Study on an Architect-Oriented Workflow for Freeform Surface Design Tools

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Abstract. For most architects, it is not easy to transform their freeform designs into buildable constructions without precise knowledge on a specific material and its construction process. A workflow is introduced in this paper and it could be adopted by architects concerning the works of predicting the tiling results in the earliest design stage. The workflow involves pre-processing which could help architects design rational surfaces, thus saving a lot of work in the paneling process later on. The physically based modeling engine will simulate the constraints of a pre-selected material and therefore ensures a feasible result. The post-process involves visual feedback of the result as well as data formatting which help to establish a seamless connection between construction processes.

Keywords. Pre-process; material specification; construction simulation; evaluation.

INTRODUCTION

Although CAD tools of this new era have made the process of building complex geometry much easier for architects, it is still hard for architects to control the built quality of their freeform surface. Without enough knowledge on a specific material and its construction process, architects have to pass their freeform model to engineers or façade developers to continue the paneling process, which leaves their designs out of control. As a case study on a built freeform project near Suzhou Creek in Shanghai, China (Figure 1), the final paneling surface with RHEINZINK system was totally distorted from what the architect proposed. The sealing line, the directions of two neighboring patterns, and patch positions are far from satisfactory.

There are some unpublished paneling algorithms that are kept as business secrets in real projects such as in some practices done by Gehry Technology. Some intro can be found in various papers such as Digital Surface Representation and the Constructability of Gehry’s Architecture (Shelden, 2002). More introduction of their practices can also be found on their website [1]. The existing published algorithms on the paneling problems come in two ways. Kangaroo, developed by Daniel Piker (2011) a plugin for Grasshopper on the Rhino platform uses a bottom-up method. The internal physics engine deals with different forces and can generate good paneling results most of the times, though the engine is not only targeted for the paneling problems. The Evolute tool developed by the Evolute team [2] is the other way round. The internal engine uses a top-down method and it’s really fast. The engine is targeted for the paneling problem and deals with many possibilities. However, almost all the paneling engines today don’t take the material properties
and constructions techniques of the selected material into account. The result may be quite expensive or even unbuildable. In practice, the material has to be selected before paneling begins and many constraints of the material have to be considered during the paneling process. The features of the material weigh much in the real workflow.

In this study, a new workflow is introduced, which is expected to bridge the gap between architects and the specific material-oriented knowledge and also serve as the framework for tool development. These will help to generate more buildable paneling results and assist architects to take back the control on their freeform surface design. The research is supported by the Fundamental Research Funds for the Central Universities, and Laboratory for Historical Architectural Diagnosis and Ecological Reconstruction Technology, Key Laboratory of Ecology and Energy-saving Study of Dense Habitat (Tongji University), Ministry of Education, China.

RESEARCH

A complete workflow

Many existing workflows only focus on the paneling computation. As a complete solution to deal with the practical problems, it’s necessary to include Pre-Processing, Material Assignment and Post-Processing into this workflow. (Figure 2)

Pre-Processing

Pre-Processing acts as a rationalization process before the paneling computation. In many cases, freeform surfaces can be rationalized into a combination of several rational surfaces such as cylindrical surfaces and conical surfaces. These surfaces are defined with easy mathematical functions which could simplify the process of paneling computation. Furthermore, this helps the architect design rational surfaces in the first place, which provides possibilities to control the sealing line as well as the directions of neighboring patterns in the initial design stage.

Pre-Processing includes zoning and refitting. The surface should be zoned into several areas according to the curvature variations before the refitting begins. The refitting is a process of surface approximation using rational primitives and there are many existing algorithms to choose from. Good references can be found in Variati. In the case of the above project, the original design surface is divided into five zones according to their similarity to the primitives. Zone 1 is refitted with a semi sphere. Zone 2 is like a part of a cylinder. Zone 3 is refitted with a plane with a little bending. Zone 4 can be deemed as a developable surface with limited curvature and Zone 5 can be approximated with an extruded surface along a single rail. (Figure 3)
The freeform surface is divided into five zones with their primitives refitted.

The RHEINZINK Flat-Lock panels and the paneling test in the factory lab.

Material Assignment
Material Assignment ensures a precise simulation of a certain material, thus improving the feasibility of the final result. The characteristics of a defined material give rise to many constraints in the fabrication and assembly process. These constraints are often neglected in the paneling process which may cause unbuildable results. In the workflow, the material property and construction tolerances are taken into simulation via ways of converting them into geometric constraints, so called physical behaviors in the physics engine. In this case, the same RHEINZINK Flat-Lock panel system is used again. The extent of curvature and stagger using such panels is surveyed through experiments before establishing the model in the computer. (Figure 4)

The joint between two neighboring panels act as a hinge joint in the computer physics. In the established physics model, the neighboring panels are joined using hinge joints. However, in the real cases, the maximum kink angles between neighboring panels are constrained to a limited angle because of the tectonic requirements of this type of panel. As you can see from the second illustration, the angle constraints are further applied to the model. The flanging of the panel allows for limited rotation and translation happened between neighboring panels. The rotation can be simulated via act of hinge joints while the translation can be imitated by the softness between neighboring panels which is actually a limited deviation. (Figure 5)

As you can see, the process of material assignment is the process of transforming physical behaviors of the real material into its corresponding behaviors in the physics engine.

