

Bridging Topology Optimization and Additive Manufacturing

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EMI 2016

Engineering Mechanics Institute Conference 2016

PMC 2016

Probabilistic Mechanics & Reliability Conference 2016

Outline

- **Density-based T.O. with SIMP for Additive Manufacturing**
 - Comments on filtering
 - Comments on penalization
- **Applied (large scale) example**
- **Lessons learned & ideas for the future**

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Density-based Topology Optimization

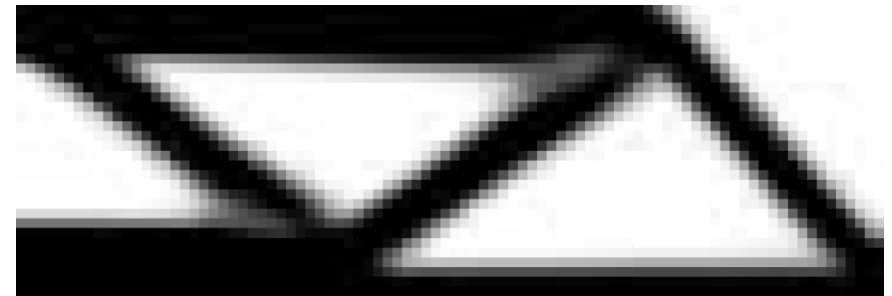
□ Filters in density-based formulation:

- Sensitivity filter (1-field)
- Density filter (2-fields) —————
- Projection filter (3-fields)

USED IN THIS
WORK



UNFILTERED
(CHECKERBOARD)



FILTERED

Review on filtering:

Sigmund O, Maute K (2013) "Topology optimization approaches." Structural and Multidisciplinary Optimization 48(6):1031-1055

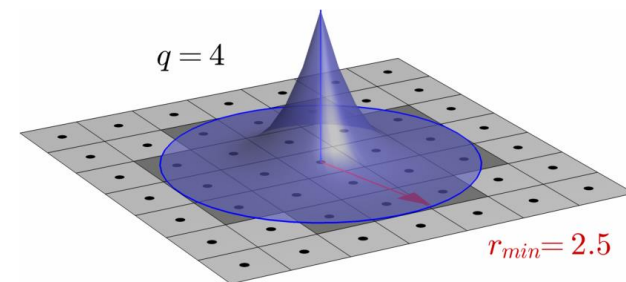
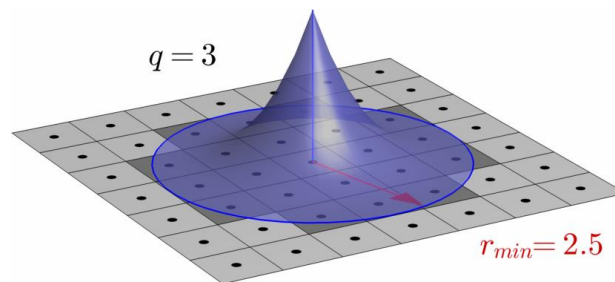
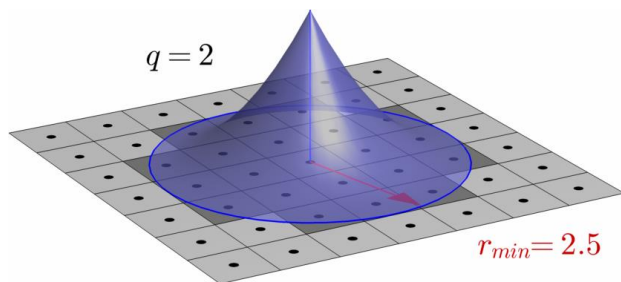
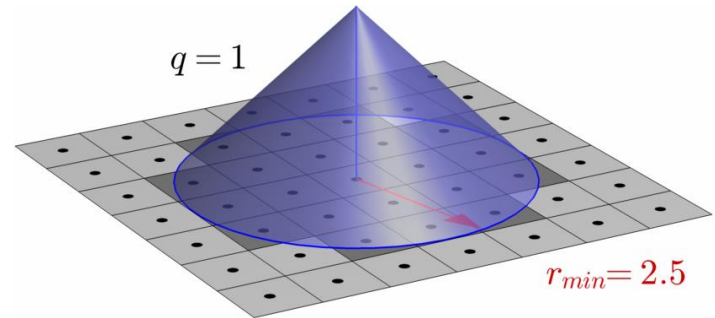
Density-based Topology Optimization

