[SIN]UOUS: *Developing a Pattern Fabricator Bridging between Visualization in the Digital and Fabrication in the Physical*

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Abstract. We describe a domain-specific design tool capable of creating and fabricating complicated curvilinear patterns within the early stages of the design. This tool entitled "[SIN]uous" is a parametric design application that allows both the customization and fabrication of dynamic patterns created by the combination of SINE and COSINE functions. This tool allows designers and architects to design curvilinear patterns and manufacture schematic physical models of them in a short period of time, using rapid prototyping equipment such as a laser cutter. This tool consists of several modules, including a pattern maker, a fabricator, and a 3-D simulator. Using this tool, patterns are generated by manipulating variable parameters and fabricated according to the assembly sequence easily and quickly through algorithms by locating nodes of intersections. The end result is an exported computer file compatible with laser cutting technology. We expect that this design tool will facilitate the transition between the virtual and the physical, thus resulting in a better design product.

Keywords. Pattern; Fabrication; Fabricator; Rapid Prototyping.

1. Introduction

This paper demonstrates the experience of developing a design tool capable of creating and fabricating curvilinear patterns within the early stages of design. With recent advances in CAD software, the capability of producing complex patterns has increased with minor attention paid to the complexities in the virtual environment. However, it is difficult for existing CAD software to fabricate patterns beyond the virtual to the physical environment because the existing CAD software doesn't support the specific operation for the process of fabrication. Accordingly, the new design tool presented in this paper supports both parametric drawing and fabrication for a physical model.

Traditionally, three-dimensional physical models are powerful devices that help clients and/or designers present and communicate designs within the initial design stage in order to acquire feedback. To create physical models, considerable manual skill and dexterity are required. The advent and adoption of CAD/CAM technologies, such as a 3-D printing, laser cutting technology and CNC (computer-numerical control) routers, have made it possible for designers and architects to easily produce complicated physical artifacts computationally. However, these technologies demand a significant amount of technical expertise with the exception of laser cutting technology. Utilizing this laser cutting technology, we developed a tool for designers and architects to create and fabricate schematic physical models of curvilinear patterns in a short period of time. This tool entitled "[SIN]uous" is a parametric design application that allows both the customization and fabrication of dynamic patterns created by the combination of SINE and COSINE functions and is composed of several modules including a pattern maker, a fabricator, and a 3-D simulator. Using this tool, patterns are generated by manipulating variable parameters and fabricated according to the assembly sequence easily and quickly through algorithms by locating nodes of intersections (these nodes are translated in grooves for quick assembly, eliminating the use of adhesives). The end result is an exported computer file compatible with laser cutting technology. We expect that this design tool will facilitate the transition between the virtual and the physical, thus resulting in a better design product.

Further research issues that have been identified include: extending beyond the curvilinear to various other pattern types and developing a three-dimensional module which can explore enhanced ways of creating and modifying patterns in the virtual environment beyond mere 3-D simulation.

2. Patterns in Architectural Design

Historically speaking, in the realm of architectural design, the value of patterns as the primary aesthetic of buildings has been a constant issue. The question was always one of whether they are necessary or not, as exemplified in the debates between the modernist and the post-modernist architects. Nonetheless, the popularity of creating and using new patterns in architectural design is undeniable—patterns have recently been invented and used all over the place: on exterior fa ades, in interiors, and even as a constructional principle (Figure 1). Today, some building types such as department stores, cineplexes, wedding chapels, and galleries do not demand a relationship between inside and outside. With this bifurcation, the exterior allows for more specialized attention, so the aesthetic importance of the building fa ade accordingly increases (Moussavi and Kubo, 2006). In addition, many recently invented patterns in architecture are closely related with the building's structure and conform to the construction (Schmidt et al., 2005).

Figure 1. Curvilinear Ceiling Pattern: Harvard Gund Hall

This means that it is necessary and important for these patterns to be considered together with other architectural elements in the initial design phase. Thus, architects and designers need to produce their design alternatives quickly and evaluate them in both virtual and physical terms. However, it is difficult for architects and designers to create and then apply the complex patterns to their designs in its early stages, since complex patterns require so much time to be manufactured. Thus, this hinders immediate feedback.

