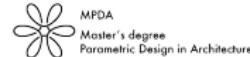


Geodesic Patterns

for Freeform Architecture

Alan Rynne
September 2018

UPC - MPDA'18



Index

1. Objective
2. Background
3. Construction technique
4. Algorithmic strategies
5. Shape optimization
6. Analysis
7. Conclusion

Objective

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

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

Background

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

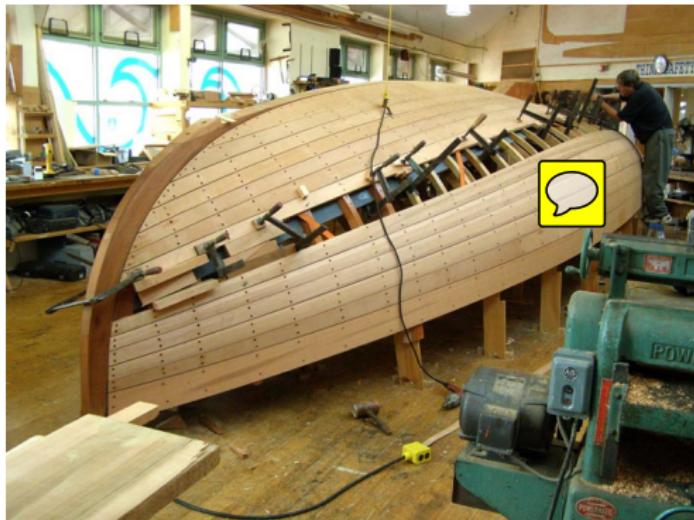


Figure 1: Traditional boat building

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:

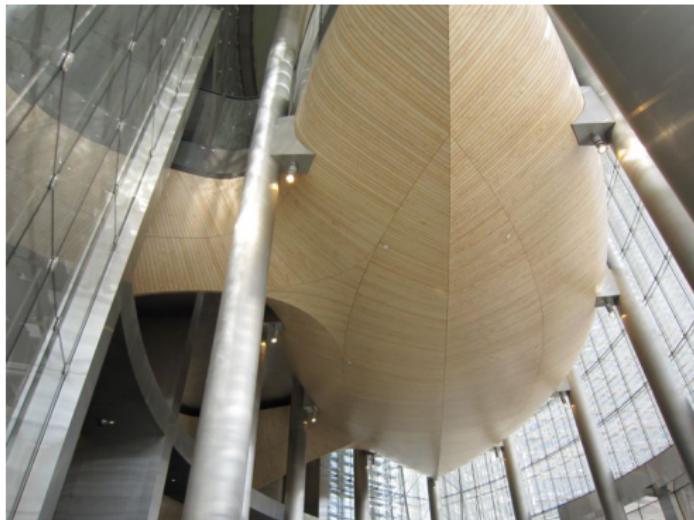


Figure 3: Burj Khalifa by Frank Ghery

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



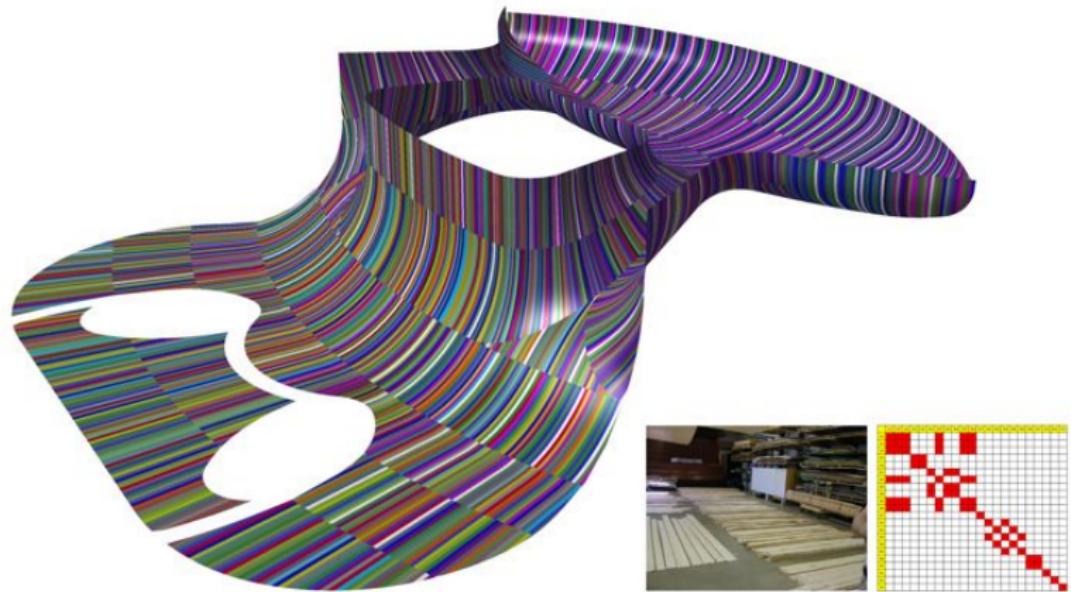
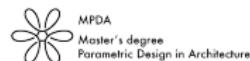


