Utilizing Rapid Prototyping for Architectural Modeling

E. F. Kirton, AIA
Department of Architectural Building Engineering Technology
New England Institute of Technology, Warwick, RI 02886

S. D. Lavoie
Department of Mechanical Engineering Technology
New England Institute of Technology, Warwick, RI 02886

ABSTRACT- *This paper will discuss our approach to, success with and future direction in rapid prototyping for architectural modeling. The premise that this emerging technology has broad and exciting applications in the building design and construction industry will be supported by visual and physical evidence. This evidence will be presented in the form of photographs, video recordings and several models of student projects. Our approach to the future of this technology is discussed without a definitive conclusion, as despite our successes we remain in an exploratory mode regarding software, equipment and industry adoption.*

I. INTRODUCTION

Rapid Prototyping within the building design and construction industry is distinctly an emerging technology. The basis for this modeling technology is the mechanical engineering and manufacturing industry where the technology was initially developed. Transferring the knowledge base, modeling and prototyping experience to a sister industry is a challenging problem. This transfer requires consideration of many issues, including differences in industry specific software, modeling variations related to visual and detail requirements and dramatic scale dissimilarities between the subjects being modeled. In short the current state of the art in rapid prototyping for mechanical design is not easily transferred to the building design field.

II. ARCHITECTURAL MODELING

Models have always been a significant study and presentation tool in the architectural and building design industry. They are used today by architects for the exploration of options, to enhance the understanding of space and as a presentation media. Prior to the development of software capable of representing buildings as a three dimensional model, perspective and isometric drawing along with constructed physical models were the only available means of three dimensional visualization. Each of the traditional methods has its own individual intrinsic value, and each will retain a place in the architects design and presentation arsenal long after rapid prototyping has been adopted by the industry. While each of the traditional methods possesse individual value, they all have a common liability. Time is that common fault. In our modern world for better or worse ’time is money’, and all of the traditional methods consume great quantities of both. Rapid prototyping becomes a viable approach as the result of the coincidence to two technological advances. The development of the 3D printing technology is of course the primary driver. This primary driver supported by the current architectural software capabilities and their intensive use for three dimensional modeling by architects in practice today.

The use of computer models for ‘on screen‘ investigations and design exploration as well as electronic rendering and animated ‘cyber tours’ of proposed projects is extensive in practice today. As a result the data required to produce physical models rapidly and economically utilizing 3D printers is available in most offices today. This data is produced as a part of routine project documentation practices. The rapid prototyping industry has the capability to produce the models, with a proven track record in the manufacturing industry. Our contention is that all that is required is an introduction.

III. RAPID PROTOTYPING APPLICATIONS

a. Industry acceptance

The contention that an introduction is all that is required is of course an over simplification of the problem. The successful introduction of this technology to the architectural and building design industry will only be accomplished by addressing two primary issues. First the software interface issues must be addressed. Secondly the efficiency and economy of the models must be demonstrated. The architectural industry is comprised largely of small to medium size firms with between 5 and 25 employees. The principals of these firms must be convinced that this technology is easily adaptable economical and effective. Because the best and arguably only way to convince practitioners of the viability of this approach is demonstration, we have developed examples to generate excitement among the student body. Students are encouraged to produce 3D printed architectural models using their studio projects as the experimental subjects. Models have been produced using files from Autodesk Architectural Desktop (ADT), and Autodesk VIZ. Each attempt has had its own timeline and series of discoveries. Each with its own relative measure of success. As students graduate, interview with and join architectural practices, their portfolios and personal excitement concerning 3D printing, raises awareness and fosters adoption among practioners.

b. 3D Printers

We have experimented with two types of 3D printers. The Dimension Stratysys, using ABS plastic as a prototyping material, and the Z-Corp Spectrum Z 510 (with assistance from Tech Ed Concepts[1]) using powder and emulsion as a material.

c. Scale, size, detail

The Stratysys is a plastic extruded wire 3D printer, with a layer thickness of 0.01”, producing models in ABS plastic. The primary limitation inherent to the process is that it is seemingly impossible to model any feature with a thickness less than 0.03 inches. This coupled with an 8”x8”x12” build area creates a challenge for an architectural model. The Spectrum Z-510 utilizes powder and binder as a material, with a layer thickness between 0.0035” and 0.0008” . The printers resolution is 600 x 540 dpi with a build area of 10” x 14” x 8”. The minimum build thickness is similar to the 0.03” of the stratysys.

