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Fresh Press Modeler: A generative system for physically based low fidelity prototyping

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ABSTRACT

For designers, digital manufacturing machines, such as laser cutters and CNC machines, support rapid prototyping of low-cost, low fidelity physical models. These machines can be used as an alternative to additive manufacturing. Unfortunately there are few CAD tools that provide access for fabrication of complex 3D geometries with these 2D fabrication machines. The literature contains a few novel systems that generate planar structures as models built of layered material or as interlocking planes with unique joining features. In this paper, a *Fresh Press* modeler is presented as a novel system that generates tailored geometry for ease of assembly. A major benefit of *Fresh Press* is the ability to produce fabrication data leading to a watertight planar structure. Assembly between planes is sustained by interlocking finger joints generated on each planar component of the model. The *Fresh Press* modeler parameterizes planar surfaces and interlocking features for user control and model quality. We end by demonstrating the system with examples of solid models and negative models used for mold making.

1. Introduction

The demand for physical prototypes by designers is growing. It is common knowledge that designers of all scales need artifacts for reflection and decision making as part of an iterative feedback loop in design [1]. Mostly there is a growing need for low-cost, low fidelity physically models [2].

Unfortunately, the limited volume and size of models available from common 3D printers do not satisfy the needs of designers of very large products such as boats, planes and buildings. Instead, many designers construct models as planar surfaces using conventional hand-held tools. Architects, for example, craft model parts using knives and saws, later assemble them by hand with conventional tools and adhesives.

Alternatively, today it is possible to manufacture models directly from CAD data from 3D digital data using laser cutters and CNC machines. In this case, fabrication data are prepared using keyboard driven modeling and drafting techniques. Then, designers use laser cutters to fabricate model parts which are assembled to a physical model. Due to the manual modeling involved in the process, this approach is often limited to making models that are not larger than a meter square.

There are few commercial systems that support the production of artifacts greater than one cubic meter at a reasonable price. A few companies have begun to address this problem by manufacturing very large scale 3D printing machines that produce high fidelity, yet costly models [3]. A notion in the rapid prototyping community has been that design success is related to the quality of prototyping; however, studies in a well cited paper suggested that simple, low fidelity models manufactured quickly lead to good, well informed design outcomes [2].

The research community has begun addressing the need for methods to generate low fidelity prototypes as alternatives to the widely accepted additive methods found with 3D printing. Novel methods are graphics based algorithms used to generate models as a collection of objects from a starting model. Current approaches are used to manufacture furniture, toys and models as interlocking, interlacing and sewn physical objects [4–7]. However, these approaches and tools do not address the need for a system that generates components that assemble easily as a watertight model.

A simple method of low fidelity modeling using CAD software and a laser cutter is demonstrated as a desktop-sized staircase model in Fig. 1. This model was generated first in CAD as a solid mesh model. Interlocking 2D components were drafted for cutting in a matter of days by keyboard and mouse entry using the initial mesh model as a guide. After, the components were laser cut from drafted parts in less than two hours, painted and assembled the next day in less than an hour. A low fidelity model was produced in approximately three days.

A production system that can generate physical artifacts quickly impact architects, civil and product engineers. Finished volumes of a watertight structure can be used by the design community as low fidelity models for design review of many sizes. We believe that the woodworking industry and concrete casting industries could benefit

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from rapid construction methods to deliver solid shapes and forms for casting [8]. A successful system of model production will address learning aspects associated with initial modeling and physical output.

The *Fresh Press* modeler is a production system that creates a 3D watertight model of interlocking planar structures from a solid mesh model. The system takes a triangle mesh model as an input, extracts planar surfaces of the model, generates finger joints [9] at the intersection of the surfaces to enable interlocking connection. The outcome is digital data of the planar surfaces with joints ready for fabrication. Basic user controls define material thickness, the number of interlocking fingers along an edge and the tolerance of cutting. The physical structure can then be assembled manually to produce a representation of the original model. A snapshot of the process is shown in Fig. 2.

2. Related work

Interlocking planar structures derived from 3D mesh models were introduced broadly by architects and engineers as a means to design and produce complex structures efficiently [10]. A system approach used to generate wooden structures was demonstrated and organized as a grammar, the main result of which was a plywood cabin built of interlocking parts [11,12]. Rules within the system were designed to guide modeling when decomposing an initial shape model into interlocking components. The system was not automated or programmed, instead components were modeled by keyboard and mouse entry aimed at describing opportunities that could come from the system.

