Geodesic Patterns

for Freeform Architecture

Alan Rynne

September 2018

UPC - MPDA'18

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Master's degree
Parametric Design in Architecture

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Objective

Discretize a given freeform surface into panels with the following properties:

1. Panels must be ***developable*** (Shelden 2002)
2. Panels should be of approximate ***equal width***
3. Panels should be ***as straight as possible***
4. Panels should ***bend by their weak axis*** to approximate the surface.

Background

The use of *straight developable planks* is widely used in:

Figure 1: Traditional boat building

Also common practice in naval engineering industry:

Figure 2: Connected developable patches for boat hull design

Frank Ghery

This techniques have also been used in the architecture world, mainly by **Frank Ghery**.

His façades are usually a collection of connected developable surfaces.

Latest architectural work following this techniques was:

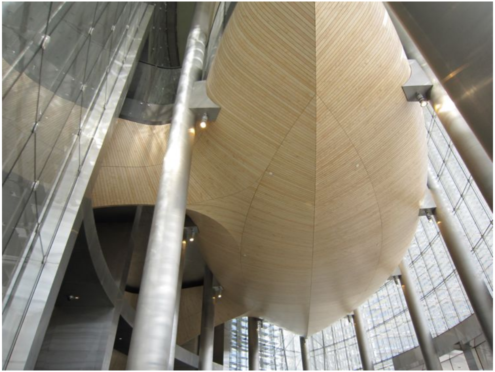


Figure 3: Burj Khalifa by Frank Ghery

It was designed as a collection of:

- **Developable surfaces**
  - *Which can be covered by equal width planks*
- **Surfaces of constant curvature**
  - *Which can be covered by repeating the same profile*

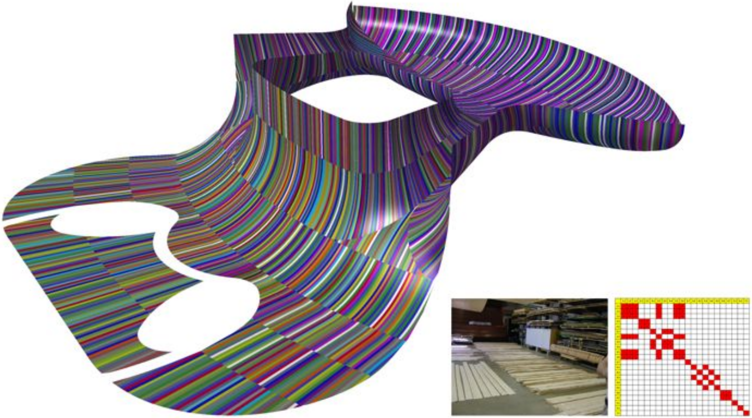


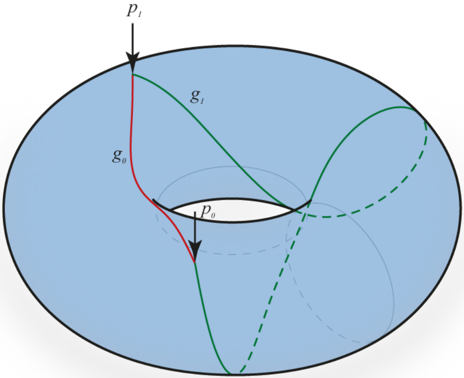
Figure 4: Burj Khalifa final panel solution

Construction technique

Geodesic curves

A geodesic curve is the generalization of a *straight line* into *curved spaces*.

In this research, we concentrate on the concept of ***straightest geodesics***.



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Developable surfaces

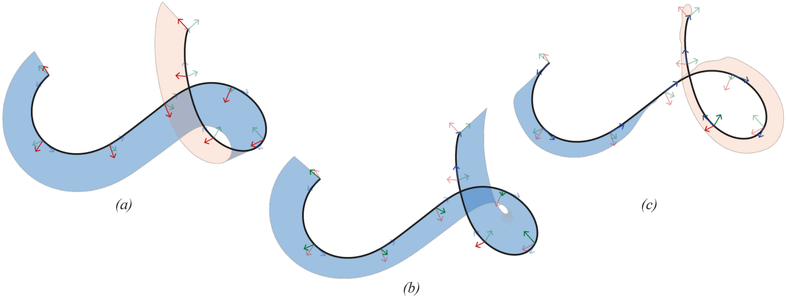

Figure 6: Surfaces with ***0 gaussian curvature***. Meaning, they can be flattened onto a plane ***without distortion***

Developable surfaces

- surfaces that can be flattened.
- can be generated by a single curve.

Geodesic curves

- are straight lines in a curved space.

If Panels are generated using geodesic curves on the surface
Then Resulting panels will be ***developable*** and mostly ***straight*** when flat.

