Geodesic Patterns

for Freeform Architecture

Alan Rynne

September 2018

UPC - MPDA'18

MPDA
Master's degree
Parametric Design in Architecture

UNIVERSITAT POLITÈCNICA DE CATALUNYA
BARCELONATECH
School of Professional & Executive Development

Index

MPDA
Master's degree
Parametric Design in Architecture

UNIVERSITAT POLITÈCNICA DE CATALUNYA
BARCELONATECH
School of Professional & Executive Development

Objective

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

1. Must be ***developable*** (Shelden 2002)
2. Should tend to have approximate ***equal width***
3. Should be ***as straight as possible***
4. Cannot bend by their strong axis but,
5. can have a twist and bend by their weak axis

Plank A plank is timber that is flat, elongated, and rectangular with parallel faces that are higher and longer than wide. (Wikipedia)

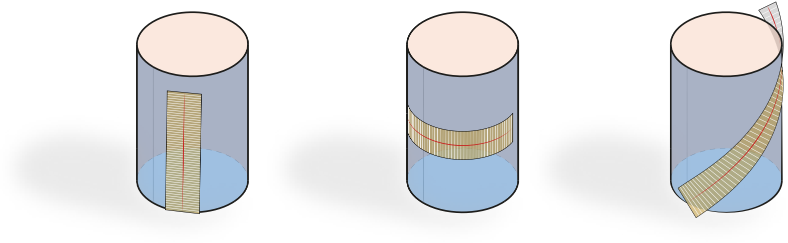


Figure 1: A straight plank laying on a cylinder on different directions.

Background

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

Figure 2: Traditional boat building

Also common practice in naval engineering industry:

Figure 3: 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:

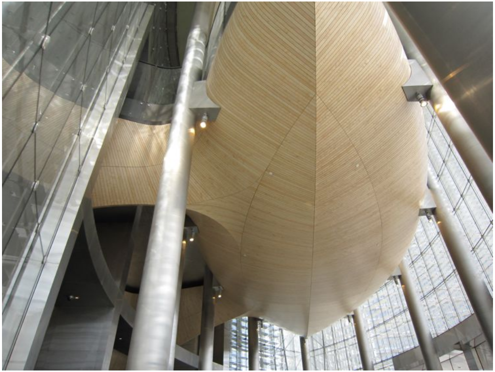


Figure 4: Burj Khalifa by Frank Ghery

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*

MPDA
Master's degree
Parametric Design in Architecture

UNIVERSITAT POLITÈCNICA DE CATALUNYA
BARCELONATECH
School of Professional & Executive Development

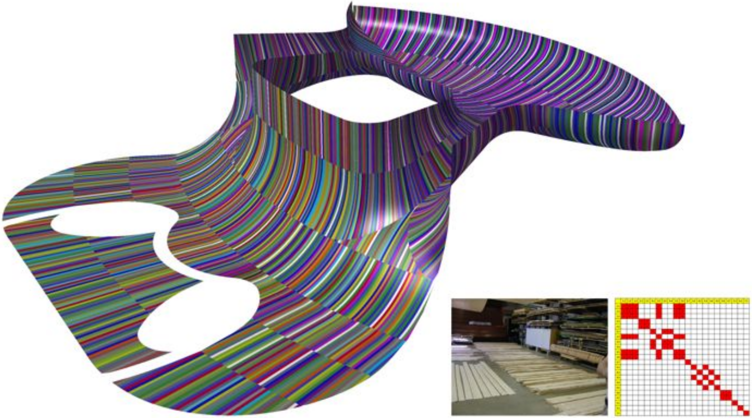


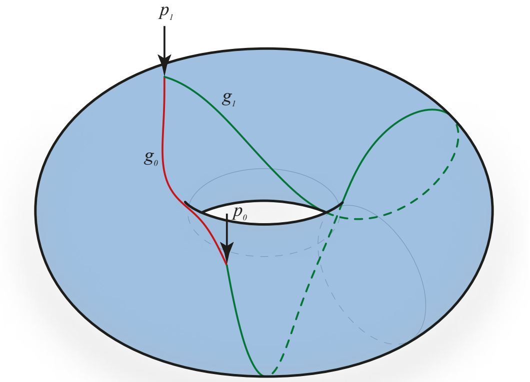
Figure 5: Burj Khalifa final panel solution

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***.