2.1. Automated systems

Initial automated systems that generated planar structures with interlocking features were developed soon after. Oh et al. developed a semi-automated modeling system, in which connections between planes were identified by the modeler [4]. Automation supported a need to offload laborious modeling tasks to the computer. The program worked best to generate small toys and furniture. Generating slots and joints from complex starting models revealed limitations in the system that were addressed later by Lau et al. [13]. Last, an automated planar structure modeler was developed by Schulz et al. [14], whose approach was creating an expert system with a large collection of parametric components, such as boards, wheels and connectors (e.g. screws and hinges).

2.2. Cross planar structures

Cross planar models can be defined as a class of models built of intersecting layers of material across two directions allowing rapid generation of abstract shapes from mesh models. McCrae et al. [15] developed an interactive system requiring a user to pick a subset of planes of a model based on relative importance to represent the model. Saul et al. [16] created a chair-design system, in which the orientation of the slots could vary according to the geometry of a

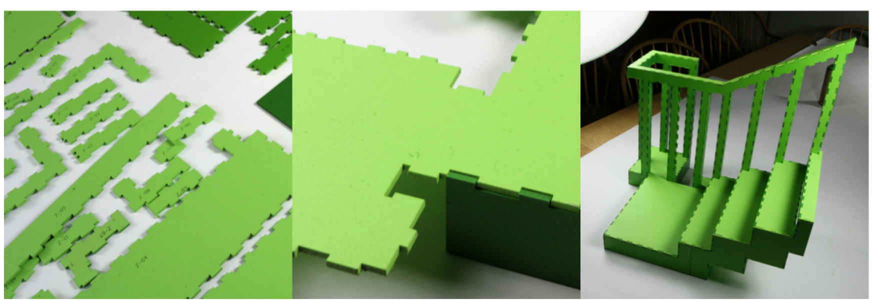

Fig. 1. A desktop model measuring ($53 \times 38 \times 48$ cm^3) laser cut of masonite. Finger joints were drafted through keyboard entry within CAD software.

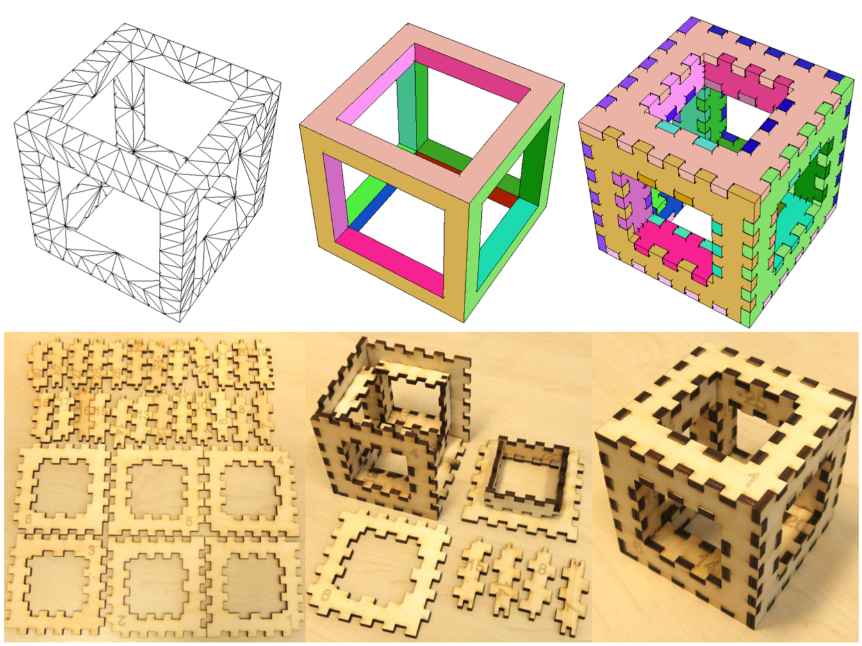

Fig. 2. Planar surfaces complete with finger joints at edges are generated by Fresh Press Modeler from a triangle mesh model.