Towards a Design Science of Design and Fabrication and with Rapid Prototyping

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Introduction

Over the past 10 years many architects have focused on the production of free form designs as computer generated images and less as physical products (models or building). Both magazine and design books have graced their covers with curvy almost sensual images of free form designs. These images almost ignore the complexities of construction or any potential as a materialized construct. Unfortunately we have yet to discover methods of free form fabrication as design models befitting the budgets of most clients. Could it be that they are too complex for most designers to study? As a general pedagogy it could be said that humans lack the scientific knowledge of curves in ways common in nature. It could also be said that this lacking contributes to a reduction of buildings to boxes decorated in curves or curvy forms.

Until recent the typical array of shapes for play by designers has been rectangles, spheres, cones, triangles, squares and cylinders – Euclidean Geometries. These shapes have dominated the work of architects from Palladio's Villa Rotunda to Michael Graves Postmodern structures. Architects have mastered their construct as models built of wood or plastic and buildings of steel and concrete. Modern architects have demonstrated that it is possible to design and build variations of Euclidian shapes as free standing or interrelated designs. However few express the ability or desire to build outside of the known Euclidean shape set. Recently, computer based modeling, rendering and rapid prototyping have expanded the list of possible Euclidian and non-Euclidian shapes for play by designers. Referred to as free form shapes, they do embody a language beyond the traditional list of shapes constrained by the tradition of drafting and machine tooling. It is possible to build these shapes as a one of a kind sculpture with unique details and hand crafted component assemblies. Unfortunately there are few clear methods that illustrate how designers can effectively build free form shapes for design projects as scaled models. The potential of an effective scaled model is acquired information in design that will make full scale production economically feasible.

For creative design fields an effective means to produce free form models has been rapid prototyping (2001 Cooper). However because of limits in machine size, cost and manufacturing time these devices are limited in their production capabilities. Although architects and product designers have now adapted rapid prototyping to parts of the process these machines are mostly used by product designers (McDonald 2001). Products from sneakers to car parts are manufactured with these machines as free form models of a variety of materials. For architects physical modeling is important, they provide design incite on lighting, structure and the relationship of architectural spaces. As designers consider rapid prototyping an integral tool in design production questions on best practices with these machines emerge. How should a free form shape be modeled in CAD? How can we build varying scales of models? Can rapid prototyping inform full scale construction?

This paper presents a study of free form design in search of a science behind model production when using rapid prototyping. It is assumed a science will contribute to language that spans many design cultures from architecture to product manufacturing with curves (boatbuilding, furniture, etc).

Rapid Prototyping Research

Free form fabrication is a typical term for rapid prototyping where any shaped model can be manufactured by way of reduction to minimally stacked built layers produced by controlled machine operations (Cooper 2001). These machines produce physical artifacts collection of thin or thick printed layers adhered to newly produced layers many times over. Model quality is based on model strength, surface smoothness and fabrication speed. Advancement of these outcomes is impacted by research into machinery and software. Machine research is focused on physically sound, structurally effective model manufacture of a variety of materials from metal to plastic and ceramics and machine speed (1997 Beaman, et al) (2003 Gebhardt) (2003 Chua). Research considers variation in the nature of layer bonding, machine speed and improvement of model density as a few areas of study. Some also focus on the advancement of inexpensive rapid prototyping machinery as a means to make fabrication a viable for all (2005 Lipson). Research in rapid prototyping software focuses on advancements in file translation from a solid model to machine tool paths as a repetitive serious of functions (2002 Gibson). This includes optimization of model slicing, control of tool paths for smoother faster layer production, and improved methods to build model supports for all scale machines. Unfortunately, current research does not alter the nature of rapid prototyping in terms of product size. A few researchers have considered alternative software tools for rapid prototyping as a means to explore early stage designs (2002 Wang) (2002 Simundetti) also these studies employ conventional rapid prototyping machinery and software.

Multi Layered Machine Descriptions

Rapid production of physically large artifacts for architects will facilitate a need to understand internal spaces, external forms and possible construction outcomes during design. One approach to build physically large free form artifacts is to build machines of infinitely larger sizes ultimately leading to a building size printer (2004 Khosnevis). In this model artifact size is a dependant of machine capacity. Alternatively, an effective means to control artifact size is a redefinition of geometry sent to rapid prototyping machinery (2006 Griffith and Sass). Current rapid prototyping software slices solid models to printable layers. We explore a second set of functions that subdivides a model into discrete parts as objects with attachment strategies prior to slicing. It is believed that infinitely larger artifacts can be built by subdivision of an initial shape into objects. By generating parts (based on machine size) with a physical assembly from a large shape object rapid prototyping machines can act as manufacturing machines. In this research scripts were written within existing CAD software that to subdivide a surface into specified components with joineries as part of the subdivision algorithm. Results of this translation are a variety of physical size free form models easily assembled by hand (Figure 1).

