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RESEARCH ARTICLE

Restructuring surface tessellation with irregular boundary conditions

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Abstract
In this paper, the surface tessellation problem is explored, in particular, the task of meshing a surface with the added consideration of incorporating constructible building components. When a surface is tessellated into discrete counterparts, certain unexpected conditions usually occur at the boundary of the surface, in particular, when the surface is being trimmed. For example, irregularly shaped panels form at the trimmed edges. To reduce the number of irregular panels that may form during the tessellation process, this paper presents an algorithmic approach to restructuring the surface tessellation by investigating irregular boundary conditions. The objective of this approach is to provide an alternative way for freeform surface manifestation from a well-structured discrete model of the given surface.

1. Introduction

There is increasing interest in exploring complex freeform shapes in contemporary architectural and design practice. Frank Gehry (Lindsey, 2001) and Zaha Hadid (Jodidio, 2009) are prime examples of pioneering avant-garde designers who have incorporated freeform shapes into their designs. The development of manifesting freeform designs relies heavily on a core geometry, which is used from early conceptual form finding to final detailed building assembly. Among the various techniques for freeform shape construction, a NURBS (Non-Uniform Rational Basis Spline) surface is perhaps the most commonly exploited geometrical model (Piegl and Tiller, 1997). To manifest a NURBS surface, a discrete model, namely a mesh model, is employed. The meshing process generates an approximation of a given freeform geometry. In design practice, the modeling and subsequent, fabrication of an intriguing, sometimes intricate, freeform shapes requires an extension of the meshing process to include considerations of incorporating

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constructible building components. This is referred to as the surface tessellation problem, which is the subject matter of this paper. There is a close relationship and analogy between elements of a mesh and the components of a freeform design, for example, faces associate with panels, edges to structural frames, and so on.

1.1. Objective

The features of a given surface boundaries are essential for surface tessellation. For example, boundaries (also called edges) delineate the appearance of a freeform shape, and indicate where surface analysis starts and where it ends. Boundaries also identify whether a surface has been trimmed, that is, parts of the surface have been removed. Trimming can occur in the interior, or exterior of a surface. Figure 1 illustrates an original NURBS surface on the left and a trimmed surface, with both interior and exterior edges, in the middle. When tessellating a trimmed surface into its discrete counterparts, the irregularly shaped panels emerge at these trimming edges, as shown on the right of Figure 1. This is a commonly seen problem in NURBS-based freeform architectural designs as the simple iso-parameterization is not enough to resolve the potential irregularly shaped panels at these trimmed boundaries.

By exploring the surface boundary conditions for tessellation-based patterns, we present an algorithmic approach for generating boundary-driven meshes. Specifically, the quadrilateral mesh is used to exemplify the approach applied to the formation of the tessellation structure with irregular boundary conditions. Our objective is to present a general algorithmic solution to discretize freeform surfaces with regular pattern-based elements, and to develop strategies for solving constraints from irregular surface boundaries.

1.2. Background

In applying principles from computational geometry to the manifestation of freeform design there is emphasis placed on meshing arbitrary surfaces into discrete building components. Each component is procedurally constructed from a base polygonal pattern, typically, a triangle or quadrilateral (Wang, 2009).

There has been a shift from using triangles as the base pattern to approximate freeform shapes towards using quadrilateral patterns, which is gaining considerable interest in both constructive geometry theory as well as in architectural practice and research (Pottmann et al., 2007b). For reasons of physical construction, it is often preferable to convert a curvilinear surface into planar elements. There are published techniques for such conversions. For example, Pottmann et al. (2008) presents a fine-tuned approach to discretizing the freeform surface with planar quadrilateral elements. However, Pottmann's approach of initiating a representative mesh with merely quadrilateral faces may not always be possible, and often requires manual remodeling of the original surface. This reverse-engineering process relies heavily on the preparation of an initial coarse mesh and on how well this initial mesh represents the target shape (Pottmann et al., 2007a). Such an approach, in one sense, is less intuitive for designers to consider in the design process yet it could be very efficient given that the initial coarse mesh truly represents the ultimate shape.

An alternative approach presented by Cutler and Whiting (2007) looks at a re-meshing technique by iteratively clustering neighboring mesh elements and fitting them onto the closest planes. Their result demonstrates an algorithmic approach to post-restructuring an originally triangulated mesh into planar elements for architectural fabrication. The outcome of this approach is organic and formulated with arbitrary polygonal shapes. The bubble mesh (Shimada and Gossard, 1995) presents a physics-based algorithm to automate mesh generation by simulating bubble packing. The strength of this algorithm lies in its ability to control size, anisotropy and orientation of mesh formation. As this approach initiates the bubble packing from the existing boundaries, the generated result will be close to what will be described in this paper given that the entire boundary conditions are taken into the optimization process.

In brief, aforementioned approaches explore how the mesh elements could be structured by optimizing the constraints of interest, such as, pattern, planarity, sizing, etc. However, all these approaches currently do not provide the flexibility of intervention from users/designers to inform, or direct, how surface tessellation could be further improved to facilitate design exploration, in particular, at the early design conceptual phase. Given the seminal role of the surface boundaries during the tessellation process, most of the aforementioned algorithms emphasize on the automation of the mesh element generation and overlook the potential of incorporating boundary conditions for customizable surface tessellation.

The tessellation problem becomes even more challenging as the complexity of boundary conditions grows as does the

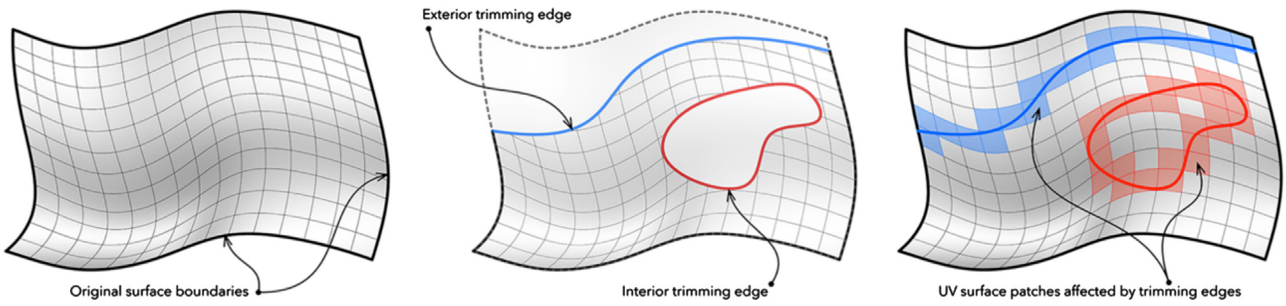

Figure 1 (Left) original NURBS surface (middle) trimmed NURBS surface (right) sub-surface patches affected by trimming edges.