

Engineering a new architecture through barycentric element based topology optimization

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Research Objectives

- To apply topology optimization to the field of structural engineering through high-rise building design
- Utilize manufacturing and layout constraints to make results more meaningful
- Address the importance of achieving a balance between engineering and architecture for efficient, sustainable design

Introduction: Engineering and Architecture

- Historical examples of structures by architects with strong and innovative engineering concepts

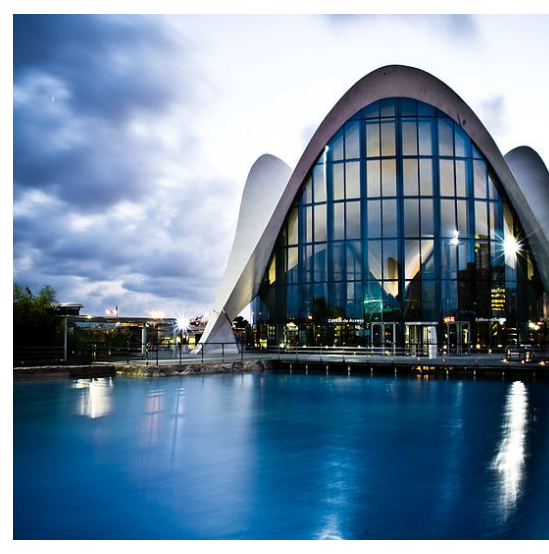


Antonio Gaudi¹

[1-3] Multiple websites



Buckminster Fuller²



Felix Candela³

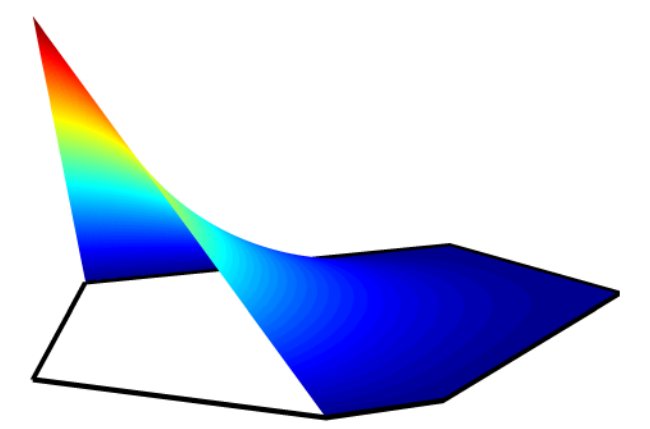
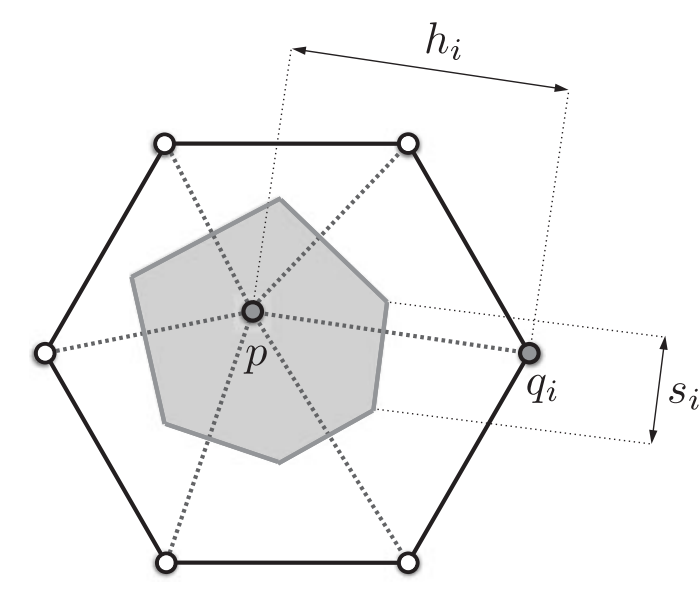
- Goal: overcome dichotomy between architectural aesthetics and engineering efficiency using topology optimization

