Rapid prototyping and rapid manufacturing at Foster + Partners

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Over the last 15 years, rapid prototyping has been an integral part of the design process in the car and aerospace industry. Recently the architecture profession has started to use these techniques in its design process (2006 Greg Corke), and some architecture schools have begun experimenting with these technologies.

Foster + Partners was one of the first practices to fully integrate rapid prototyping within its design process. The technology was initially seen as a sketch model making tool in the early stages of the design, and in particular for projects with complicated geometries. It surpassed this purpose within a year and it is now seen an essential design tool for many projects and in for many project stages. As of spring 2008, the office's rapid prototyping department now produces about 4000 models a year.

Besides, or perhaps because of, rapid prototyping, Foster + Partners has started to experiment with rapid manufacturing. This first was done through the design and manufacture of a Christmas tree for the charity organisation Save the Children. Foster + Partners has also committed to a research project with the Freeform Construction Unit at the University of Loughborough. Its goal is to design and manufacture a 3D printer that will be able to print building components or even complete architectural structures.

INTRODUCTION

Model making has always played an important role in the development of an architectural design at Foster + Partners. Architects explore the conceptual form, layout and detailing concepts through the use of sketch design models. Rapid prototyping has been used as a technique in the office for many years; however, these rapid prototyped models were made for presentation only, under the supervision of the Modelshop and the Specialist Modelling Group (SMG). They were undertaken for projects involving forms or structures that were too complex to realize in any other way.

With the introduction of in-house rapid prototyping machines, the architectural design process within the practice has changed. This paper will outline the introduction and development of rapid prototyping technology at Foster + Partners in four stages: the trial of rapid prototyping technologies; retroactive modelling and trial projects; first projects to use 3D printing; and the adoption of 3D printing as a standard design tool. The paper will outline some early explorations with rapid manufacturing using rapid prototyping technologies and discuss research into new rapid manufacturing processes.

TRIAL OF RAPID PROTOTYPING TECHNOLOGIES

Rapid prototyping as an in-house process was brought to Foster + Partners through the Yacht Plus Boat Fleet project in May of 2005. It was felt that modelling the hull geometry of the boat required an accuracy that was not achievable by an architectural assistant carving foam by hand in the sketch model shop. Before committing to any sole technology, Foster + Partners bought in two different, relatively inexpensive, rapid prototyping machines to test in an architectural design environment: The ZCorporation Spectrum 510 3D Printer, which produces parts using a glue and plaster-like powder, and a Stratasys Dimension 18 Fused Deposition Modelling (FDM) machine, which produces parts in nylon plastic.

The 3D printer quickly became the favourite and was soon used for other projects. The 3D printer could produce models fast enough for the architectural design cycle, with a maximum build time of about 16 hours and an average build time of about 4 or 5 hours. It could also manage any complexity of form because it is self-supporting as it prints. The resolution was about 0.5mm, the print bed size was quite large (250mm x 350mm x 200 mm), and multiple parts could be printed at one time. The FDM machine had much longer build times, up to 120 hours, and regularly took more than 24 hours to complete a print. Rapid prototype parts were not self-supporting and required the addition of support structures, which required later removal. Though this was supposed to be easy procedure it proved to be anything but. The resolution of the machine was similar to the 3D printer, but the build size was smaller and only one part could be printed at a time. An advantage the FDM machine had over the 3D printer was in the strength of the parts produced.

The Boat Fleet project was the only live project using the 3D printer as part of its design process during this stage, though digital files from previous projects were used to test both printing technologies. The rapid prototyping machines were not getting much use at this point, with only one or two prints a week on average.

RETROACTIVE MODELLING AND TRIAL PROJECTS

In order to provide proof of concept to company directors of this new technology and justify the purchase of a new machine, the SMG used the 3D printer to produce models of many different projects, at many different scales, demonstrating different design intentions. This opportunity was also used to produce models of previous projects that involved complex geometry. Three-dimensional printing provided the opportunity to model projects that had been too geometrically complex to model by hand. This proved to be a rewarding process, especially for those designers who work on complex and/or computationally developed projects. Designs that had previously been impossible to model could now easily and quickly be 3D printed. These projects, which previously could only be viewed on a screen, or a paper print, could now be realized in three dimensions. The 3D prints would always initiate a conversation about some unseen aspect.