In other words

We wish to cover a given freeform surface with a pattern of **geodesic curves** with equal spacing.

This can only be achieved if the provided surface is already *developable*.

A compromise exists between the *curve spacing* and the *curves geodesic property*

Algorithmic strategies

Obtaining Geodesic Patterns

These are the main methods for the obtaining successful geodesic patterns:

1. The ***parallel transport*** method
2. The ***evolution*** method
   2.1 The ***piecewise geodesic*** evolution method
3. The ***level-set*** method

The parallel transport method

Vector parallel transport

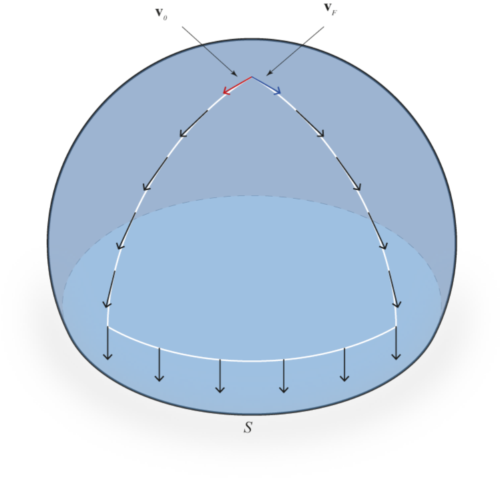

Figure 7: Parallel transport of a vector over a path on a sphere

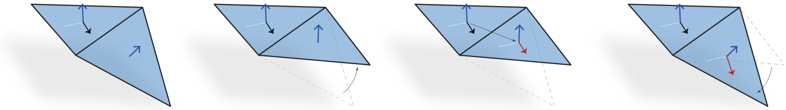

Figure 8: Parallel transport over two adjacent mesh faces

P.T. Implementation

Input: A surface Φ, represented as a triangular mesh (V,E,F), a specified distance W, a threshold ϵ and a maximum number of iterations.

Output: Set g of geodesic curves of approximate equal distance, $g_i, \quad where \quad i = 0, ..., M$

1: Place a geodesic curve g_0 along S such that it traverses across the whole surface.
2: **return** The geodesic pattern G of all g_i's.

There are **three** *extreme* cases depending on the ***local gaussian curvature*** where g lies on Φ:

Positive curvature Panels will have **Maximum width** on g
Negative curvature Panels will have **Minimum width** on g
0 gaussian curvature: Panels will be of equal width

P.T. Example

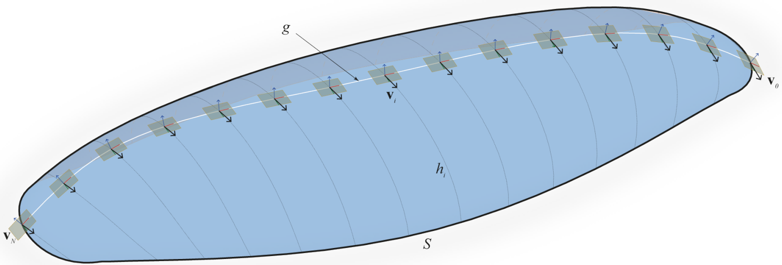

Figure 9: Parallel transport method over a positive curvature surface

P.T. Results

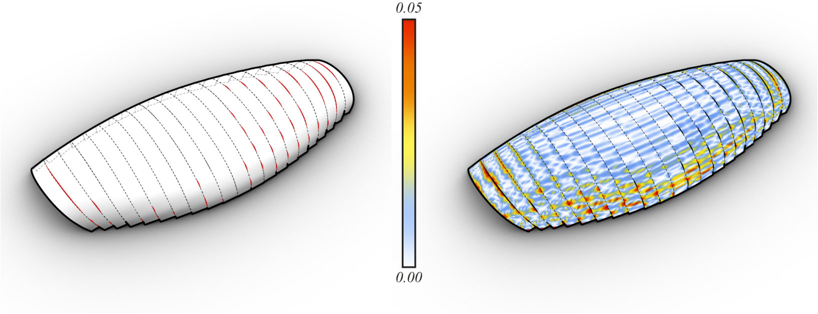

Figure 10: TNB generated panels & distance to original mesh

The Evolution Method

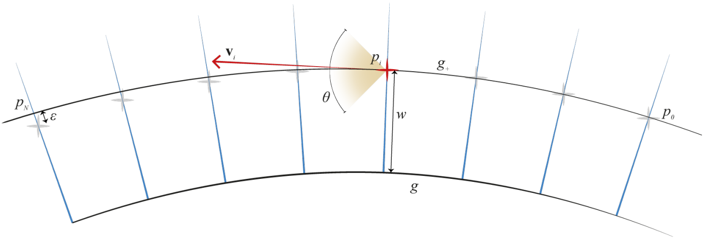

Figure 11: Calculating the best-fit geodesic

Evolution Implementation

Input: A surface Φ, represented as a triangular mesh (V,E,F)
Output: Set of geodesic curves $g_i, \quad where \quad i = 0, ..., M$