□ convolution (blurring) of the density field

$$\bar{\rho} = \mathbf{H}\rho$$

with
$$\mathbf{H}_{ij} = \frac{h(i, j) v_j}{\sum_k^{N_e} h(i, k) v_k}$$

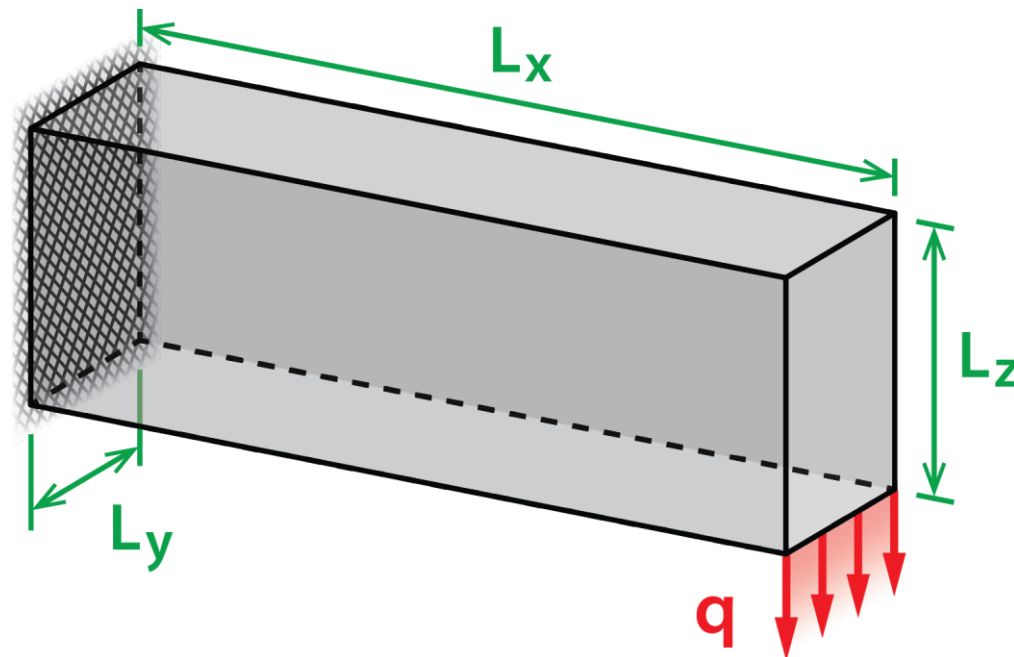
$$h(i, j) = \begin{cases} [r_{min} - \text{dist}(i, j)]^q & \text{for } r_{min} - \text{dist}(i, j) > 0 \\ 0 & \text{otherwise} \end{cases}$$