Polygonal Finite Elements

Laplace shape functions using natural neighbors:

$$\phi_i(\mathbf{x}) = \frac{w_i(\mathbf{x})}{\sum_{j \in \mathcal{J}} w_j(\mathbf{x})}$$

$$w_i(\mathbf{x}) = \frac{s_i(\mathbf{x})}{h_i(\mathbf{x})}$$



Polygonal shape function

C. Talisch, G. H. Paulino, A. Pereira, and I. F. M. Menezes. "Polygonal finite elements for topology optimization: A unifying paradigm." *UNME*. Vol 82, No. 6, pp. 671-698, 2010.

Basic Topology Optimization Framework

- Optimal design problem:

$$\min_{\mathbf{d}} f(\mathbf{d}, \mathbf{u})$$

$$s.t. \quad g_i(\mathbf{d}, \mathbf{u}) = 0 \quad \text{for } i = 1, \dots, k$$

- Example: Minimum Compliance

$$\min_{\mathbf{d}} f(\mathbf{d}, \mathbf{u}) = \mathbf{p}^T \mathbf{u}$$

$$s.t. \quad g_1(\mathbf{d}, \mathbf{u}) = \mathbf{K}(\mathbf{d}) \mathbf{u} - \mathbf{p}$$

$$g_2(\mathbf{d}) = V(\mathbf{d}) - \bar{V}$$

- Other Criteria:

- Eigenmodes

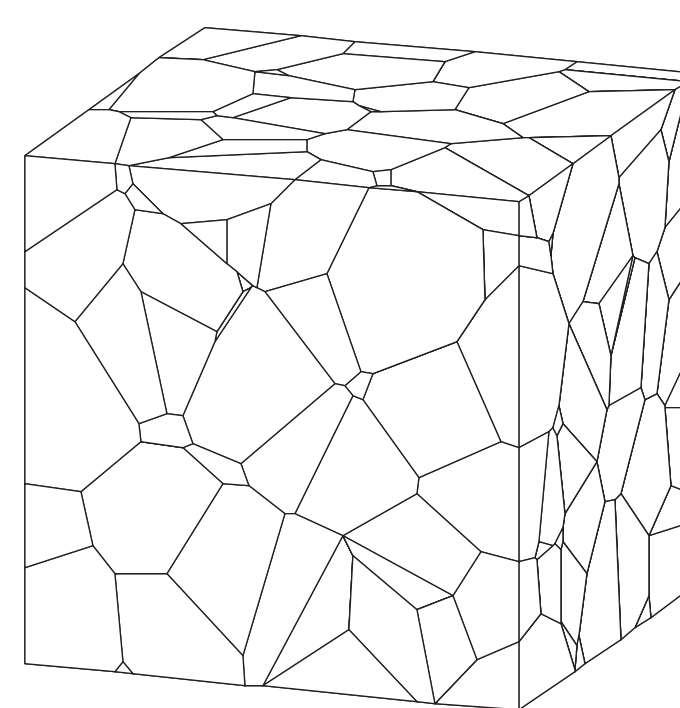
- Deflection (P-Δ)