Place a geodesic curve g_x along S such that it divides the surface completely in 2.
Divide the curve into N equally spaced points p with distance W.
Place an vector $\mathbf{v}$ onto p_0
Parallel transport that vector along g_x as described in [@fig:parTransProc].
for all points p_i where i = 0,...,M **do**
    Generate geodesic curve $+g_i$ and $-g_i$ using vector $\mathbf{v}_i$ and $-\mathbf{v}_i$ respectively.
    Join $+g_i$ and $-g_i$ together to obtain g_i
    Add g_i to output.
end for

Evolution Method Results

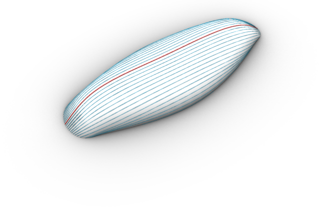

Figure 12: Evolution method example

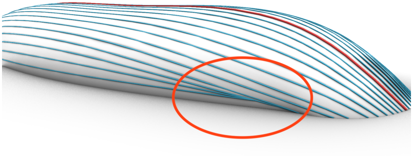

Figure 13: Evolution method problems

Local changes in curvature produce:

- Sharp panel endings in positive curvature areas
- Panel width increase in negative curvature areas

The Piecewise Evolution Method

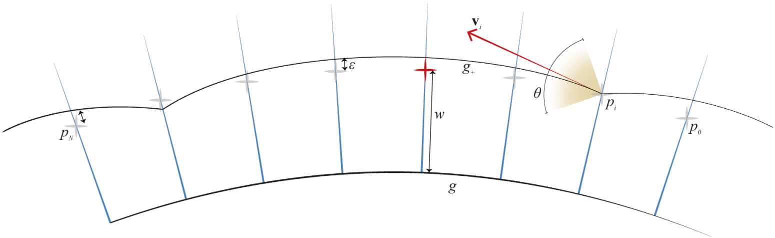

Figure 14: Calculating the best piece-wise geodesic

Piecewise Ev. Implementation

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Piecewise Ev. Results

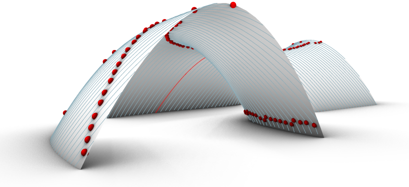

Figure 15: Piecewise Test

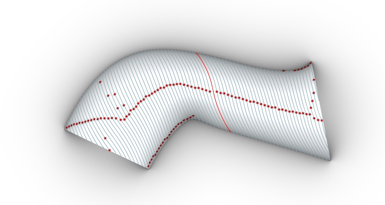

Figure 16: Piecewise Test

The level set method

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Mesh Level-sets

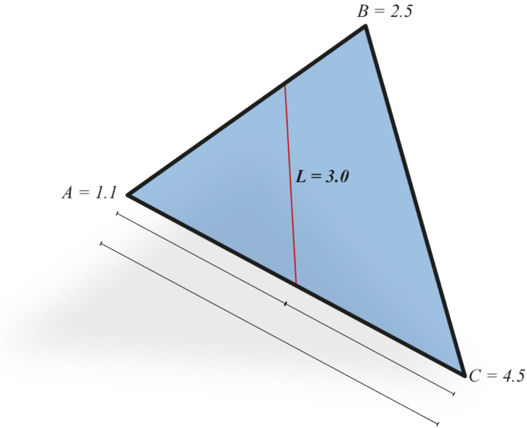

Figure 17: Level set on a single mesh face

Level-set Implementation

INSERT ALGORITHM HERE

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Results

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Modeling planks

Tangent developable method

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Bi-Normal method

Comparison

Optimization

Piecewise geodesic vector-fields

Developability of triangle meshes

MISSING K.CRANE'S IMPLEMENTATION IMAGES!

Analysis

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Gaps in panelization

???

Stress in panels

???

Conclusion

Thanks[1]

[1] Special thanks to . . . FILL IN LATER!

Appendix

Resources

PUT LINKS TO GH COMPONENTS HERE + OTHER NICE SOFTWARE!

References i

Shelden, Dennis Robert. 2002. "Digital Surface Representation and the Constructibility of Gehry's Architecture." PhD thesis, Massachusetts Institute of Technology. http://hdl.handle.net/1721.1/16899.