Figure 4: Burj Khalifa final panel solution



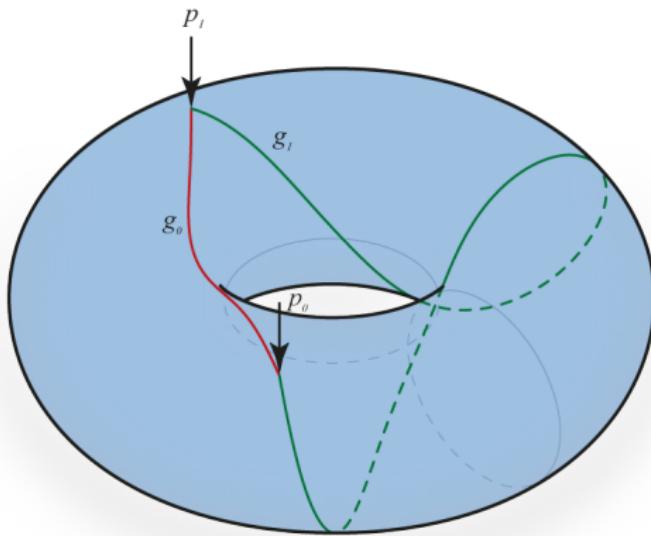
Construction technique



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***.



Developable surfaces

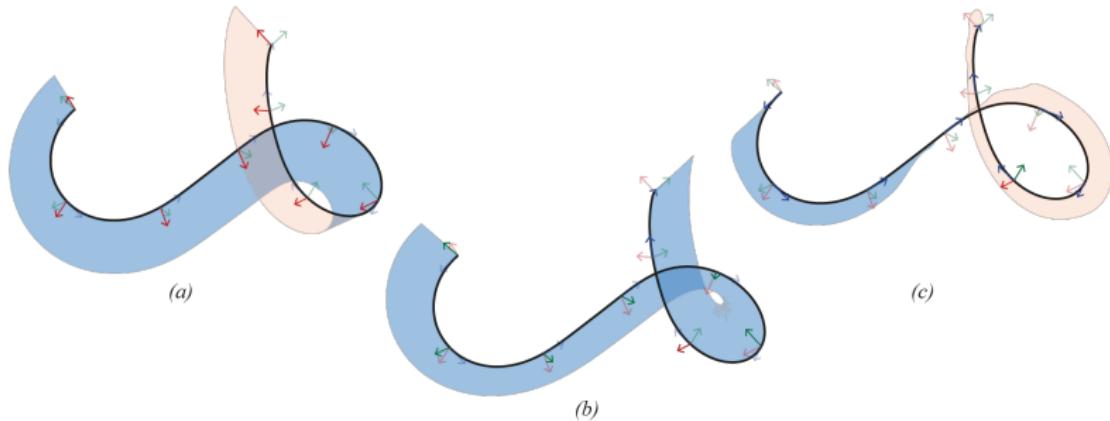


Figure 6: Surfaces with *0 gaussian curvature*. Meaning, they can be flattened onto a plane *without distortion*



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 *curvature* of the geodesic properties.