- Buckling load

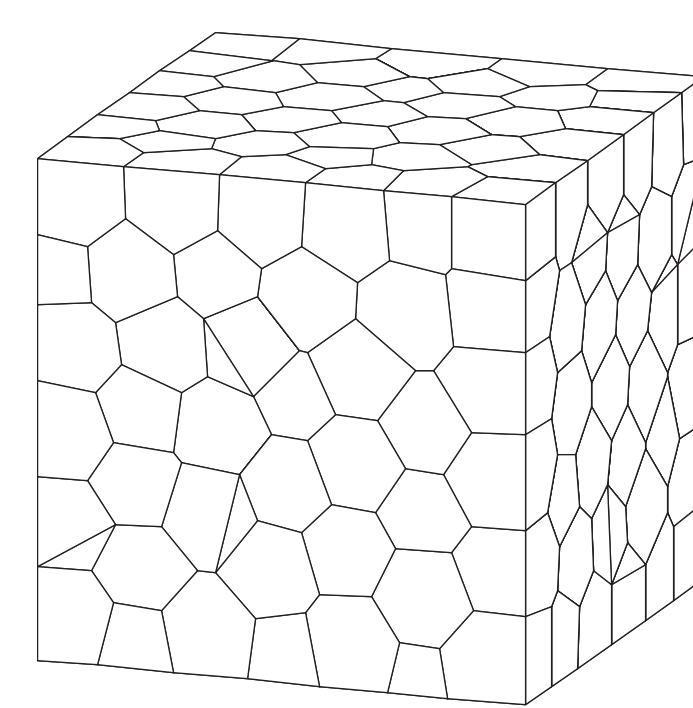
- Natural frequency

Application of Barycentric Elements: Polygonal Meshes for Design

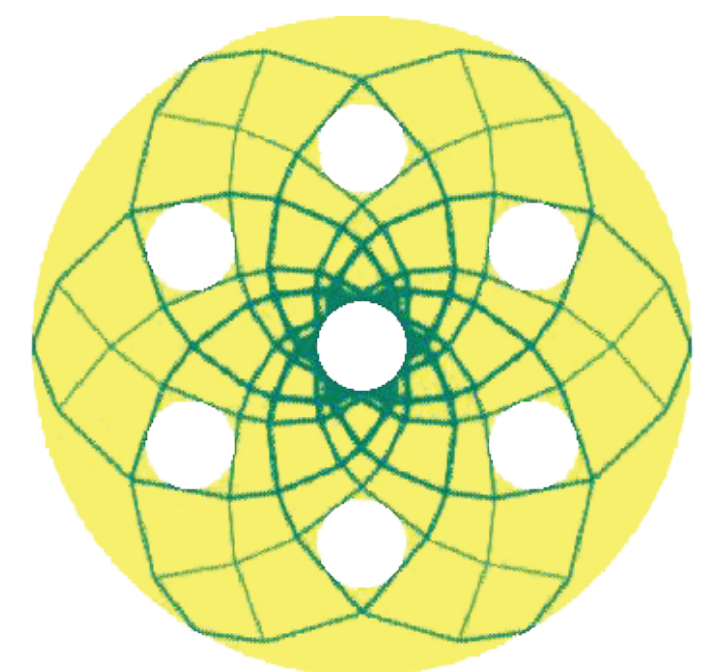
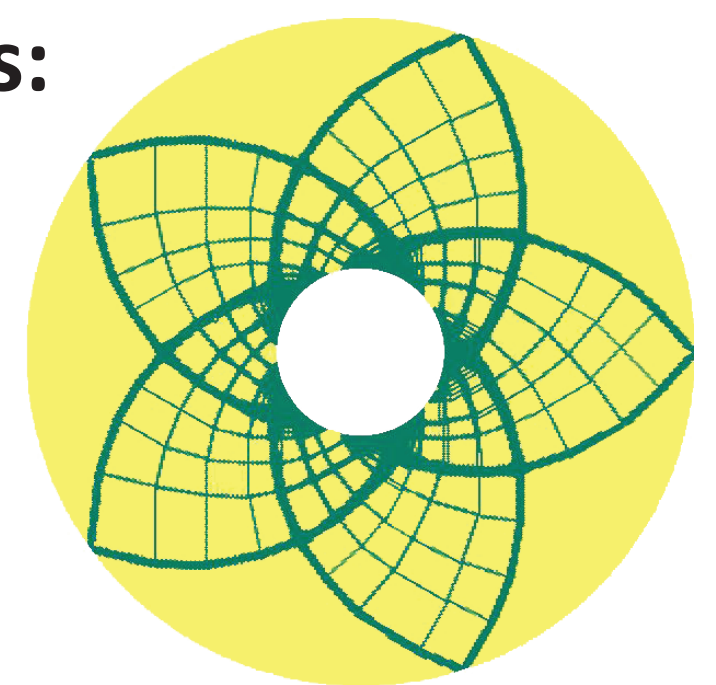
3D Voronoi mesh (CVT):



