Fabrication-Aware Geometry Processing

Panozzo, Daniele
ETH Zurich

https://hdl.handle.net/2324/1547103

出版情報：MI lecture note series. 64, pp.113-115, 2015-09-18. 九州大学マス・フォア・インダストリ研究所
バージョン：
権利関係：

MATHEMATICAL PROGRESS IN EXPRESSIVE IMAGE SYNTHESIS 2015
Sep 25-27, 2015, Nishijin Plaza Kyushu University, Fukuoka

Fabrication-Aware Geometry Processing

Daniele Panozzo*
ETH Zurich

Abstract The advent of commodity 3D manufacturing is increasing the demand for advanced design tools that make the designed shapes physically realizable. In this talk, I will present fabrication-aware algorithms to solve classical geometry processing problems such as intersection-free mesh deformation, surface parametrization and semi-regular meshing. In particular, I will focus on the interactive design of tangent vector fields, whose applications include the conversion of raw point clouds into coarse control grids, the design of planar tessellations and the design of self-supporting masonry buildings. To conclude the talk, I will give an overview of recent techniques that use mesh parametrization algorithms to apply a texture map to real-world objects using hydrographic printing.

Keywords: Geometry Processing, Digital Fabrication, Self-Supporting Surfaces, Hydrographic Printing, Quadrilateral Meshing, Appearance-Mimicking Surfaces.

1 Extended Abstract

The advent of commodity 3D printing is revolutionizing the way people think about designing and prototyping: a designer can now hold in her hands a 3D object hours after its design is complete, drastically reducing costs and enabling quick iterations over many designs. Additive manufacturing enables new applications that were impossible with traditional production processes.

However, the majority of software tools and algorithms currently used to create, manipulate and process digital geometry are not fabrication-aware: they model the shape as an abstract entity that often does not satisfy practical requirements such as stability, robustness or lack of self-intersections. This leads to a large gap between the digital design and the physical fabrication, which is the major obstacle preventing digital fabrication to become mainstream and to deeply change our working habits, in a way similar to the introduction of inkjet and laser printers. In this talk, I will present a series of works that strive to fill this gap, providing computational design tools that rely on numerical optimization to create fabrication-ready designs, which can be directly fabricated using digital fabrication technologies.

Avoiding Self-Intersections: A 3D model must be free of self-intersections to be suitable for fabrication. Technically, this means that no elements should intersect (in the case of thin layers such as cloth) and that no volumetric element has negative volume (in case of volumetric representations). This requirement is surprisingly difficult to enforce, especially during design [1], and it is often omitted in favor of simplicity and speed. While this is not a critical problem for models used in movies or games (the overlaps will often not be visible), it becomes mandatory to solve before models can be

---

*panozzo@inf.ethz.ch

Figure 1: Preventing self-intersections during modeling leads to more intuitive results that are ready to be 3D printed.

fabricated. A 3D printer cannot print infinitesimally thin layers, and it thus needs to fill the interior of the shape, which is not defined and impossible to compute in presence of self-intersections.

Avoiding self-intersections during deformation is particularly simple if each point is restricted to move on a ray pointing the origin [2]. While this reduces considerably the deformation space, this special deformation is ideal to automatically create appearance mimicking surfaces starting from triangle meshes (Figure 2). The produced surfaces are, by construction, free of self-intersection and ready to be fabricated via 3D printing.

Figure 2: A collection of appearance-mimicking surfaces.

Planar panelization: Quadrilateral meshing algorithms are gaining popularity in the graphics community to convert high resolution triangle meshes into coarse control grids for Catmull-Clark subdivisions. They can also be applied to design planar tessellations, which are ideal for glass and steel construction, due to the low cost of producing flat glass panels. Starting from a planar tessellation, a building can be constructed by replacing each face with a *flat* glass panel, that is much less expensive to manufacture. Mathematically, the edges of a quadrilateral mesh with flat faces define

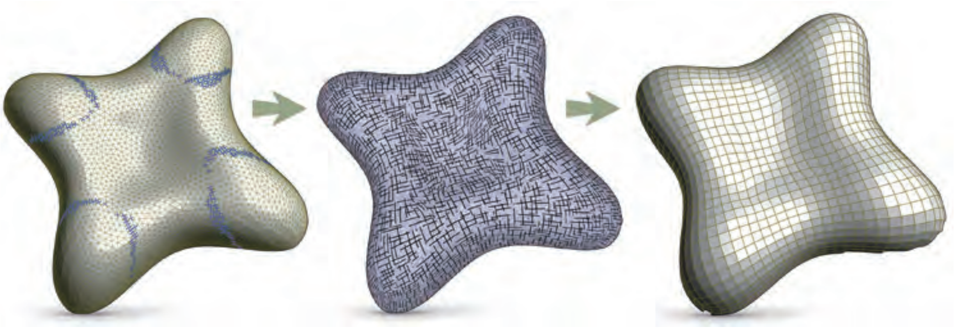

Figure 3: Planar quadrilateral meshes are used in architectural geometry to design free-form glass and steel structures. The designer specifies a set of alignment constraints (left), the constraints are interpolated in a conjugate direction field (middle) that is automatically converted into a mesh with planar faces (right).