Paneling
Recent advances of paneling algorithm incorporate the merits of both discrete local and continuous global optimizations, such as mentioned in Paneling Architectural Freeform Surfaces (Eigensatz, Kilian, Schiftner, Mitra, Pottmann and Pauly, 2010) on the problem of reusable molds and the optimization of conjugate directions in Designing Quad-dominant Meshes with Planar Faces (Zadravec, Schiftner and Wallner, 2010). In this case, the paneling algorithm get the constraints from a predefined material li-
library. To ensure a precise simulation of the constraints, the simulation based modeling technique is used, which will allow the algorithm strictly follows those constraints extracted from the database as well as some common rules (You are not expecting panels penetrate through your design surface) to provide the most accurate result which assembles the real world cases. The ideas are inspired by Physics-Based Generative Design (Attar, Aish, Stam, Brinsmead, Tessier, Glueck and Khan, 2009) as well as a very good introduction in Baraff and Witkin’s (1997) Siggraph 97 course notes called Physically Based Modeling.

After assigning joints and constraints in the previous process, the subdivided primitives are to be dropped onto the design surface. The advantage of the refitting the freeform surface into various primitives in the pre-processing stage is that the primitive is a good starting point for the dropping process. Paneling on these primitives are far easier than paneling the corresponding freeform surfaces. The dropping translation vectors are determined by the relative position between the corresponding primitive and the design surface. The collision detection algorithm is also applied between the design surface and all the panels. (Figure 6)

Moreover, as for a fast and stable simulation, a good time step should be set according to different scenarios. As you can see, the paneling process can be illustrated using the following four steps. (Figure 7)

**Post-Processing**

Post-Processing includes visualization and data management of the paneling result. It’s helpful for the architects to evaluate the quality of the paneling result as well as exchange information in the team.

As a complete set of solution, visual feedbacks of the resultant geometry are included as well as some works related to construction drawings such as numbering and dimensioning. It’s also possible to export the statistics shown in the viewport to a neatly formatted excel sheet, which is usually a prerequisite to share the result with the construction engineers. (Figure 8)
able to simulate the construction tolerances while paneling, most resultant panels are not in the same size. Though the smoothness generated by the introduced workflow is no match for the results generated by the Evolute Pro, but it still conforms with the construction techniques while creating most panels with exactly the same size. (Figure 9)

### A COMPARISON

The advanced algorithm developed by the Evolute Geometry and available function in their Evolute Pro Rhino plugin is a truly revolutionary solution to optimize the discretization of the freeform surface. The above sample surface is paneled with Evolute Pro Academic version and the result is quite even and smooth. However, the Evolute Pro tool is unable to simulate the construction tolerances while paneling, most resultant panels are not in the same size. Though the smoothness generated by the introduced workflow is no match for the results generated by the Evolute Pro, but it still conforms with the construction techniques while creating most panels with exactly the same size. (Figure 9)
DISCUSSIONS AND CONCLUSION
Though being capable of simulating the material properties, the workflow relies heavily on the material testing and it cannot be wrapped into a software package to simulate general materials. However, the value lies in this new way of paneling which could reduce the cost by making more panels come in the same size while still be buildable.

The workflow proposed here will provide architects with an efficient way to design freeform surfaces. The whole workflow can be illustrated by the image below [Figure 10]. Pre-Processing and Material Assignment help architects do a rational design with buildable results. This will not only add to the precision and performance of the paneling algorithm, but also provide more controls for the architects on the sealing lines and the directions of neighboring patterns in their initial design stage, which may enhance the esthetic quality of the paneling result. Physically based paneling ensures a better simulation of the constraints applied in the assembly process. It’s a workflow for designing architectural freeform surfaces with more control, less cost, and better quality. Currently, the Pre-Processing and Post-Processing have been built already, and the material-assignment process is in test to involve more complex geometries. Part of the paneling engine has been built already to incorporate four joint types and constraints. More constraint types and soft body simulation is under development and more test has to be done to ensure the engine could work stably.
FUTURE WORKS
Two things are on the schedule of the development. One is enhancement and tuning of physics engine to make it better cope with all sorts of paneling problems. The other is more about the efficiency. Currently, the collision detection runs on multi-core CPUs, as the most computational intensive part of the whole process, the optimization on the performance using CUDA technology will be the best choice. These future developments will allow a more stable and instantaneous feedback of the paneling result.

REFERENCES
Shelden, D 2002, Digital Surface Representation and the Constructibility of Gehry’s Architecture, Massachusetts Institute of Technology, Massachusetts.