that accompanied the disadvantage of lacking the feasibility check for the design details or sections. Small models were usually used for schematic design. Final models made at the end of a semester were usually printed in 1/200 or 1/400 scale.

Type 2 data represent a more important measurement in preparing 3D prints since the work had to be done before Type 1's categories started. The size of total auxiliary files did not necessarily reflect the time needed to print a 3D model. The total file size ratio of the instructor's work and the works on CDs handed in by students at the end of the semester were counted. The final CDs presented by students included images, models, presentations, movies that were related to the design, design alternatives, and site studies. The ratio reflected the compatibility of the student's modeling environment and RP environment. The software environment required model collection and image mapping before RP files were transferred. The number of files increased before they had to be saved as compatible VRML format or files with RP modification by thickening the walls to increase strength. The files also came from the details design like the photo booths. Some students' total file size were about 1 GB because many design alternatives had been developed. Progress models were printed along each stage of design.

Tab. 1. RP statistics

		2004 semester					*earlier semester*					
	students	A	B	C	D	E	F	G	H	I	J	K
Type 1	model scale	1/200	1/200	1/200	1/400	1/200	1/200	1/200	1/200	1/200	1/200	1/200
	number of elements	6	5	2	1	1	1	1	1	1	1	1
	number of outputs	5	1	1	1	1	1	1	1	1	1	1
	color prints				x	x	x				x	x
	resolution	28926	5861	4052	4090	3965	3937	8682	8067	7921	9646	6305
	manual time (hours)	05:30	04:30	10:00	0	07:00	0	0	0	0	0	0
	RP time (hours)	11:58	2:34	1:19	3:28	4:39	3:16	2:53	02:45	02:39	7:10	4:17
	modeling time ratio	0.46	1.75	7.59	0	1.51	0	0	0	0	0	0
Type 2	MB in instructor	77.9	64.4	109	425	50.5	1370	42	46.5	1331.3	5.85	3.21
	MB in students	1159	567	193	926	116.2	N/A	219	666	232	429	567
	file size ratio	0.07	0.11	0.56	0.46	0.43	N/A	0.19	0.07	5.74	0.01	0.01

modeling time ratio: time for manual model vs. RP prints; file size ratio: instructor / student file size in total resolution: a unit in measuring the volume of a model; MB in instructor: size of all the files related to a student's work; MB in students: the size of all the files provided by students

A different approach was selected in the latest semester when only the parts of design that were made of free form needed to be printed by RP machine. So the modeling time included that of RP output and manual work. Compared to an earlier semester, students only had to reduce the model into a smaller scale in order to produce the RP output once. So the modeling time ration of the cases in the earlier semester was all in 0. Tab. 1 showed that each student's work was probably a unique type. Among these 11 cases, there are three cases that have to be explained:

- Case A, which spent the most output time, had a design involving surrounding blocks. In order to include the lengthened roof, the six parts spent about 12 hours in order to print in a monochrome mode. The strategy was to enable future assembly, and study the inter-relationship between the roofs and the frames. The ration of time for manual model and 3D print was about 0.46.
- Case C represented the least amount of print time and the highest modeling time ratio, 7.59. According to the student, extra time was spent in switching the representation for staircase in order to get the details of each step completed. This was an example showing that more modeling time could have been saved if all the models had been printed by RP machine.
- Case I represents the model that was ill defined. The instructor tried to fix it by choosing different formats, but ended up with many versions of the same design. It's very common to create a RP file more than 100 MB. In this case, a single file of 433 MB was created using the test process. That color model, which measured 547 layers and 4721 million pixels, would take 2:52 to complete the whole model. Because the model of the earlier version had not been created with sufficient structural support for itself, the color output was abandoned.

6.2 Qualitative Evaluation

In addition to the quantitative evaluation, the characteristics of geometric data inherited from traditional format or modeling experience may not be feasible in the RP prints. The exemplification mainly came from the 3D symbols like furniture. A digital model created for one purpose may not be fully ready for RP processing. The differentiation of purpose, when virtual models are created, seems to differentiate their fabrication manner as well. One assumption is that since a complete architecture RP application may not yet be ready, each model will have to be individually prepared in the meantime.