Engineering for Press Fit Components

Although masonry construction is hundreds of years old wall build processes embodies many steps and stages of physical assembly with block and mortar. Here an algorithmic approach is explored that translates a surface to a wall construction by reduction of a shape to unique units with associated attachments. There are three stages within the subdivision from initial shape to tool paths (Figure 2);

a. Stage One - Shape → Unit
b. Stage Two - Unit → Unit with attachment
c. Stage Three – Unit to layered slices (with traditional rapid prototyping software)

Shape to unit transformation is the reduction of an overall design shape (the wall in Figure 2) to units whose largest sizes b_h is based on the maximum volume of the machine. With a software approach a variety of overall size artifacts is possible based on the number of units and the size of each unit. Novelty in this study is the ability to design joinery between units each unit that controls the assembly, strength and possible overall forms. Best for free form design with integrated attachments is that the overall shape is maintained during physical assembly by curve tabs and slots (Figure 2b & 2c). Joinery is integrated into each unit allowing for direct access to geometry for material testing such as finite element analysis or formulas in friction coefficients. Variables in this method are based on press fit theories as defined mostly by plastics industries. Their formula considers insertion force, torque, maximum stress and interference (2003 Tres). These factors in joint design determine geometry and joint integration within the part. They also offer opportunities to use t_t, t_h & s_1 as variable that control model strength and assembly speed

(Figure 2). CAD files generated by the script were printed as individual components on a ZCORP 402, scripts were written for Rhinoceros 3.0 with Microsoft Visual Studio NET 2003 (Figure 3).

Conclusion

Presented here is a method to generate free form designs as physical models that assemble and disassemble for transportation or design additions. This study illustrates a means to produce free form shapes beyond the boundaries of a common 3D printer, in this case as an assembly of computer generated units. Needed is further research of this type for improved means to pretest variables associated with gravity and model strength within software. Future goals expect that unit manufacturing will be by means of industrially base printers of concrete versus plaster or plastic. Most important is intelligent software that allows for model manufacture that generates based on physical reasoning in support of creative processes.

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Figures

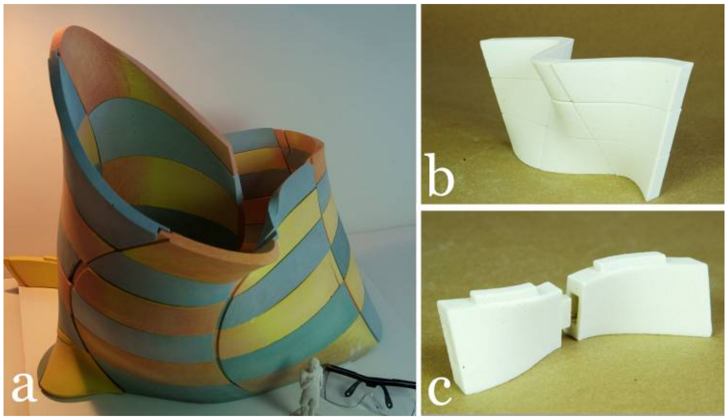

Figure 1. 3D printed model of components and saftey glasses for scale

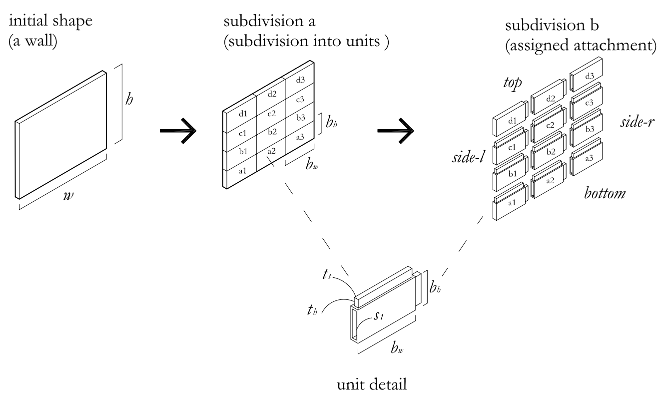

Figure 2. rules for the subdivision of initial shape

Figure 3. five designed surface models and subdivided shapes as larger 3D prints.