a conjugate field [3], which can be designed with a simple and efficient algorithm [4] that allows architects to interactively experiment with different planar tessellations by simply specifying a set of desired alignment constraints.

Free-Form Masonry Structures: The automatic creation of quadrilateral meshes can be used to design and tessellate of free-form masonry structures [5, 6]. These structures are composed of unsupported stone blocks and they stand thanks to their special geometry where all blocks are in static equilibrium. The block pattern used is a quadrilateral mesh, where an edge every two is removed to create a staggering effect that increases the interlocking between the pieces, simplifying the construction and improving the structural properties of the masonry building.

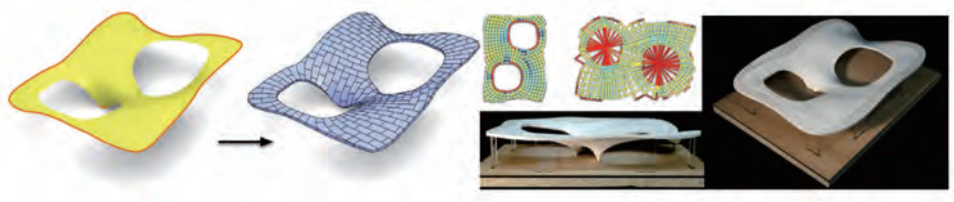

Figure 4: An input surface is automatically transformed into a masonry 3D model. The equilibrium of the surface is represented by two planar graphs that encode the directions and magnitudes of all forces. The generated blocks are 3D-printed and assembled into a physical model of the surface that stands in compression without using glue or reinforcements.

Hydrographics Printing: In the digital world, assigning arbitrary colors to an object is a simple operation thanks to texture mapping. However, in the real world, the same basic function of applying colors onto an object is far from trivial. One can specify colors during the fabrication process using a color 3D printer, but this does not apply to already existing objects. Paint and decals can be used during post-fabrication, but they are challenging to apply on complex shapes. I will introduce a method to enable texture mapping of physical objects, that is, to allow one to map an arbitrary color image onto a three-dimensional object [7]. The approach builds upon hydrographics, a technique to transfer pigments printed on a sheet of polymer onto curved surfaces.

Figure 5: We start with a real-world object and a digital 3D model of this object. Using off-the-shelf 3D modeling software, we define a color texture on the digital model. Our algorithm then automatically generates a flat image that we print on a polymer film. We use hydrographics (water transfer printing) to apply this texture onto the real-world object. Our approach compensates for the deformation that happens during the transfer process, so that the final result looks like what we specified on the 3D model.

References

[1] David Harmon and Daniele Panozzo and Olga Sorkine and Denis Zorin: Interference Aware Geometric Modeling, ACM SIGGRAPH ASIA 2011.

[2] Christian Schüller and Daniele Panozzo and Olga Sorkine-Hornung: Appearance-Mimicking Surfaces, ACM SIGGRAPH ASIA 2014.

[3] Yang Liu and Weiwei Xu and Jun Wang and Lifeng Zhu and Baining Guo and Falai Chen and Guoping Wang: General Planar Quadrilateral Mesh Design Using Conjugate Direction Field, ACM SIGGRAPH Asia 2011.

[4] Olga Diamanti and Amir Vaxman and Daniele Panozzo and Olga Sorkine-Hornung: Designing N-PolyVector Fields with Complex Polynomials, EUROGRAPHICS Symposium on Geometry Processing 2014.

[5] Daniele Panozzo and Philippe Block and Olga Sorkine-Hornung: Designing Unreinforced Masonry Models, ACM SIGGRAPH 2013.

[6] Mario Deuss and Daniele Panozzo and Emily Whiting and Yang Liu and Philippe Block and Olga Sorkine-Hornung and Mark Pauly: Assembling Self-Supporting Structures, ACM SIGGRAPH ASIA 2014.

[7] Daniele Panozzo and Olga Diamanti and Sylvain Paris and Marco Tarini and Evgeni Sorkine and Olga Sorkine-Hornung: Texture Mapping Real-World Objects with Hydrographics, EUROGRAPHICS Symposium on Geometry Processing 2015.