Designing Volumetric Truss Structures for Computational Fabrication

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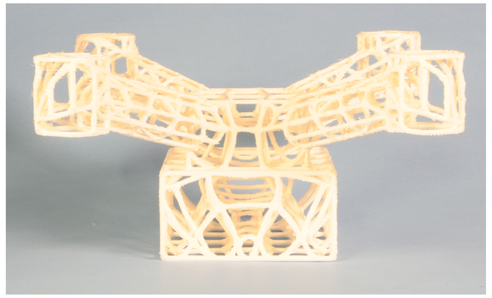
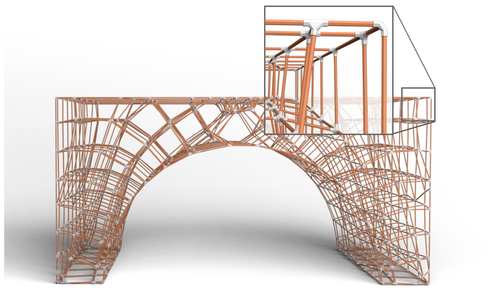
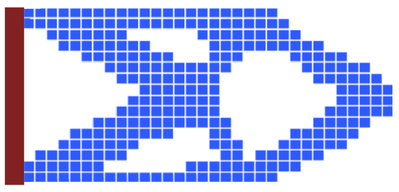
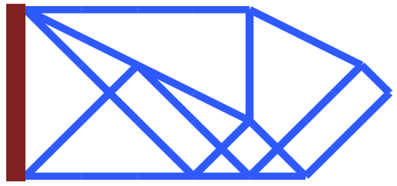
Problem Statement

Building structures that are not just strong and lightweight, but also amenable to user control.



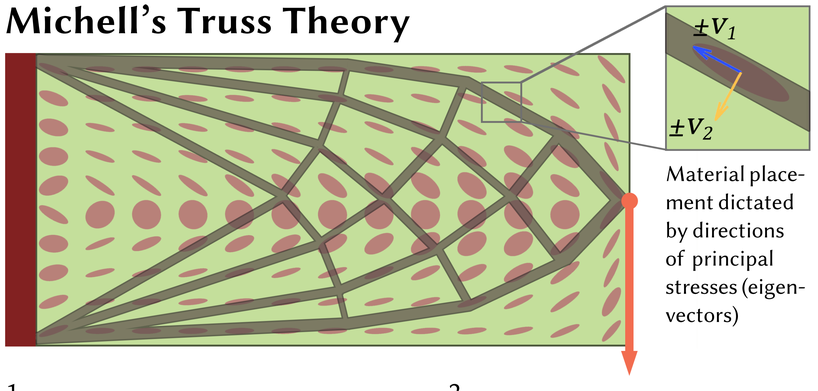



Existing Methods

Existing topology optimized structures are hard to control

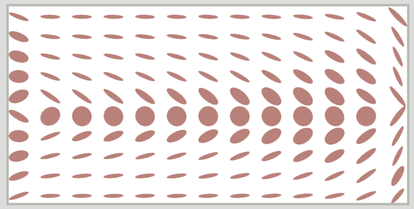
Michell's Truss Theory



Material placement dictated by directions of principal stresses (eigenvectors)

Problem Description

Input mesh (2D or 3D) with boundary conditions



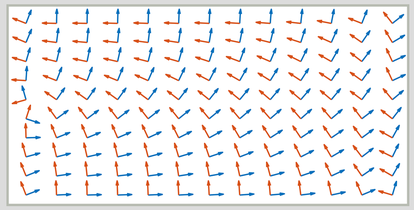
Stress Field

Finite Element Analysis to solve for stress tensor field

Aligning a frame field with the stress field:

$$\sigma^i = Q^i \Lambda^i (Q^i)^{-1} \qquad S^i = Q^i (\Lambda^i)^{1/2}$$

$$\min_{\mathbf{r}} \ \|\mathbf{r}_2^T S^i \mathbf{r}_2\|_F + \|\mathbf{r}_3^T S^i \mathbf{r}_3\|_F + E_{smooth}$$

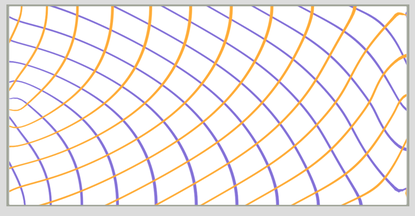


Smooth Frame Field

Iterative optimization to obtain a smooth frame field

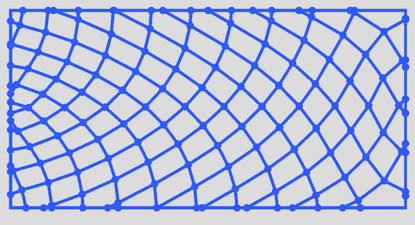
Texture gradient aligned with frame field:

$$\mathbf{G}_i = G(\mathbf{r_i}) \qquad \frac{\partial \phi}{\partial \mathbf{x}} \mathbf{r_i} = \mathbf{e}_i \quad \forall i \in \{1,2,3\}$$



Parametrization

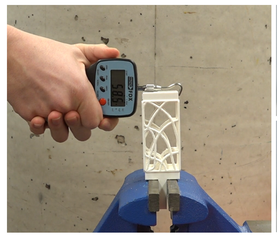
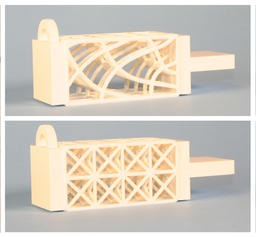
Quadratic program to get texture parametrization



Truss Layout

Tracing parameter isolines to get truss graph layout

Mechanical Testing

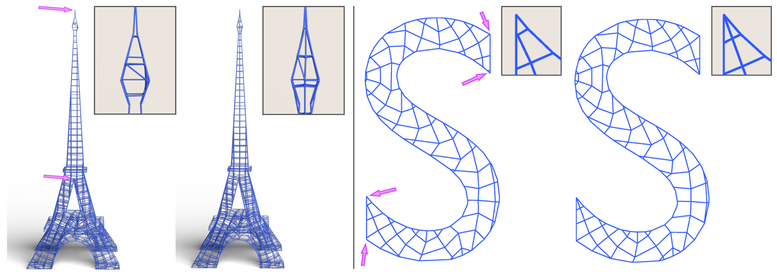



The optimized structure tolerates a 35% higher force

Efficient Density/Thickness Control

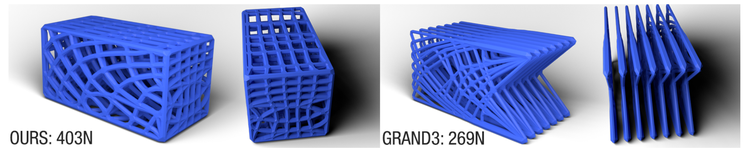

Easy to customize for different fabrication technologies

Truss Node Snapping



Snapping to corners for improved visual quality

Comparison with Existing Methods



GRAND3 structure lacks cross-beams; fails in real-world

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