- The symbol for visual presentation may not be well defined as a physical model: The symbol was usually made with polygons with almost no thickness, which created unclosed boundaries. As a result, some parts supposedly inside the model were vacant and some parts outside the symbol became solid.
- The symbol for visual presentation is not strong enough for physical support of itself: The material strength is different from that of a normal linear member made, for example, of wood or steel. So a two-dimensional surface, like a polygon or delicate part of small or thin size, may not be structurally strong enough for supporting itself. Symbols or objects remained in place during and after binder was applied, but fell into parts when it was removed from the sink, or during the de-powdering process. Other broken pieces resulted from ill-defined symbols or unreasonably sized building parts.
- A suitable construction manner needs to be applied: An RP machine transfers a VRML model file into its format in terms of slices of layers. Thus two adjacent parts will remain separated if their touching faces are put in adjacent but different layers. Unfortunately, it is a common situation that most architecture symbols like furniture are made with parts closely placed, not hinged, welded, or bolted together. This situation, which is understandable but undesirable, shows a possible conflict in switching between a virtual world and the real world.

7. INFLUENCES ON ARCHITECTURE

The RP application in architecture is not only a modeling issue, but also plays a role in connecting the virtual world and the real world.

7.1 A pedagogical Exploration

It appears that a regeneration of virtual design in a physical form can help both students and instructors better understand design studio works. Because the RP process provides a view with a better sense of depth, a combinational experience can be acquired, especially as students can physically touch the models to examine dimensional or textural relationships.

The printed models can also be used as 'fingerprints' to note a student's progress, providing a means of pedagogical verification on the part of the instructor. It appears that a 3D printer is a good tool for visualization as well as ambiguity substantiation. Its image-mapping characteristics enhance its role as a helpful teaching aid. At the first sight of the models made by the printer, students are usually surprised to see what their designs really "look" like. In fact, instructors are also surprised, and find they are able to use the models for many purposes, for example, to inspect whether the clearance between stair rises and beams would be sufficient for human height.

7.2 Interdisciplinary Exploration

A traditional RP application represents a closed domain in an STL-oriented software environment and model-making process. Formal RP mainly exists in the fabrication of parts in industrial design. But in an open community, RP becomes part of a design visualization system that combines auto-stereographic LCDs for HMD-free display and 3D scanners for data retrieval. Examples show that, in architectural fields, RP is available for different areas of study, such as design theory, construction details, urban environmental models, etc.

7.3 Transfer between Different Types of Reality

The switch between a virtual world and reality enables a two-way channel periodically coming from either side. The geometric objects used to visualize ambiguous spatial relationships can now be presented through the RP process. A direct connection between a virtual world and reality can be achieved. The immersive experience in a virtual world can now be an explicit experience of a physical model as well. We believe it would be valuable to use the neutral characteristics as a physical model for an unbiased representation of virtual artifacts.

To reduce the differentiation between a virtual representation and a physical model, the data is directly sent to a 3D printing machine, skipping an ordinary modeling procedure that may lead to a deviation of design perception. Although there are restrictions in representing transparency, the response of first-time review of a physical model that is directly substantiated from concept will be satisfied.

The interaction between virtual world and reality can be seen as follows:

- From virtual world to reality: This level of interaction comes from the original RP data that were retrieved and manipulated in a virtual world.

- From Internet to reality: A direct connection between Internet and reality can be achieved. It seems that a connection is established between data that are Internet-ready and the model shop next door. It is like the window of a fast-delivery service being operated on the Internet. The student's project was downloaded and printed in a different course, 3D Modeling, in which a model with smaller size was applied. Future application includes the output of design collaboration works.
- From reality to reality: This level of interaction comes from the data retrieval from scanned point clouds and photogrammetric model creation. At this level, an 'as-built model' of the site can be printed as another proof of the reality for building environment. We have used this technology to print construction details of retaining walls based on the models created from point clouds.