The primary limitations for architectural modeling are inherent to the Dimension machine, the 0.03 inch minimum thickness that can be produced and the relatively small build area. When prototyping a mechanical part at full scale the 0.03 minimum build thickness is a very realistic tolerance. The challenge in architectural prototyping is in the scale translation of a building tens or hundreds of feet in dimension to an appropriate size for the machine to model. In our case the maximum build area of the Dimension machine, 8”x8”x12”. The building model can of course be scaled down to fit within the build area. The problem arises with the individual elements of the building model, The glass of the windows for instance is ¼” thick. When this thickness is scaled down along with the building it’s thickness reduces to the point where it is thinner than the 0.03” minimum tolerance of the machine. The glass disappears! As do hundreds of other architecturally significant details. Elements with insufficient thickness, the steel I beams, curtain wall mullions, window sills, decorative elements on the façade, all disappear. Each of these elements must be adjusted in the model, so that when scaled, a minimum dimension of 0.03” is maintained.

The test subject we have used is a tourist information center (figure 1), a brick and steel building with a glass curtain wall. The building is 30’ x 30’ in plan and 24’ tall

Figure 1. Building model rendering in VIZ

A model 5” x 5” in plan requires the building to be scaled down 72 times, using a scale factor of 1/72, 0.0139. At this scale the ¼” glass is 0.0035” thick, ten times smaller than the 3D printer can produce. The glass must be thickened by ten times to a minimum thickness of 2.5”. The problem cascades to the glazing mullion which is thick enough to be printed however now thinner than the glass it supports. The mullion held by a frame, frame by a wall, each in turn must be thickened to maintain its appearance as supporting element for the other. The machine tolerance of 0.03” is the minimum, we have generally attempted to maintain twice this minimum as the practical limit for thickness and offset distance of façade elements requiring visual definition. As a result, fine architectural detailing is often lost or vague at best.

d. Architectural software

Autodesk Architectural Desktop produces an efficient very complete model. The specific modifications to element thickness and type have been for the most part easy to complete. Glass thickness, window frames, walls and like elements are easily modified in ADT and most other architectural modeling programs. The larger challenge is with the detail elements such as aluminum extrusions and rolled steel elements. The columns of the tourist information center for instance are W 8 x 31 hot rolled members. This member is modeled accurately by ADT, 8” deep with flange and web thicknesses of 7/16” and 5/16” respectively. Both of these elements are smaller than the 2.5” threshold of the modeling process. As a result when printed they disappear. A custom member must be developed, the options are an I beam 8” deep with flange and web thicknesses with minimum 2.5” dimensions, or opt for a simpler shape. We chose a solid square for this model. Small aluminum extrusions that are part of curtain walls have similar issues however their modification is not as easily accomplished. Our experiments have yielded iritic results with the curtain wall objects, and we continue to explore solutions to this problem. In our studio the models are generally transitioned to Autodesk VIZ for rendering. The 3D printers require a stereo lithograph ‘stl’ file (stratysys) or a VMRL ‘wrl’ file (spectrum Z 510) as the base file for the production of a model. We have experimented with both programs and are having significantly better results when exporting the ‘stl’ file from VIZ. ADT does not export a ‘wrl’ file, as a result VIZ has been our sole resource for the ‘wrl’ files.

e. 3D Printer Comparisons

For mechanical prototyping the functional toughness of ABS plastic which is the result of the Dimension Stratysys is the perfect material. The strength and durability of the material creates usable/workable models (figure 2).

Figure 2. Prototype swing table

For architectural prototyping however, the ABS plastic along with the inherent problems mentioned above have us searching for a better solution. The Z Corp Z 510 which creates models in materials such as high performance plaster, cellulose, and a sand mixture at this point, appear to be a solution. The models can also be produced with various colors which adds a special flair and realism. There are similar limitations regarding the practical limits of thickness, however, the similarities end there. The process employed by the Z 510 produces a much more defined model which does not lose the fine architectural detail lost in the Stratysys model. For an architectural model the strength and durability is not so important. Drop the Z 510 model and it will surely break.

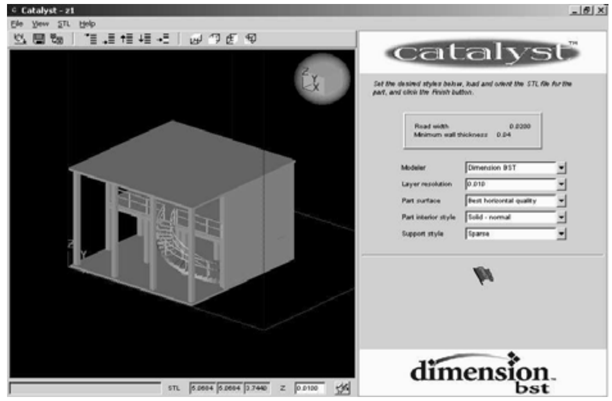

Figure 3. Stratysys processing the model

The image above (figure 3) is a screen capture of the Stratysys software calculating the production file. The input file is a stereo lithograph, exported from either ADT or VIZ, as we noted previously we have been more successful with the files exported from VIZ, however either is acceptable. The estimated build time for the model with a final size of 5” x 5” in plan is 23 hours.