Developable surfaces

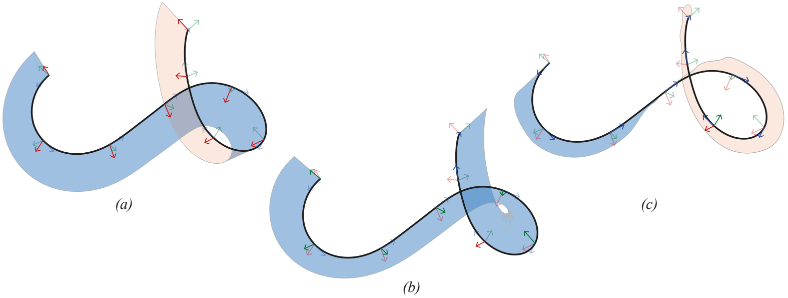


Figure 7: Surfaces with ***0 gaussian curvature***. Meaning, they can be flattened onto a plane ***without distortion***

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.

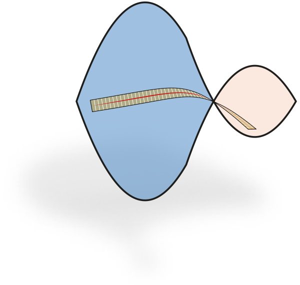


Figure 8: A straight plank laying on a hyperbolic paraboloid

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

MPDA
Master's degree
Parametric Design in Architecture

UNIVERSITAT POLITÈCNICA DE CATALUNYA
BARCELONATECH
School of Professional & Executive Development