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

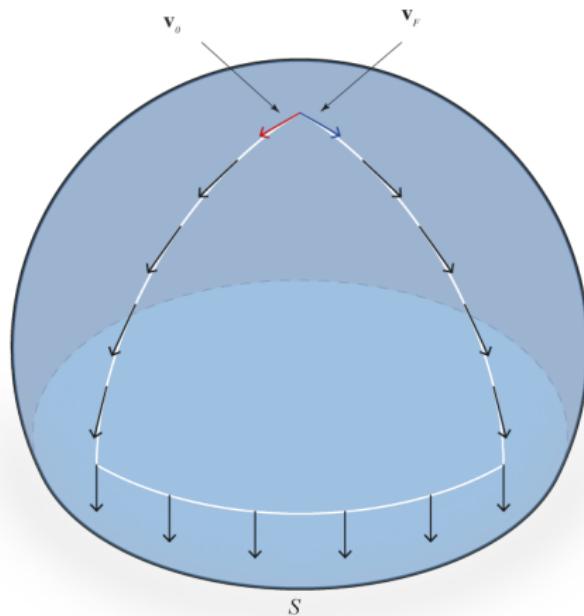


Figure 7: Parallel transport of a vector over a path on a sphere

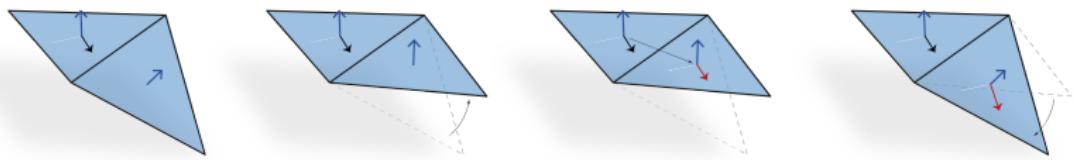


Figure 8: Parallel transport over two adjacent mesh faces

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 , where $i = 0, \dots, M$

- 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

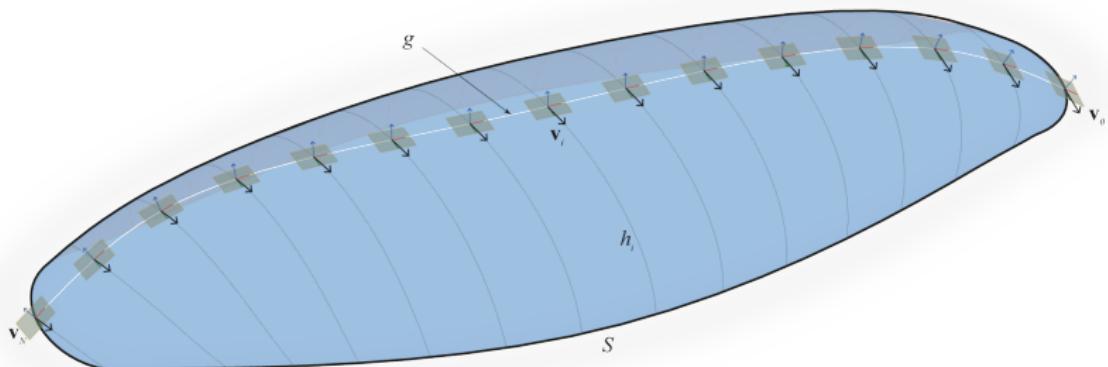


Figure 9: Parallel transport method over a positive curvature surface

P.T. Results

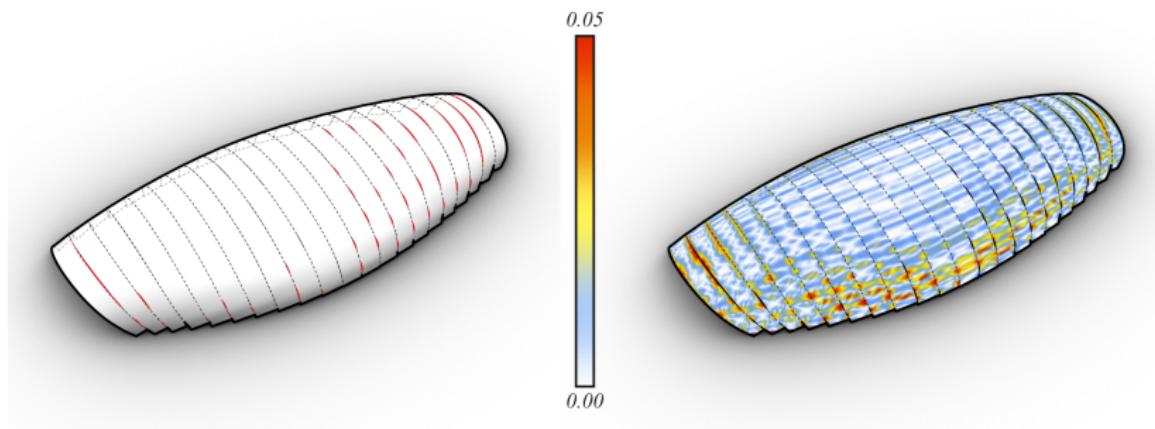


Figure 10: TNB generated panels & distance to original mesh



The Evolution Method