A computer program was written by the SMG that produced mathematical surfaces. Another series of custom digital tools could populate these surfaces with generated components. The forms created using these processes used simple

Fig. 1: Boat Fleet Yacht Plus 3D Prints

Fig. 2: Thomas Deacon Academy Atrium Roof

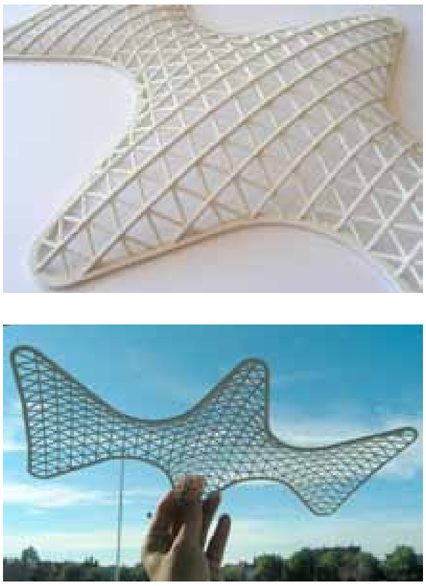
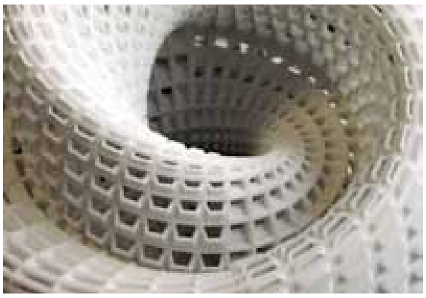


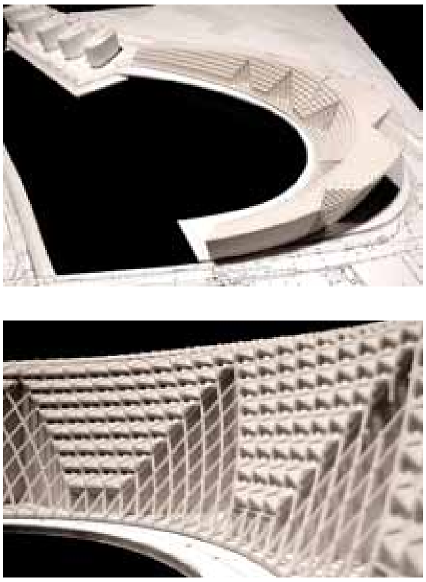
Fig. 3: 3D Printed Mathematical Surfaces



algorithms, but produced complex forms. These forms were used to test the limits of complexity the 3D printer could handle. As long as the digital file was not corrupt, it would print.

After these tests, Foster + Partners decided to purchase a 3D printer and integrate it into its design processes. At this point, even though 3D printing was not available for general projects, we were printing about five prints a week.

Fig. 4: 3D Printed Studies for Eurogate



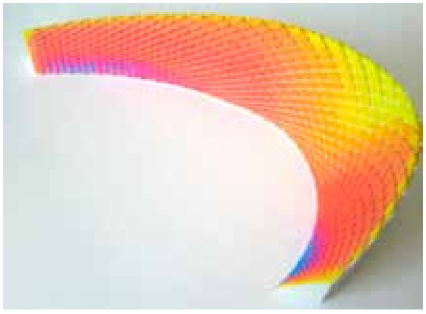
FIRST PROJECTS TO USE 3D PRINTING

The formal introduction of 3D printing to the office began with a SMG lecture on rapid prototyping and the display of the best 3D printed models. Several project teams began to use 3D printing as a way to develop design options; these were often projects involving the SMG. 3D printing was a process that was at first regarded with scepticism, then with amazement, soon became an ordinary and expected part the design process.

An extremely important aspect of the 3D printing process was that it was fast enough to match the architectural design cycle. A design could be discussed in a design review, changes could be updated in the CAD model, an STL file could be made from the 3D digital model, the file would be set to print overnight, and a new 3D printed model could be placed on the table for a design review the next day.

The SMG began to develop special digital tools and a series of standard techniques for 3D printing. It was necessary that CAD models were modelled in solids before being exported from Microstation into STL format. In order to print the same model at different scales, a strategy of using placeholder shapes and centre lines were used – these placeholder entities could then be thickened using the custom digital tools, TubeMan and Thicken. Minimum thicknesses for structure, skin, and model bases was established. Techniques and workflow processes were developed to produce the best possible models without taking too much time.

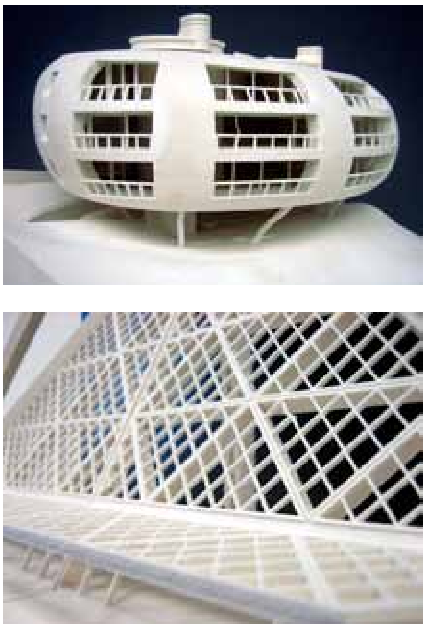
Fig. 5: 3D Printed Mathematical Surface



The ZCorp 510, the in-house 3D printer, is one of the few rapid prototyping machines on the market that can produce full colour prints; however, its colour capability was not the reason it was chosen as the rapid prototyping machine for the office. The colour capabilities were later found to be a useful tool to display environmental analysis in three dimensions. Special computer programs were written to translate the environmental analysis data back into the CAD environment. Once the data was back in CAD, the geometric entities could then be thickened to solids and printed.

