SCRIPTED MOCKUPS

Bridging Digital and Physical through Computation.

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Abstract. This paper illustrates a method of user-level software development -computer programming within a Computer Aided Design application environment- as means of collapsing the process of translating complex geometric objects from the digital to the physical reality.

1. Introduction

Computation technologies expanded the realm of expressive design possibilities by making accessible complex geometries, such as NURBS curves and surfaces. Yet, various intricacies emerged, such as the problem of translating the digital design artefacts into physical objects. Rapid prototyping and digital fabrication, as both transferring mechanisms between the digital and the physical, became important aspects of the design process.

We identify the processes of translation, apart from their products, as crucial for the development and evaluation of design, for they offer multiple intermediate representations for engaging design (Loukissas 2003). Our research is founded in the mindset of architectural sketching by computation, which renders methods of bridging design in a digital context and physical object-making (Kilian 2003). Even though our product is a technique with a specific style of producing physical prototypes, from a given digital representation, we understand the thought process as a generic methodology of design in the digital.

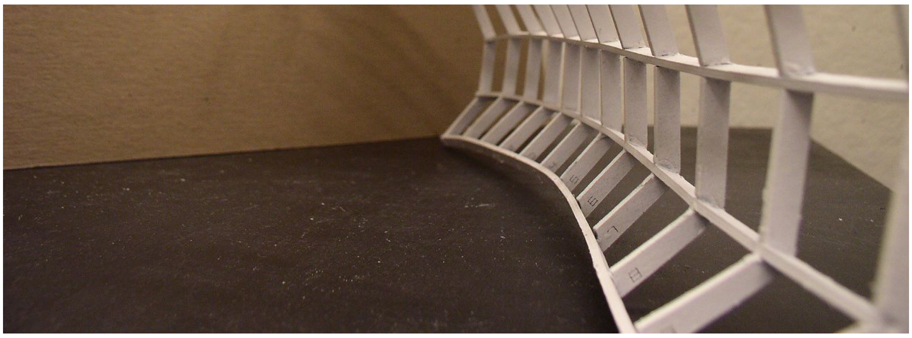

Figure 1. Scripted Mockups

2. Description

We developed a set of computer scripts that analyze arbitrary NURBS surface-patches into networks of interlocking ribs, flatten the decomposed elements, and lay them out in sheets. Essentially, the scripted process generates prototyping specifications suitable for extrusion style fabrication technologies such as Laser-Cutting, CNC-Milling and Water-Jetting. The scripts in this way automate the process of prototyping by eliminating the phase of intermediate geometric modeling. The process eventually bridges between a “purely digital” aspect of design and an “almost physical” manifestation of it.

3. Implementation

The prototyping applet was written in the Visual Basic™ Scripting language which is bundled with the Rhinoceros™ Computer Aided Design platform. The final script was composed out of three core components: the analysis module, the translational module and the layout module.

3.1. THE ANALYSIS MODULE

The analysis module’s purpose was to generate a network of interlocking ribs on top of the given surface patch. The script divided the surface into a number of cells, per parametric direction, and overlaid a grid of points on top of it. The grid of points provided the registration for the ribs’ joints [Figure 2]. The points were translated along each parametric direction on top of the surface’s tangent plane, from the registration points. The amount of translation was defined by the requested thickness of the ribs [Figure 2]. The new points were translated along the normal vector (and its inverse) of the registration points. This transformation produced the requested depth of the interlocking groove pattern [Figure 2]. The adjacent joints were connected with each other to produce the final three dimensional prototyping specification.

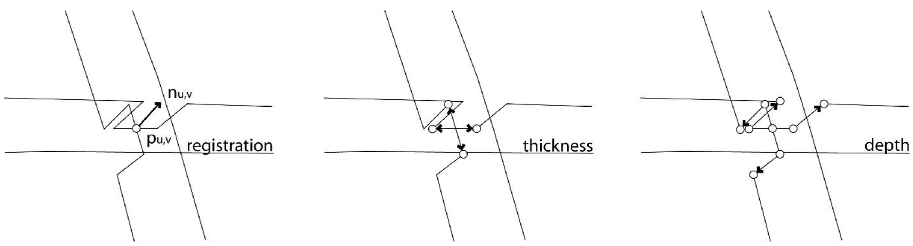

Figure 2. Joint generation.

The process did not require for modeling of solid or surface geometric components, because the geometry could be processed computationally in non-visual modes. We decided to add the option of automated geometric modeling for enabling the pre-evaluation of the final prototyped products [Figure 3].