3. Digital Fabrication Using Rapid Prototyping

Current digital fabrication for architecture has a two-part process: rapid prototyping and CAD/CAM production (Sass, 2006). Rapid prototyping is a group of techniques used to quickly fabricate a scale model of a part prior to mass production (McDonald, Ryall and Wimpenny, 2001). CAD/CAM production means industrial application for mass products. Recently, the application of CAD/CAM technologies has been expanding from the aeronautics industry to the architecture industry.

These days, in the initial design stage of architecture, a laser cutting machine is the most compelling and useful method for rapid prototyping because a wide range of materials can be cut or etched with consistently precise work (Schodek et al., 2005). The use of a laser cutter is becoming a common method within the process of architectural design.

There are some studies about tools for design and rapid prototyping. The Beaver (Nousch and Jung, 1999) program enables users to construct closets by inputting various parameters of types and sizes in an Internet-based 3-D environment. It displays the plan for the fabrication of all hardware parts and assembly instructions with text and step-by-step drawings. Oh et al(2006). describe the simple two domain-oriented design tools for fast fabrication to construct furniture and dinosaur models, respectively: the Furniture Factory and the Designosaur. The Furniture Factory, on the one hand, allows users to sketch in the 2-D environment, simulate in the 3-D environment and make connectors with instruction labels for fabrication. On the other hand, the Designosaur allows users to draw individual bones freehand and to indicate joints. Because these applications were developed for ordinary users such as hobbyists and children, the users must be able to draw all components simply and by themselves.

However, designers generally build physical model by lateral slicing a plane shape into paper-thin sections with a laser cutter. For this, they have to draw a new plane so that they can use a laser cutter. In case of complex patterns, designers have to spend much more time in making physical models during the early design phase.

For relieving these efforts, some commercial three-dimensional CAD tools, such as form Z , offer the unfold operation, which provides the effective method for constructing physical models through re-assemblage (Choi, Park and Choi, 2002). However, designers and architects might spend much time in assembling the parts because this operation unfolds all the polygons of the object without considering the smoothness of the objects (users might consider materials with smoothness for their object). Thus, this operation is not suitable for use in the early design stage.

4. [SIN]uous

4-1. SYSTEM OVERVIEW

This system is composed of three parts: a pattern maker, a fabricator, and a three-dimensional simulator. The pattern maker of our system is developed as a parametric design tool which can create and modify patterns intuitively through inputting some pattern parameters into the front-end user-interface. Through the flow of seamless data between the pattern maker, simulator, and fabricator, users simulate virtually and quickly fabricate the designed pattern through the fabrication module. Figure 2 illustrates the modules of [SIN]uous.

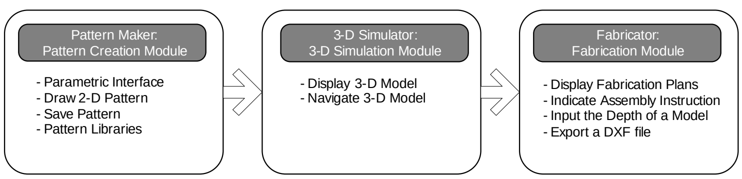

Figure 2. Modules of [SIN]UOUS

4.2. INTERSECTION ALGORITHM

The key component in the programming of this system is the intersection algorithm. The intersection algorithm serves as the seamless link between the three interfaces of the program: the pattern creation module, the fabrication module, and the 3-D simulation module. According to the parameters of the pattern maker of this system, a series of vertexes are plotted and are then connected with vector lines.

Using these vertexes, the intersection algorithm records the data into a series of arrays. The first type of array is a two-dimensional array which records the x- and y- coordinates of each vertex point as they are simultaneously plotted on the screen. The second type of array used in the intersection algorithm is a one-dimensional array used to calculate the distances between the two vertexes using the Pythagorean Theorem. The final type of array used in the algorithm is a three-dimensional array. This array records all intersection points found by comparing the x- and y- coordinates of each curve. However, because it is difficult for the x- and y- coordinates of each curve to have the same value, we made the tolerance area. As intersection points are found within the tolerance area, small red dots are plotted on the screen to indicate the point of intersection and simultaneously stored in the array. Figure 3 illustrates the intersection algorithm of [SIN]uous.