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

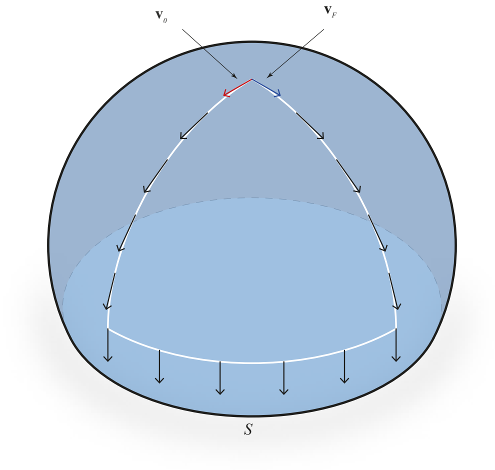


Figure 9: Parallel transport of a vector over a path on a sphere

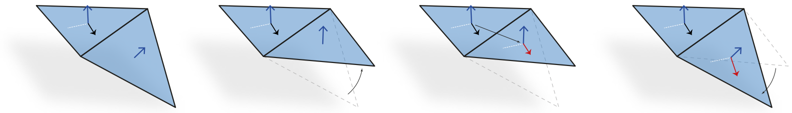


Figure 10: Parallel transport over two adjacent mesh faces

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

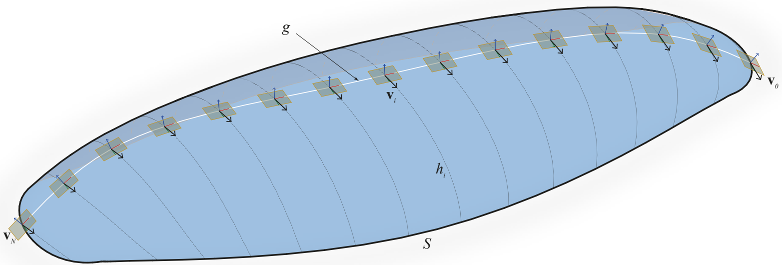


Figure 11: Parallel transport method over a positive curvature surface

P.T. Results

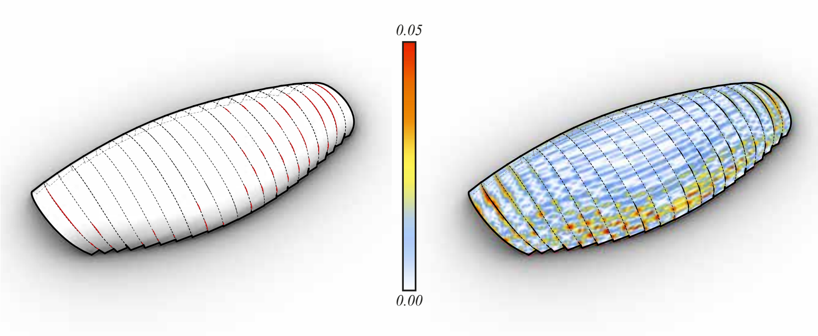


Figure 12: TNB generated panels & distance to original mesh

The Evolution Method

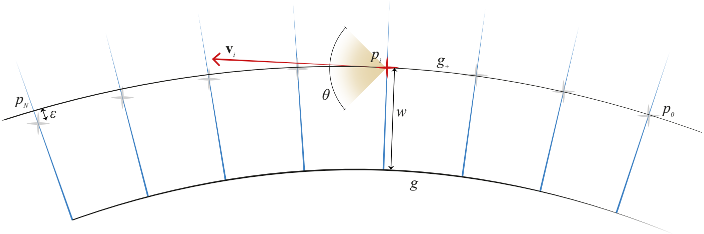


Figure 13: Calculating the best-fit geodesic

Evolution Implementation

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

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

Evolution Method Results

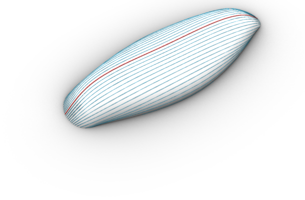


Figure 14: Evolution method example

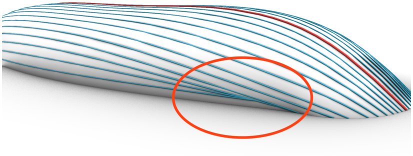


Figure 15: Evolution method problems

Local changes in curvature produce:

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

The Piecewise Evolution Method

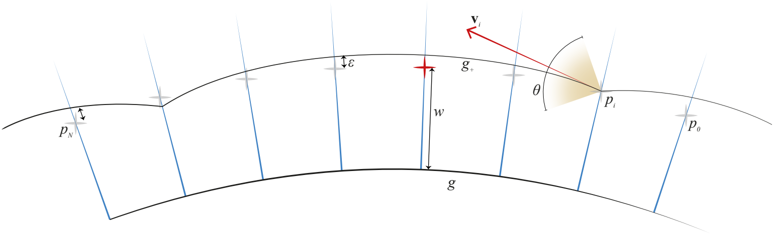


Figure 16: Calculating the best piece-wise geodesic

Piecewise Ev. Implementation

INSERT ALGORITHM HERE

Piecewise Ev. Results

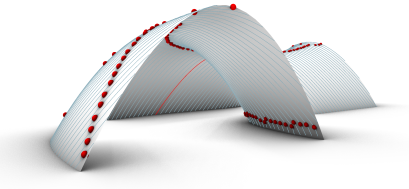


Figure 17: Piecewise Test

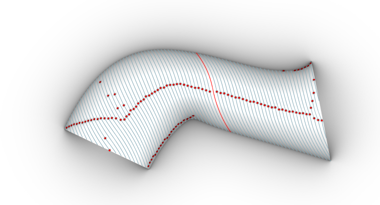


Figure 18: Piecewise Test

The level set method

Mesh Level-sets

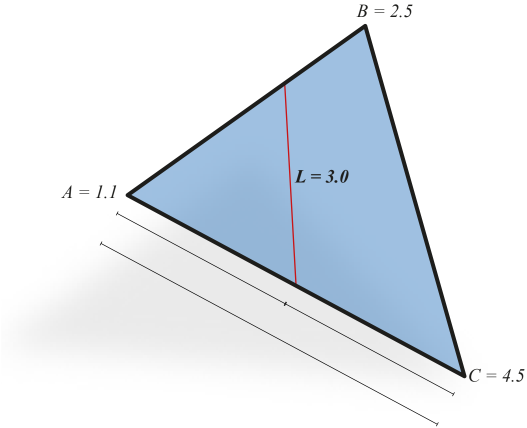


Figure 19: Level set on a single mesh face

MPDA
Master's degree
Parametric Design in Architecture

UNIVERSITAT POLITÈCNICA DE CATALUNYA
BARCELONATECH
School of Professional & Executive Development

Level-set Implementation

INSERT ALGORITHM HERE

Results

MISSING TEXT

MISSING IMAGE

Modeling planks

Tangent developable method

Bi-Normal method

Comparison

Optimization

Piecewise geodesic vector-fields

Developability of triangle meshes

MISSING K.CRANE'S IMPLEMENTATION IMAGES!

Analysis

Gaps in panelization

???

Stress in panels

???

MPDA
Master's degree
Parametric Design in Architecture

UNIVERSITAT POLITÈCNICA DE CATALUNYA
BARCELONATECH
School of Professional & Executive Development

Conclusion

Thanks[1]

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

Appendix

MPDA
Master's degree
Parametric Design in Architecture

UNIVERSITAT POLITÈCNICA DE CATALUNYA
BARCELONATECH
School of Professional & Executive Development

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.

MPDA
Master's degree
Parametric Design in Architecture

UNIVERSITAT POLITÈCNICA DE CATALUNYA
BARCELONATECH
School of Professional & Executive Development