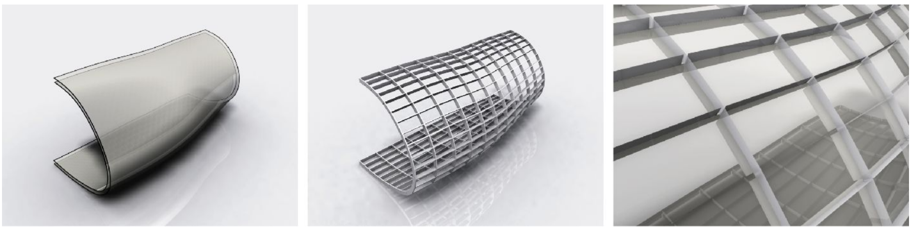

Figure 3. Surface and solid based models generated by the script.

3.2. THE TRANSLATION MODULE

The translation module transferred the three dimensional network of curves into two dimensions. The process converted the rib outlines into triangle strips following a predefined pattern [Figure 4]. The strips were transferred into XY plane by coordinate system to coordinate system transformation.

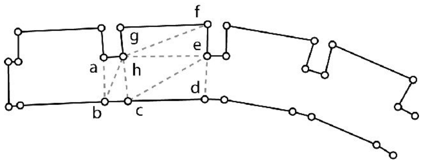

Figure 4. Flattening pattern based on triangular strips.

3.3. THE LAYOUT MODULE

The layout module prepared the flattened elements for the actual prototyping process. The ribs were sequentially numbered for assisting the prototypes' assembly. The uniquely identified elements were packed together by an axes-aligned-bounding-box algorithm, implemented for its low complexity. For allowing tighter packing and manual minor adjustments, the elements were organized in groups. The machine-path outlines and numbering geometry were color coded for allowing the identifiers to be processed in a different mode by the machine (scoring instead of cutting for instance) [Figure 5].

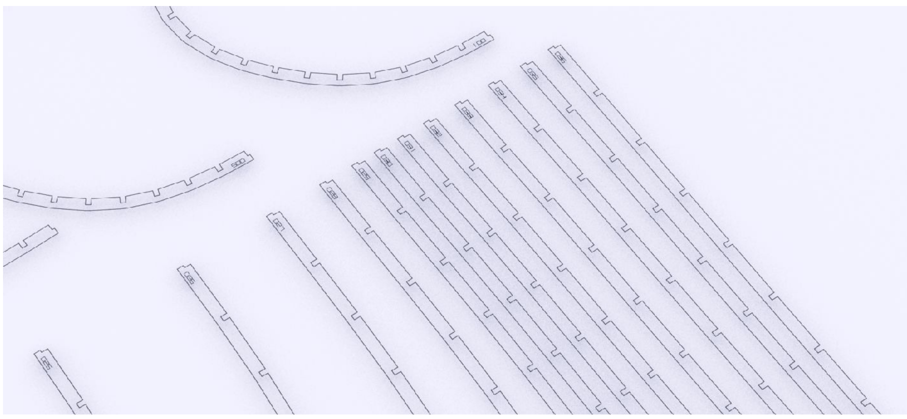

Figure 5. Flattened and laid out elements.

4. Experimentation

For evaluating the script's results we produced a series of testing models which represent some common as well as extreme conditions of possible application. We used Laser-Cutting on cardboard sheets as the prototyping method [Figure 6, 7, 8]. The script prepared the prototyping specification in a few seconds up to a few minutes depending on the density of the ribs per direction. Manual packing adjustments, depending on the bed size of the machine and material sheet dimensions, took only a few minutes, since the members were already roughly pre-packed and grouped. The machine time for preparing the elements was slightly longer and largely depended on the number of elements and thickness of the material. Finally, the process of assembly, even though it was assisted by the numbering proved to be the most time consuming.

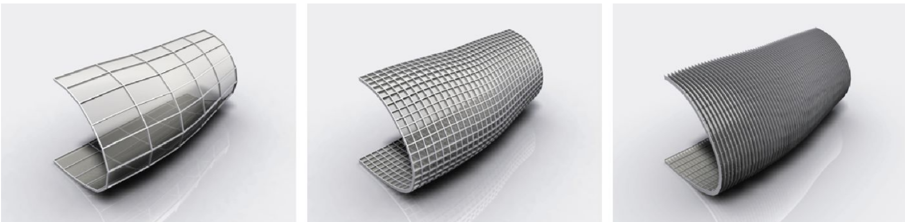

Figure 6. Variation of the ribbing density.