Density-based Topology Optimization

□ Edge-supported cantilever beam

$l_x=3$, $l_y=l_z=1$, $q=1$, $r=5$ and $\text{volfrac}=10\%$

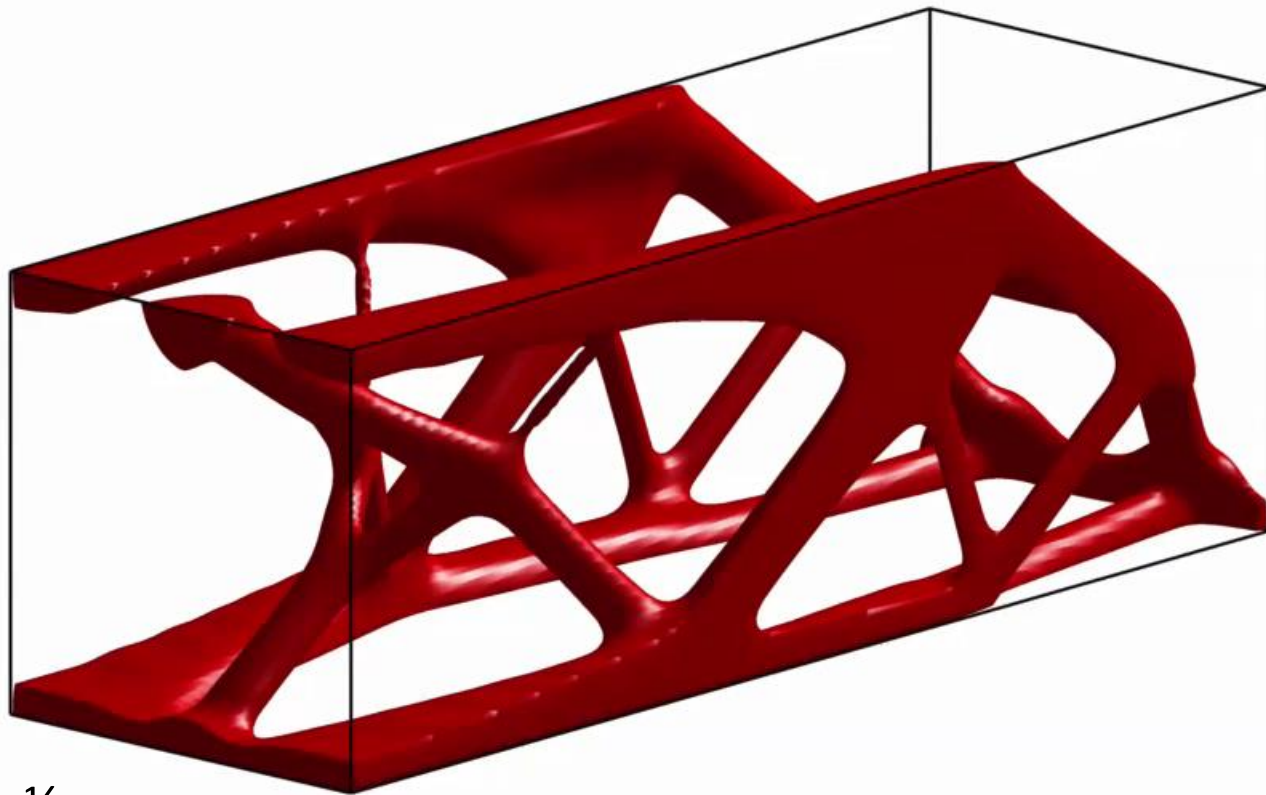


559,872 dvs for $\frac{1}{2}$
(1,119,744 total)

