Title:

Exploration of a Design Framework for Large-scale Model Manufacturing

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Keywords:
Rapid prototyping, Large-scale prototyping, Scalable planar structure

DOI: 10.14733/cadconfP.2015.12-15

Introduction:

Physical prototyping (rapid prototyping) as part of an iterative design process is becoming a standard operation for most design communities. Creating physical models with automated machines is a necessary step across many product scales [1]. Architects, boat designers and furniture makers are limited in the physical size of models that can be produced with common, affordable prototyping machines. A conceptual model of prototyping is presented as a way of addressing shortcomings for designers of large-scale products.

Unlike traditional design, where a designer produces ideas and intentions, and a constructor acts on these intentions, this research aims to create an integrated system that includes design reflection, rapid 3D model generation and 2D CAD/CAM fabrication. A generative system used to create large models named as Scalable Planar Structure (SPS) is introduced. The system minimizes repetitive CAD modelling and serves as a framework that integrates physical actions associated with making and software functions associated with design and fabrication.

Research questions here are based on the production of design information through prototyping and less on model representation or realistic interpretations. Part of the investigation was a search for a method of information production suited for the laser cutting or CNC machining of dense thick material. Physical and cognitive factors that could influence model production are also investigated. We believe these questions will lead to a design framework and an advanced software system for design makers.

Scalable Planar Structure:

A Scalable Planar Structure (SPS) is a generative modelling system that starts with a 3D shape model and ends with a physical model consists of numbered parts manufactured by a laser cutter. The system automatically segments the 3D shape and produces a set of cutting paths. Planar material, such as plywood sheets, is used in cutting. After that, the cut components are manually assembled to form a physical prototype.

Three model types are presented as cases, each capturing a novel moment in the development of (SPS). Functions written for the first few cases were driven by visual goals. Resulting models were evaluated by comparison to virtual models, efficient production and strength. Functions developed for the last two cases were designed to solve problems related to behavior and human interaction. In case one, fixed sized planar structures are generated. Later, scaling methods were incorporated that split planes into smaller parts.

Case One: A Plane:

This case generates shapes as interlocking planes with inclusive slotted geometry. Models are limited in size to the maximum length of the material stock (Fig. 1). Planes or planar shapes are created from projections taken through the initial shape model (Fig. 2). The system generates new planes from contours with interlocking features and labels classified as symbols. Planes along the same axis maintain a parallel relationship. The finished planar shape is a 2D parametric object composed of start, bottom, and ending lines and segments that join the ends of cross-plane slots. Base curves are splines generated from the initial 3D model. The base curve drives the organization of symbols, new segments and lines.

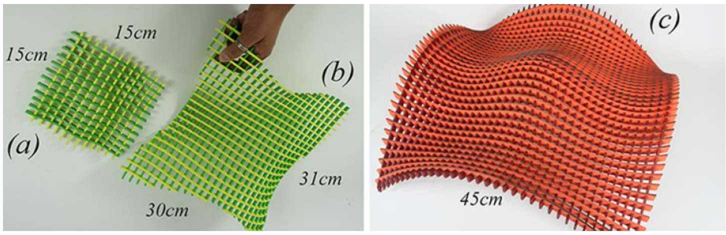

Fig. 1: Models as thin wall structures of a limited size.