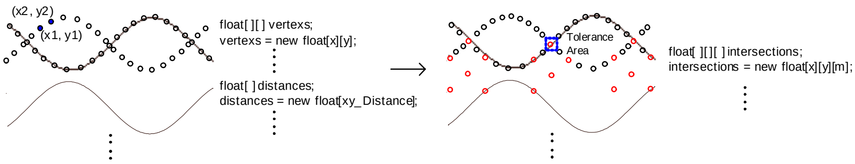

Figure 3. Intersection Algorithm

The intersection algorithm performs two functions for the fabrication of the pattern. First, it calculates the unrolled surface length of the sine or cosine curves by finding the sum of all the distances recorded in the one-dimensional array. Second, using the three-dimensional array, it locates the intersection points along the curve and draws a seam line where two curves will intersection. The end result is a series of bars with intersection joints ready to be exported into a CAD file. By using this CAD file along with laser cutting technologies, a three-dimensional pattern can be fabricated.

4.3. IMPLEMENTATION

There are an infinite number of patterns that can be created and fabricated using [SIN]uous. Depending on the complexity of the pattern, its chosen materiality, and scale, some patterns are more easily constructed than others. Using [SIN]uous, we present a project that shows the limitations and potential of the program in creating and fabricating a pattern.

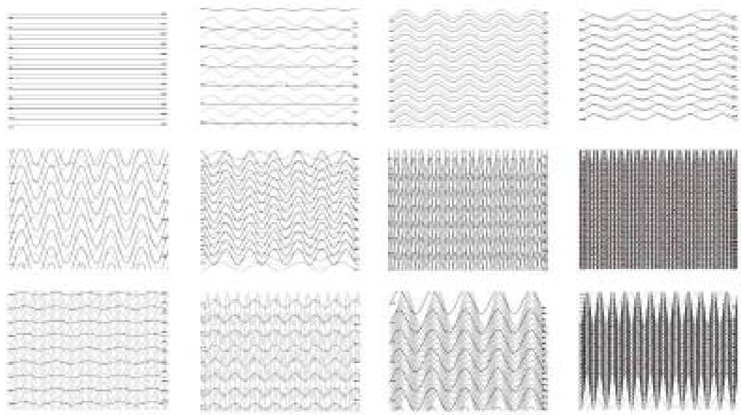

Figure 4. Patterns Produced by [SIN]uous

4.3.1. Pattern Maker

In the pattern maker, patterns are created by adjusting parameters—the number, the length, the height, and the interval—of multiple sine and cosine curves. According to these parameters, we created numerous patterns with varying complexities (Figure 4). Switching back and forth between the pattern creation, simulation, and fabrication modules, we quickly realized the amount of work involved in creating each pattern. The determining factor in choosing a pattern was in the location and number of intersection points. Figure 5 illustrates the pattern maker of this system.

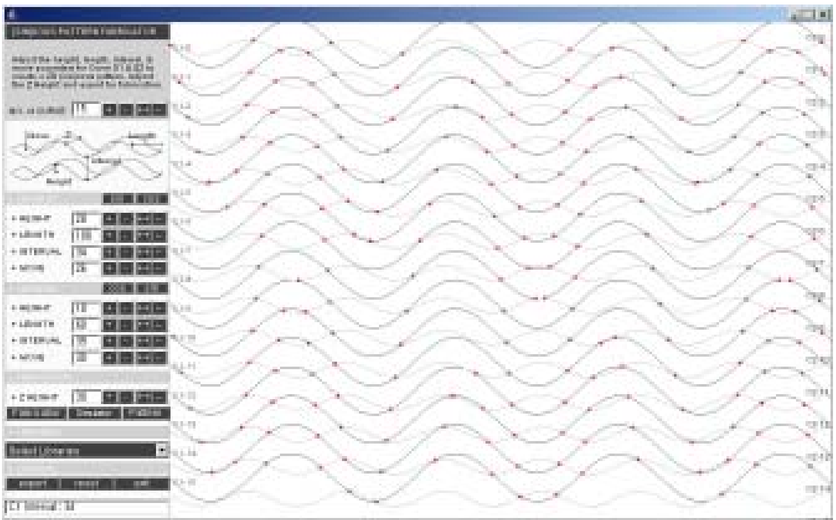

Figure 5. Pattern Maker of [SIN]uous

4.3.2. 3-D Simulator and Fabricator

Switching from the pattern maker to the 3-D simulator, users can design and choose the most suitable pattern in this system. After that, users might operate the fabricator to make a rapid prototyping model. This system automatically calculates and unrolls the sine and cosine curves into flat bars depending on the specified width. Joint lines are drawn on the bars, replacing the red dots in the pattern maker. Moreover, this fabricator provides joint numbers to facilitate assembly. This system exports the image onto the screen as vector lines in a DXF format file, ready to be used in a rapid prototyping machine. Figure 6 presents the fabricator of this system.