At this point the 3D printer was printing about ten prints a week. We found that this was almost the full capacity for one printer. There were no dedicated personnel to operate the 3D printer; all work was undertaken by members of the SMG and by individual architects using the process. This system did not work very well, the machine was not maintained properly, and there was no chain of responsibility.

Fig. 6: 3D Printed Models



THE ADOPTION OF 3D PRINTING AS A STANDARD DESIGN TOOL

Rapid prototyping has now been adopted generally by project teams in the office as a potential design tool. Many teams now use the 3D printer as an integral part of their design process. 3D prints are made at various stages in a projects design: from early conceptual studies, to detail development, and even presentation models. Because CAD modelling for the 3D printer demands careful modelling, the rapid prototyping process has helped raise the quality of 3D CAD models in the office generally.

Printing a 3D model begins with a 3D digital CAD model, a representation of the design. Often this representation is only a visual one: walls have no thicknesses and some structural elements are unrealistic, such as cantilevers, etc. When these digital models are 3D printed, the model is suddenly submitted to physical laws. This informs the architect about the feasibility of their designs as structural principles are applied. This also ensures architects and designers undertake better CAD modelling: columns must meet the ground and the roof, floor planes must line up, and surface geometries must be clean in order to be thickened.

A design is often communicated through a series of plans, sections, perspectives, models, and animations. In a design process, the 3D digital model often lacks the details that exist in the rendered visualisations and plans. All of the representations are not tuned to each other. With 3D printing it is much easier to keep everything in tune.

3D printing is relatively fast process. It is definitely quicker in comparison with traditional modelmaking, which is a slow and laborious process. Even compared to sketch modelling, which is much quicker, 3D printing is faster still and gives you an accuracy and precision that is unachievable in sketch modelling. 3D printing has allowed for smaller project teams to produce more work, more quickly. Instead of spending weeks in the sketch modelling shop, designers can work up new designs in CAD, and output sketch models on the 3D printer. In this sense, t he sketch model making process, in some cases, has become automated. When combined with the custom generative tools created by the SMG, teams can output 3D models of very complex geometries, and highly detailed solutions at very early design stages. However, even if the geometry isn't especially complex, the process still must be used simply because it is faster and more efficient than building a model in any other way.

Foster + Partners has a staff of professional modelmakers. They were initially sceptical about the introduction of 3D printing as an in-house process, seeing it as a direct threat to their positions. The need for traditional modelmaking has not decreased with the introduction of 3D printing technology, if anything, it has created more work for the modelshop because of an increased emphasis on the importance of the physical model for communicating the design, and by creating the demand for more adventurous and detailed final models.

Foster + Partners now has a dedicated room and dedicated personnel for rapid prototyping. Because of the level of demand for 3D printing services, an additional printer was purchased. There has also been an increased awareness of other types of rapid prototyping technologies. Many more models are being sent out for Stereolithography (SLA) or Selective Laser Sintering (SLS) as these processes are more suitable to produce robust presentation models. The office has now purchased the dedicated rapid prototyping software package, MagicsRP by Materialise. The rapid prototyping facilities now produce about 2500 models a year.

A direct link has been made between the digital and analog world through 3D printing. This has changed the way in which many designers think. It demonstrates the a link between the CAD model and fabrication; full scale digital fabrication becomes the next logical step. The layered manufacturing approach will most certainly continue to shift the design language of architects. Architects will no longer be held to the traditional architectural vocabulary of extruded profiles, sheet material, windows or door components, for example. A new way of thinking about architecture and building design will become necessary, where function and performance will be considered the critical criteria with which to design, instead of working within the geometry limitations of current building components.

Fig. 7: Presentation Model produced with SLA Process

Fig. 8: The Tree of Reflections

EXPERIMENTS IN RAPID MANUFACTURING

In the fall of 2006, Foster + Partners participated in the Festival of Trees, an annual charity event hosted by Save the Children. The SMG was key part of the project team and chose to use project as an opportunity to research the manufacturing capabilities of rapid prototyping technologies. The overall form of the Foster + Partners tree, called the 'Tree of Reflections', was that of a cone – the ideal form for a Christmas tree, seen in Figure 8. The leaf geometry was generated by a customised computer program. This generative script allowed parameters to be easily changed to suit different manufacturing conditions. The tree was illuminated from within by a high-power LED light, which reflected out through a reflecting cone. The reflecting cone was manufactured by Rupert Soar at Loughborough University, and was then electroplated in silver by Morganic Metal. The reflecting cone sat underneath the leaves and leaf structure, which were manufactured by EOS systems in Germany using the SLS process. As the tree was nearly two metres in height it was necessary to manufacture it in components. It was also crucial that these components could be efficiently nested within the rapid prototyping machine's build chamber.

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