8. CONCLUSIONS

Observations of student works, from pre-CAD to RP-aided CAD studios, made the instructor rethink what a design tool could achieve in concept delivery. By reconsidering some social phenomena, certain reactions from architectural design surely can be programmed as pedagogical stimuli in studios. The stimuli were visualized in design forms through RP tools. The results were satisfactory.

From an educational point of view, color RP truly delivers the closest model to a student's design without sacrificing the quality of models generated by personal skills. An overnight print would not take up too many original working hours. Although color binder printed on layers of powder is not as satisfactory as the effect of prints made on sheets of paper, seeing a color model out of the 3D printer in reality is by far the most enjoyable moment in the design process. The levels of application do not just represent an output process; an interaction between forms and appearances was made possible due to the accurate reproduction of design, constituting one of the most valuable design experiences.

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10. MODEL CREDITS

Fig. 2: T. H. Shih, undergraduate student
Fig. 3: Y. T. Su, undergraduate student
Fig. 4: J. I. Lee, graduate student
Fig. 5: J. G. Jang, undergraduate student;
Fig. 6: J. N. Lou, W. J. Yan, and C. F. Cheng, undergraduate student
Fig. 7: Y. T. Su, J. T. Cheng, undergraduate student; the author
Fig. 8: Y. T. Su and the author

11. REFERENCES

[1] Connolly. J., RP Becomes An Important Tool for One Artist's Work, *Magazine - TimeCompress.htm*, Oct. 2001.

[2] Karapatis, N. P., van Griethuysen, J.-P.S. and Glardon, R., Direct rapid tooling: a review of current research, *Rapid Prototyping Journal*, Vol. 4, No. 2, 1998, pp 77-89.

[3] Krishnamurti, R. and Earl, C. F., Shape recognition in three dimensions, *Environment and Planning B: Planning and Design*, Vol. 19, Pion, London, 1992, pp 585-603.

[4] Ming, L. W. and Gibson, I., Specification of VRML in Color Rapid Prototyping, *International Journal of CAD/CAM*, Vol. 1, No. 1, 2001, pp 1598-1800.

[5] Novitski, B. J., *Rapid prototyping. Architecture Record*, November 1999.

[6] Pham, D. T. and Gault, R. S., A comparison of rapid prototyping technologies, *International Journal of Machine Tools and Manufacture*, Vol. 38, 1998, pp 1257-1287.

[7] Rotheroe, K. C., *Manufacturing Freeform Architecture, ArchitectureWeek – Tools 2000_0927.files*, p T1.2, Sept. 27 2000.

[8] Ryder, G., Ion, B., Green, G. Harrison, D. and Wood, B., Rapid design and manufacture tools in architecture, *Automation in Construction*, Vol. 11, No. 3, 2002, pp 279-290.

[9] Sdegno, A., From Architectural Intent to a Physical Model – Representing the Chiostro Della Carita by Andrea Palladio with new technologies, *Computer Aided Architectural Design Futures 2005*, Vienna, pp 83-92.

[10] Shih, N. J., The Application of Color-image-mapped Rapid Prototyping in Architectural 3D Modeling, *Proceedings of the 21st Conference of eCAADe*, pp. 347-350, Graz, Austria, 2003.

[11] Simondetti, A., Computer-generated physical modeling in the early stages of the design process, *Automation in Construction*, Vol. 11, No. 3, 2002, pp 303-311.

[12] Strehlke, K. and Loveridge R., The Redefinition of Ornament – Using programming and CNC manufacturing, *Computer Aided Architectural Design Futures 2005*, Vienna, 2005, pp 373-382.

[13] Streich, B. and Weisgerber, W., *Computergestützter Architekturmodellbau,* Birkhauser, 1996.

[14] Tome, C. Designers spice up a miniature set by using RP technology to generate physical pepper models, *Computer Graphics World*, June, 2001.

[15] Wang, Y. and Duarte, J. P., Automatic generation and fabrication of designs, *Automation in Construction*, Vol. 11, No. 3, 2002, pp 291-302.