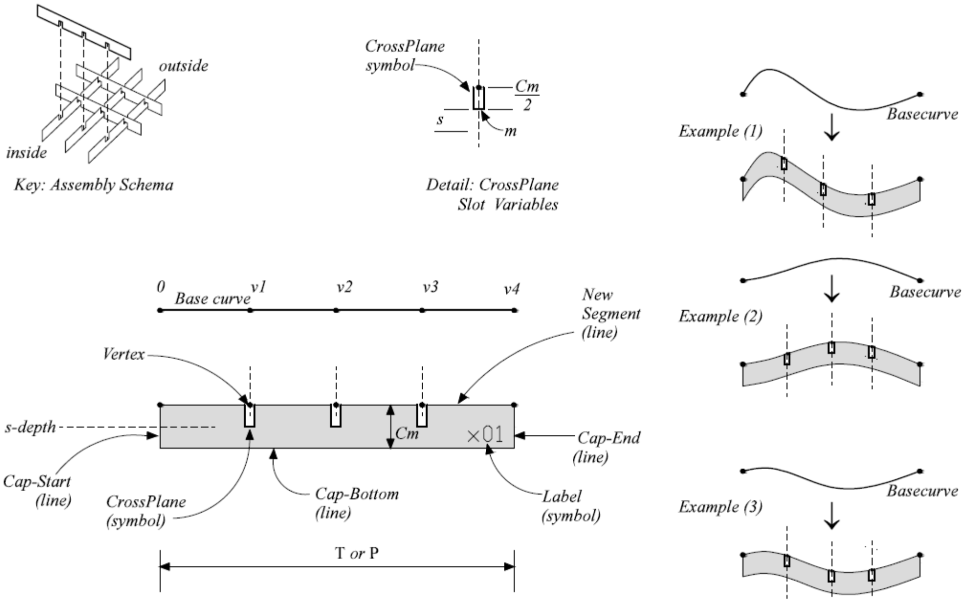

Fig. 2: Anatomy of a planar element illustrating symbols, cross-plane slots and contours in different positions.

Case Two: Sub-Planes:

A major goal of the program is to generate a range of model sizes from the same initial 3D shape model. Isotropic scaling of an initial shape model presented three challenges. First, how are smaller sets of curved planes created from a longer curve and once fabricated and assembled, will the smaller planes match the original curve as a collection of parts? Second, how best to generate attachment symbols between smaller planar shapes? Lastly, can an assembly of smaller parts be organized to create a robust large shape?

The first large-scale model was an assembly greater than one-meter along the x axis and half a meter along the y (Fig. 3). Most important for this study, its size (102x51 cm^2) meant that it was too large to be manufactured with an in-house laser cutter. A set of drawings and a 3D model of planes were generated from user-specified variables, one of which controls the maximum length of a component. In this example the longest piece was limited to 45 cm.

Fig. 3: In-plane features (left) of an assembled model atop a laser cutter (right).

Case Three: Planar Volume:

Creating 3D objects similar to common 3D printed models, is generation a planar model as a volume as opposed to a linear surface. A volume is a thin walled 3D shape composed of planes as closed shapes (planes) along one axis. Horizontal planes are cylindrical with a central axis. Each segmented component has male or female slots on either side. Cross-plane slots are organized around a central axis to allow vertical contours to be assembled from the outside. Initial shape in Fig. 4 was generated from scans from a rotary turntable.

Physical and Cognitive Challenges:

When the fabricators were asked questions related to visual quality, structural integrity, and efficiency in production, they expressed that complications in assembly were based on material choice. The programmer and fabricators also noted that model assembly was extremely complicated and physically exhausting. They said they had to take many breaks and that the duck model took two days to assemble including breaks.

Assembly as a manual process, as opposed to using the automated setups found in additive manufacturing, revealed a range of issues. The greatest concerns expressed by several fabricators involved challenges in material handling, pre-assembly of planes, and part structuring as they related to model behavior and control during and after assembly. The choice for the programmer of where to split planes into smaller sub-planes affected the strength and handling of elements. Reading labels on the sub-planes presented a challenge to the efficiency of assembly and created confusion between parts. Quantitative measures taken included time, materials, number of parts, and time ratios are recorded for further analysis of physical and cognitive challenges.

Conclusion:

Physically based prototyping has known benefits and unanswered questions. In this work we addressed questions related to basic production by fabricating models greater than a meter in length from a common prototyping machine. Assumptions were made that a large physical prototype assembled by hand could be limited by cognitive and physical factors not addressed in the literature on additive manufacturing. Resulting models demonstrated many complex concerns mostly related to human factors. Designers interested in prototyping their ideas prior to manufacturing expect and need systems of rapid production similar to the proposed SPS system, which is a scalable modeler and a realistic large-scale prototyping method. Researchers and programmers can use this system in its current state as a platform from which to build an embodied prototyping system inclusive of new measures for pragmatic and embodied cognitive activities.

Fig. 4: (1) Middle scale model built of 20 horizontal layers. (2-6) Large-scale model: (2-3) start of assembly and base parts, (4) oscillation of joints between horizontal layers, (4-5) assembly of the last 30 layers and (6) comparison in size between original model used for scanning, middle scale and final scale build from the same scan.

References:

[1] Yang, M. C.: A study of prototypes, design activity, and design outcome, Design Studies, 26(6), 2005, 649-669. http://dx.doi.org/10.1016/j.destud.2005.04.005