Figure 4. Completed model after partial support material removal

Figure 4 is a photograph of the model, during the removal of the ‘support material’. Removal of the support material is easy, at exposed locations, however where small delicate objects are in the vicinity or in partially enclosed spaces, removal of the support material can be difficult.

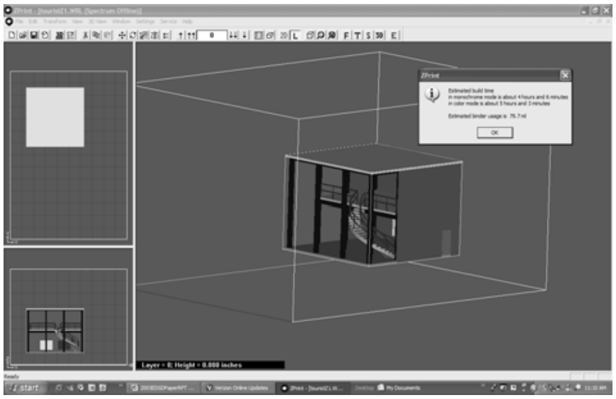

Figure 5. spectrum Z-510 processing the model

The image above (figure 5) is a screen capture of the Spectrum software calculating the production file.
The input file is a VMRL 'wrl' file, exported from VIZ; ADT does not export this file type. The estimated build time for the model with a final size of 5" x 5" in plan is 4 hours and 6 minutes (monochrome) and 5 hours and 3 minutes in (color).

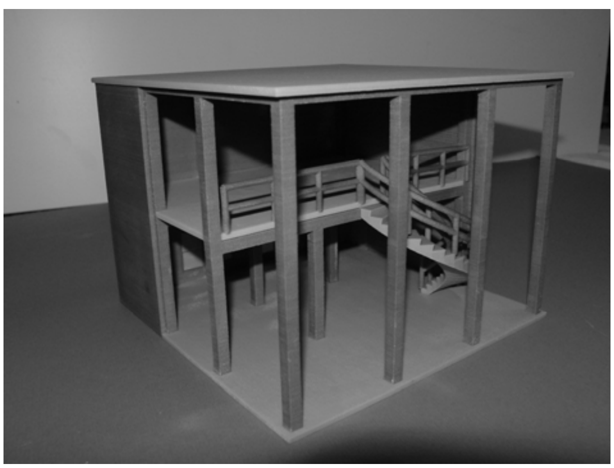

Figure 6. Completed model from spectrum Z-510

The model shown here does not require extensive support material removal as the unglued powder simply shakes out. The models do require a post production step of either waxing or gluing to toughen the otherwise fragile material.

f. Comparisons

Using the Spectrum Z 510 the estimated build time for the model at 5" x 5" is 4 hours and 6 minutes (monochrome) and 5 hour and 3 minute in (color). This compares favorably with the 23 hour and 3 minute build time for the stratysys.

When we enlarged the model to ¼" = 1'-0", a common scale for architectural models, the build area at the base was 7-1/2" x 7-1/2". The time comparison changed dramatically. The estimated build time for the model using the Z 510 is 7 hours and 18 minutes (monochrome) and 9 hours and 17 minutes in (color). This compared to a 69 hour and 3 minute build time for the stratysys. For architectural modeling this difference is critical. Dedicating the printer for nearly three days is problematic and severely limits the number of models that can be produced.

IV. STUDENT WORK

Students have been producing models using the Dimension Stratysys with acceptable results. We have been limiting the build times and therefore the final size of student projects. The following examples are a few of our successes along with renderings of the buildings.