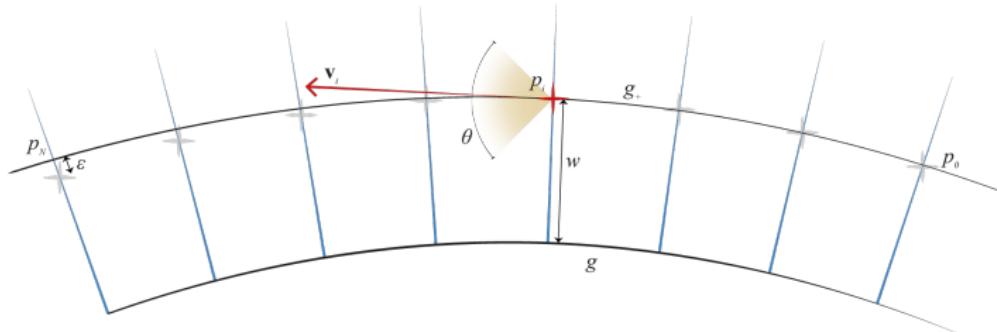


Figure 11: Calculating the best-fit geodesic

Evolution Implementation



Input: A surface Φ , represented as a triangular mesh (V, E, F)

Output: Set of geodesic curves g_i , where $i = 0, \dots, M$

- 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 a 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 $i = 0, \dots, M$ **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

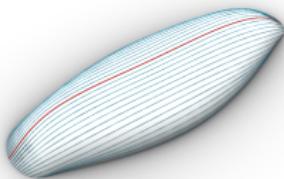


Figure 12: Evolution method example

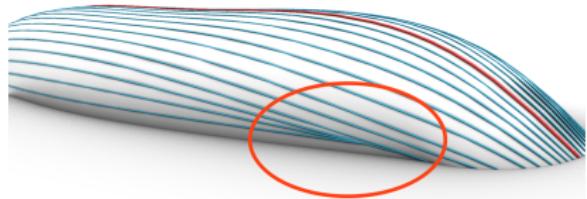
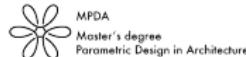


Figure 13: Evolution method problems

Local changes in curvature produce:

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

The Piecewise Evolution Method



MPDA

Master's degree

Parametric Design in Architecture



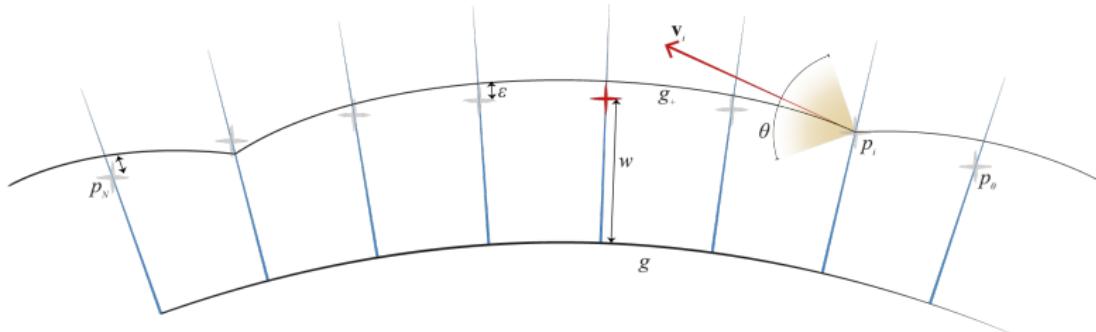


Figure 14: Calculating the best piece-wise geodesic

Piecewise Ev. Implementation

INSERT ALGORITHM HERE

Piecewise Ev. Results

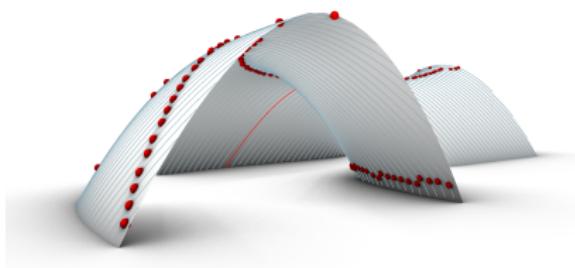


Figure 15: Piecewise Test

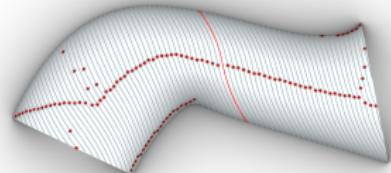


Figure 16: Piecewise Test

The level set method

Mesh Level-sets

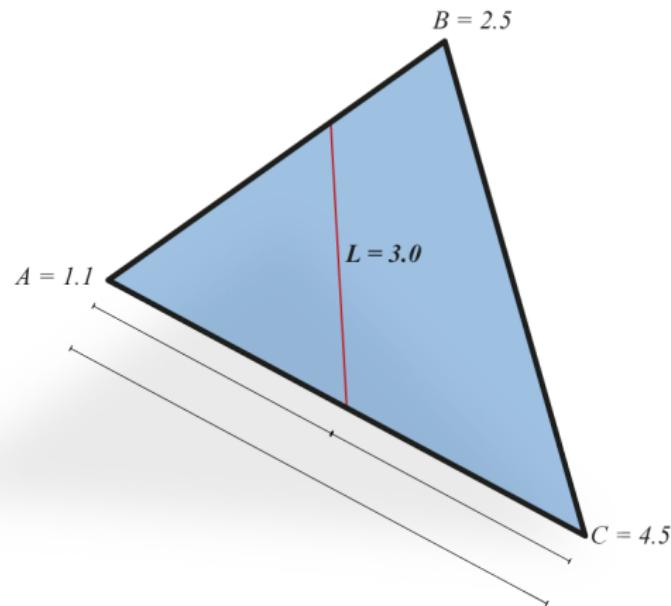


Figure 17: Level set on a  mesh face.



MPDA

Modelling and Design
Parametric Design in Architecture



UNIVERSITAT POLITÈCNICA DE CATALUNYA
BARCELONATECH
School of Professional & Executive Development

Level-set Implementation

INSERT ALGORITHM HERE

Results

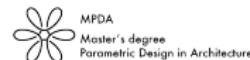
MISSING TEXT

MISSING IMAGE

Modeling planks



Tangent developable method



MPDA

Master's degree

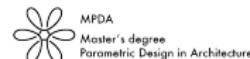
Parametric Design in Architecture



UNIVERSITAT POLITÈCNICA DE CATALUNYA
BARCELONATECH

School of Professional & Executive Development

Bi-Normal method



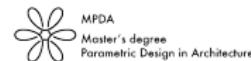
MPDA

Master's degree

Parametric Design in Architecture



Comparison



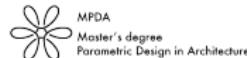
MPDA

Master's degree

Parametric Design in Architecture



Optimization



MPDA

Master's degree

Parametric Design in Architecture



UNIVERSITAT POLITÈCNICA DE CATALUNYA
BARCELONATECH
School of Professional & Executive Development

Piecewise geodesic vector-fields



MPDA

Master's degree

Parametric Design in Architecture



Developability of triangle meshes

MISSING K.CRANE'S IMPLEMENTATION IMAGES!



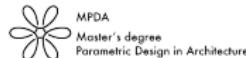
MPDA

Master's degree

Parametric Design in Architecture



Analysis



Gaps in panelization

???

Stress in panels

???

Conclusion

Thanks¹

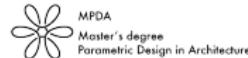
¹Special thanks to ... FILL IN LATER!



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>.