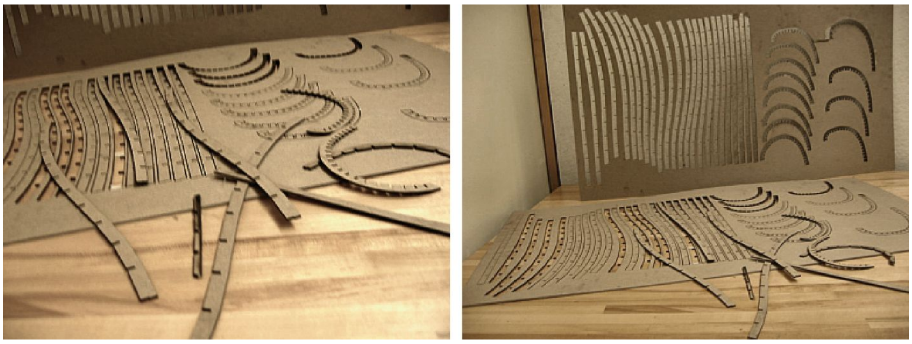

Figure 1. Laser-cut sheets of cardboard

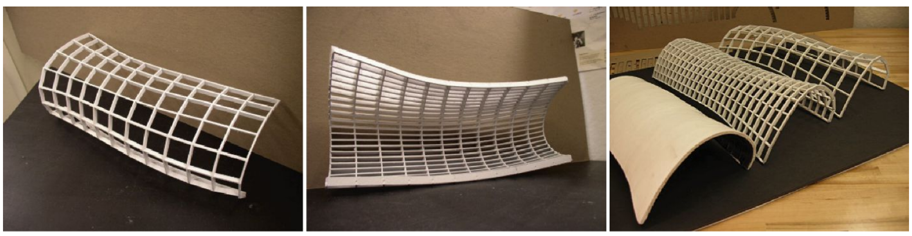

Figure 1. Assembled prototypes with various rib densities.

The process demonstrated high stability and even though we incorporated thickness tolerances in the first prototype produced, we eventually removed them in those that followed. The joint pattern proved to be efficient enough to eliminate the need of adhesives after a few initial ribs formed a stable framework. The overall form inherently incorporated errors due to both digital and physical abstraction of the process (discussed later on), but nevertheless provided an adequate representation of the original object.

5. Evaluation

5.1. POTENTIAL

The primary impact of the process is founded in its time-compression characteristics: It immediately bypasses the phase of geometric modeling which is both highly tedious and time consuming. Furthermore, the scripted approach introduced an implicit protocol of prototyping which was nevertheless explicitly encoded. In this case the script provided a generic method of producing an arbitrary number of prototypes exhibiting the same stability and uniformity as inscribed in the original encoding of the script.

Apart from the automation-oriented aspects of the prototyping script, which can be characterized as quantitative, there are effects which may be rather understood as qualitative. Those spring from the ability to think and operate on digital entities and creatively construct, in an ad-hoc mode, immediate physical objects. Moreover, once the digital mockup system is implemented it allows the generation of wide ranges of solutions which inevitably expand the realm of design investigation. In this respect we consider the project not merely as a custom software solution, but also as a methodology of design thinking which bridges between the domain of digital and physical.

5.2. LIMITATIONS

The limitations of the process can be traced in both the initial assumptions contained in the analysis module, the digital abstraction, as well as the target fabrication technology and prototyping material properties, the physical abstraction.

The analysis module assumes a grid of points, and the corresponding normal vectors, on top of the parametric domain of the surface and operates uniformly over the geometry by ignoring its underlying intricacies. While this approach provides generality and simplicity, it also contains some implicit affordances. For instance, the while the script can process any arbitrary surface, it produces reasonable results for surfaces of constant curvature and low curvature. Surfaces of high curvature produce results which are unfeasible by this method; a fact, for instance, that can be quickly observed by the self-intersecting flattened members.

On the physical aspect of the process, the material and fabrication methods also contain a set of implicit assumptions. For instance, while experiments with soft materials such as cardboard and thin aluminum proved to be successful, rigid materials would not be able to conform to and incorporate the implicit stresses on the joints due to original surfaces' curvature characteristics.

6. Conclusion

In this paper we presented a software-based prototyping system that accommodates the process of transferring NURBS surface geometries into physical models. The prototyping script was structured by three basic components which are extensible and adaptable in specific design and prototyping intentions. For instance, the analytic unit can be exchanged by a contour generating process, the translation unit may embed techniques of surface unrolling, and the layout unit may be augmented with more efficient packing algorithms or different protocols of fabrication.

We realize that as the technology rapidly advances, the prototyping and fabrication methods become more and more automated. Three dimensional printing for instance collapses the process of transferring complex geometries from the digital to the physical to a few "instructions" to the machine. For this, we comprehend that the greater scope of our project suggests a design-driven methodology of exploiting the current fabrication technologies, by employing the medium of computation.

Acknowledgements

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References

Loukissas, Y. 2003, Rulebuilding, Exploring Design Worlds through End-User Programming. SMArchS thesis, Department of Architecture, Massachusetts Institute of Technology, Cambridge, MA.

Kilian, A. 2003, Fabrication of Partially Double-Curved Surfaces out of Flat Sheet Material Through a 3D Puzzle Approach, Connecting Crossroads of Digital Discourse [Proceedings of the 2003 Annual Conference of the Association for Computer Aided Design In Architecture / ISBN 1-880250-12-8] Indianapolis (Indiana) 24-27 October 2003, pp. 75-83