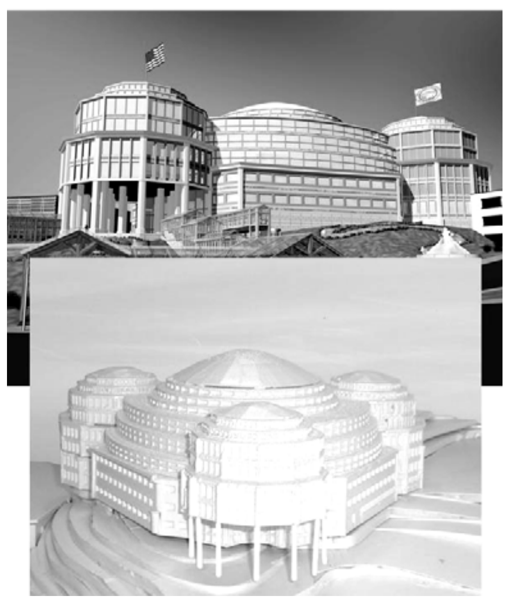

Figure 8. Alaska state Capitol design competition Adam Ricci, Andrew Vuono winter 05

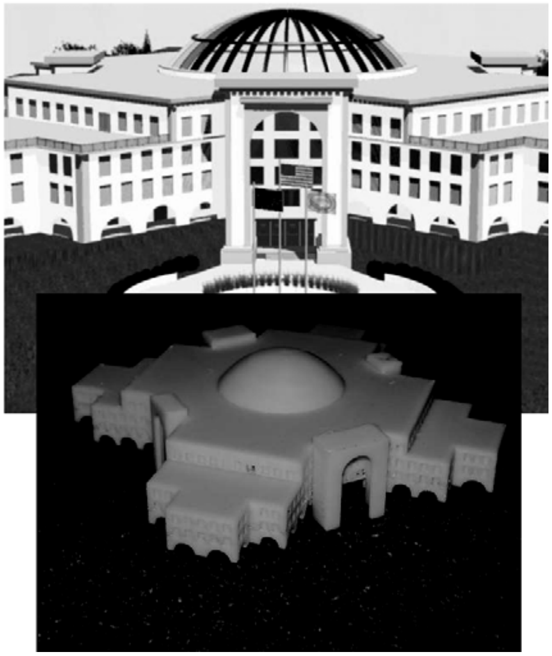

Figure 9. Alaska state Capitol design competition Shauna Laucella winter 05

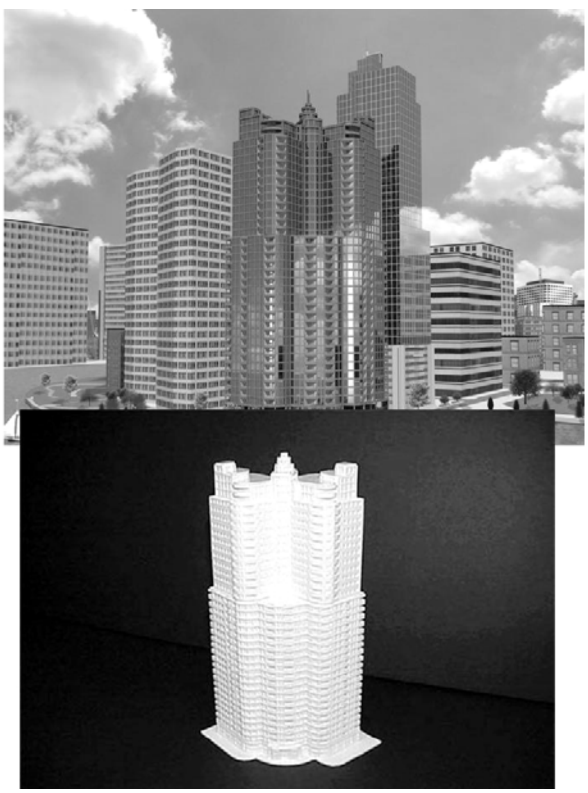

Figure 10. High rise design studio James Scotti, Daniel Dupre spring 04

V. CONCLUSIONS

At the time of this writing we are using the stratysys 3D printer for architectural modeling with an acceptable measure of success. The build time is presently the most significant problem for architectural 3D printing, as models need to be relatively large to illustrate a sufficient level of architectural detail. The support material required for the build and the difficulty of cleaning is the second significant problem. The next generation of the stratysys technology (presently available) utilizes a water soluble support material. We anticipate that this advance will solve the support removal issue. Leaving time, resulting from the model size, as the only constraint. The experimentation that we have done with the Z Corp Spectrum Z 510 has convinced us that our next 3D printer purchase will be the Z 510. The printers speed is a significant advantage for architectural modeling. Color is an interesting advantage although controlling the color in a manner that produces an acceptable architectural representation will require further experimentation.

VI. REFERENCES

1. Tec Ed Concepts, Inc of North America
   Z Corp printing courtesy of Jason Bassi and Dick Amerosa