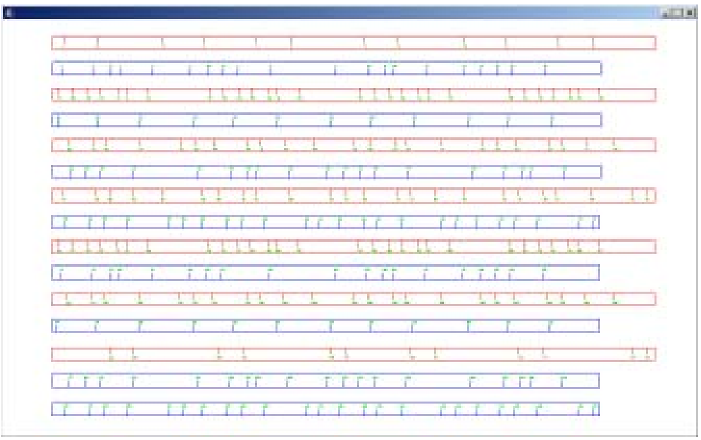

Figure 6. Fabricator of [SIN]uous

4.3.3. Rapid Prototyping

From the initial stages of designing the program, we decided to utilize one of the most common rapid prototyping machines, the laser cutting machine. The laser cutter can be found in most architectural schools and its ease of use, compatibility with other programs, and its ability to cut numerous materials seemed superior to other rapid prototyping machines. Using the laser cutter the user can take the exported DXF file and simply cut out the bars and assemble the pattern according to the assembly order. Figure 7 presents the physical pattern parts and assembled pattern model

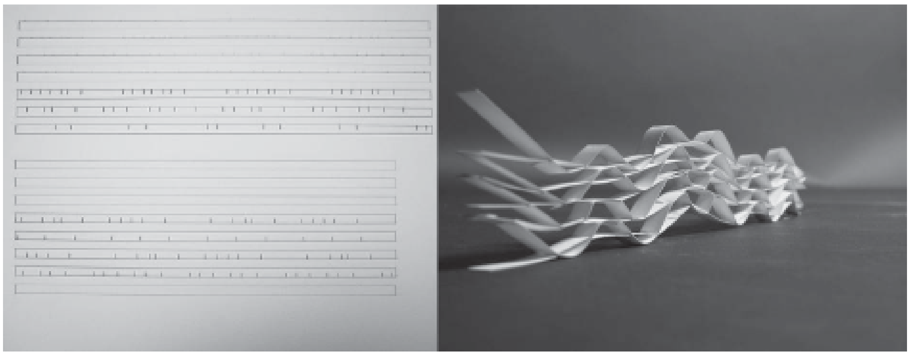

Figure 7. Physical Pattern Parts and Assembled Pattern Model: The authors created this pattern using the [SIN]uous system and a laser cutter

5. Conclusion

[SIN]uous, as described in this paper, is a domain-specific design tool which can create and fabricate complicated curvilinear patterns within the early stages of design. The main goal of this research is to investigate how to effectively make physical models with complex patterns produced by a digital design tool. Traditionally, three-dimensional physical models are the most efficient method of communication between clients and designers in acquiring feedback. However, the advent of complicated patterns and complex forms made by digital design tools is now requiring architects and designers to spend more time in making their models. When we consider that the creativity of architectural design depends on the ability to generate various design alternatives and on evaluating them in a certain amount of time through the design feedback, it is important for architects and designers to produce different alternatives during the design process (Kim, 1997; Choi and Park, 2003).

Thus, as a representative example of a pattern, we chose the curvilinear pattern because it is difficult for architects and designers to make this pattern manually with commercial design tools and to physically fabricate this pattern. Through [SIN]uous, patterns are generated by manipulating variable parameters and are fabricated according to assembly sequence quickly and easily. We expect that this design tool will facilitate the transition between the virtual and the physical, and will moreover be employed usefully and practically in the early stages of design. Therefore, this will result in a better design product. Furthermore, in the case that a design tool is developed by other researchers, we expect that our research approach in considering digital fabrication will contribute to the construction of a digital architecture in the actual environment.

Further research issues that have been identified include: extending beyond the curvilinear to various other pattern types as well as developing a three-dimensional module which can explore enhanced ways of creating and modifying patterns in the virtual environment, beyond mere 3-D simulation.

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