Initial Voronoi Mesh

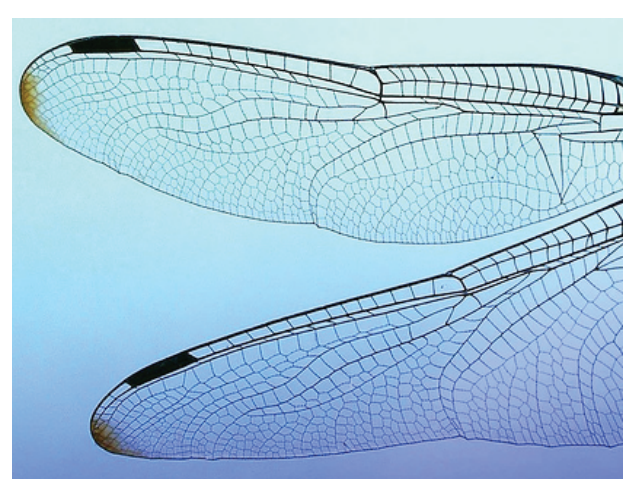
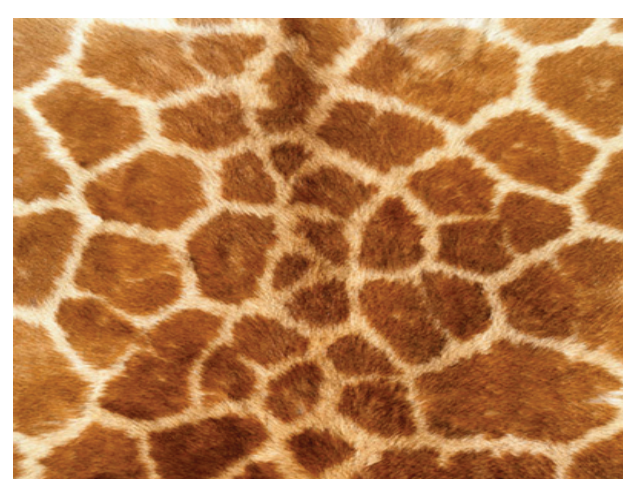
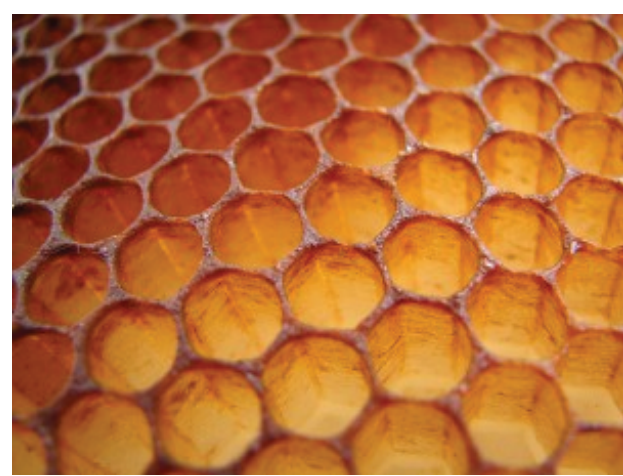


After Lloyd's Algorithm

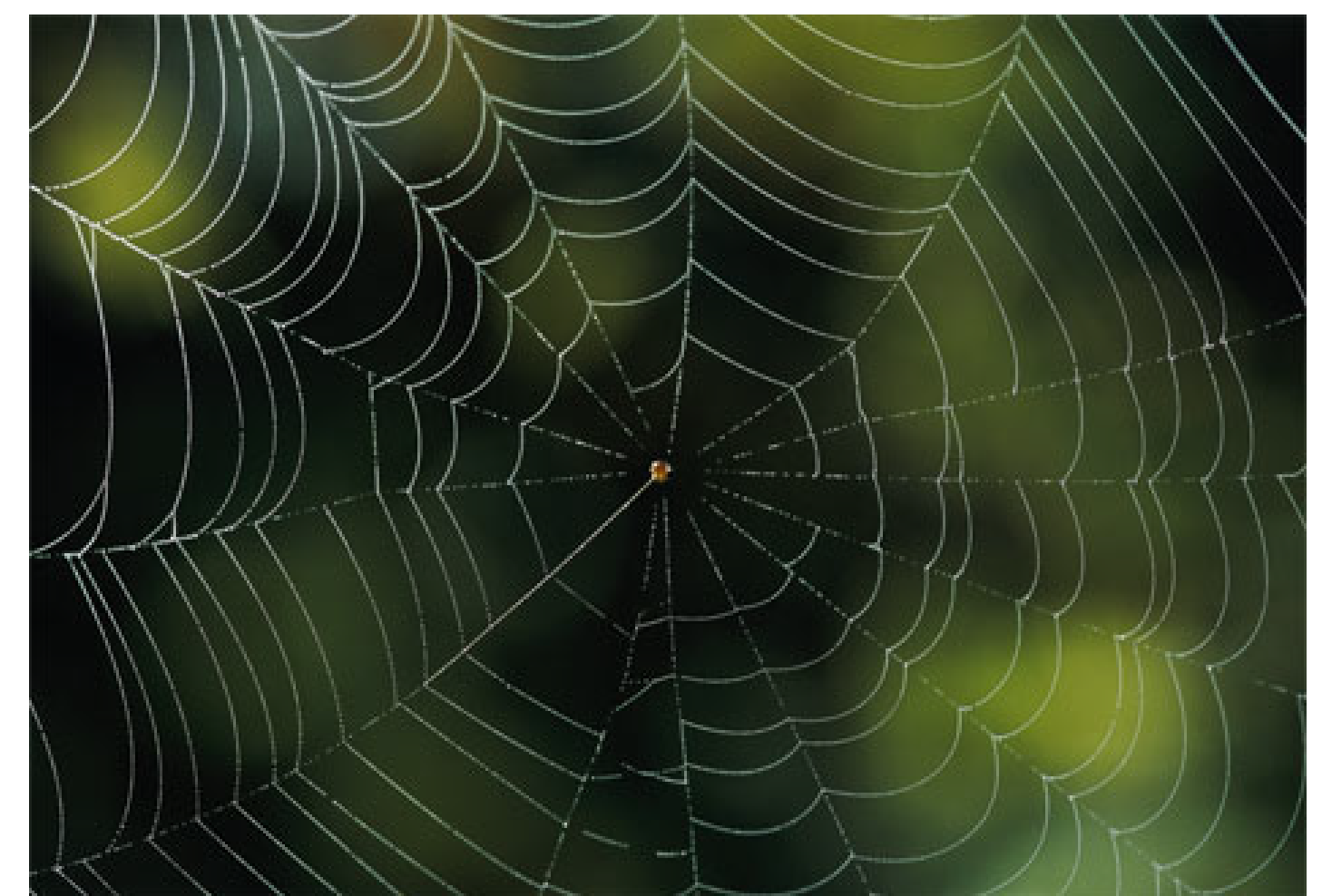


Bio-Inspired Design: Zendai Competition (China)

Polygonal elements in nature:



Picture of physical model using topology optimization results (courtesy of SOM) and resemblance to spider webs



Conclusions

Topology optimization using barycentric-elements can be a valuable tool to bridge the gap between engineering and architecture in the design industry. Moreover, resulting designs will be more efficient and sustainable, by optimizing the material consumption.

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References

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