Density-based Topology Optimization

□ Edge-loaded cantilever beam

$l_x=3$, $l_y=l_z=1$, $\text{volfrac}=10\%$, $r=6$, $q=1$ and $p=3.0$

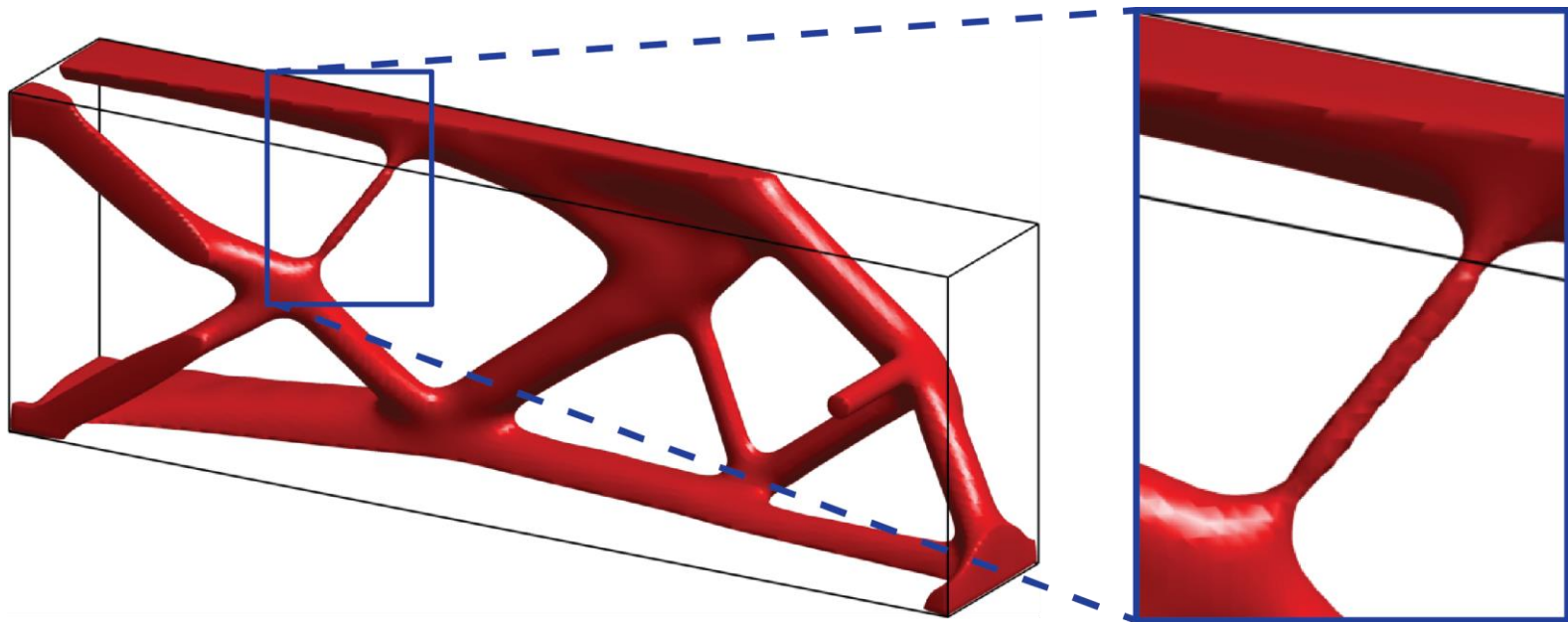


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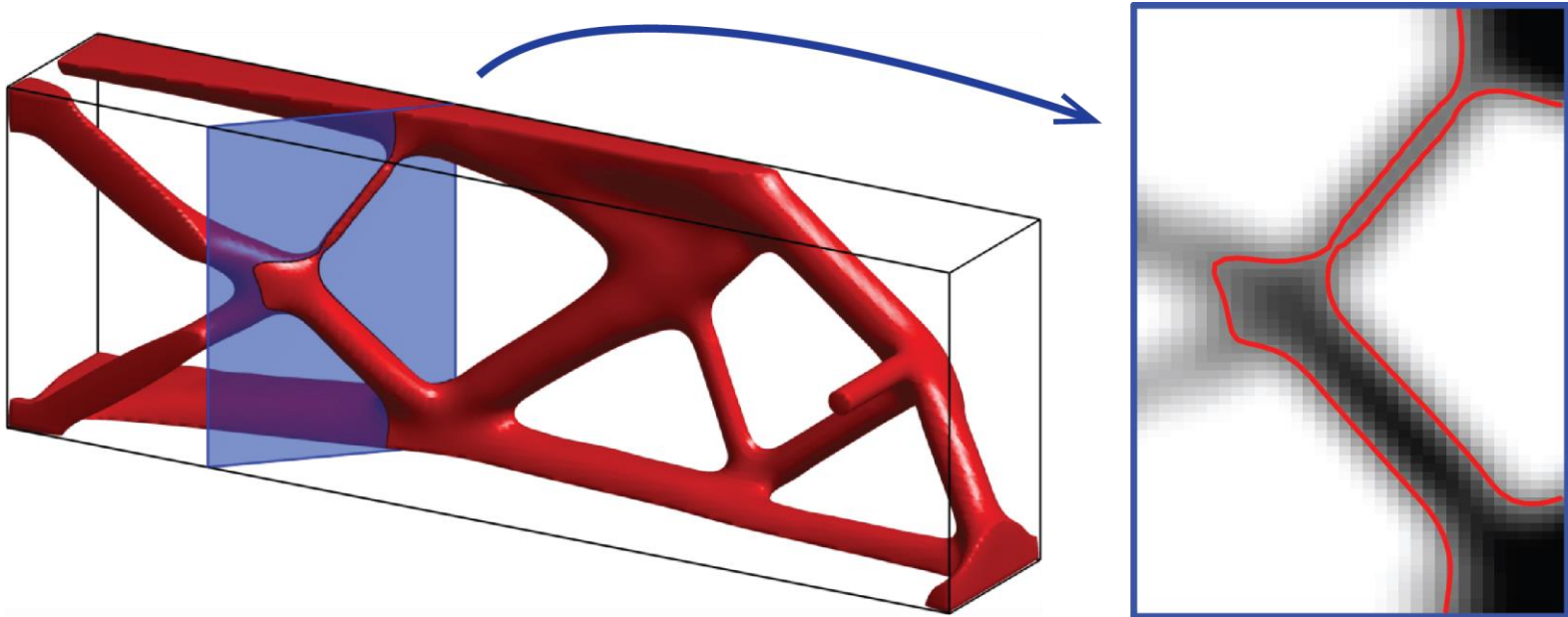


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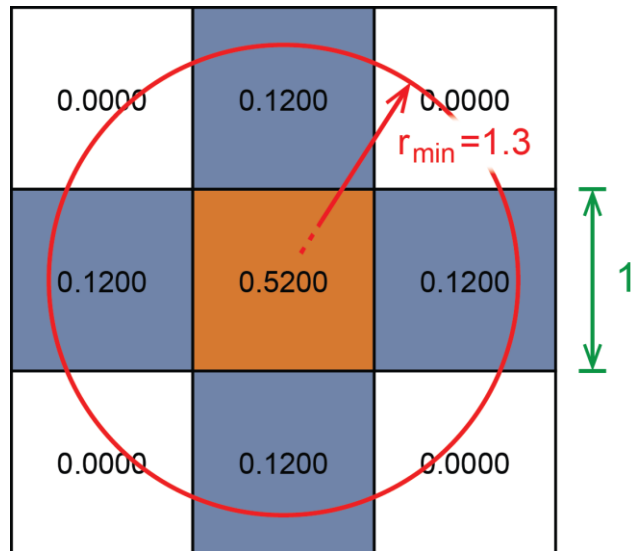
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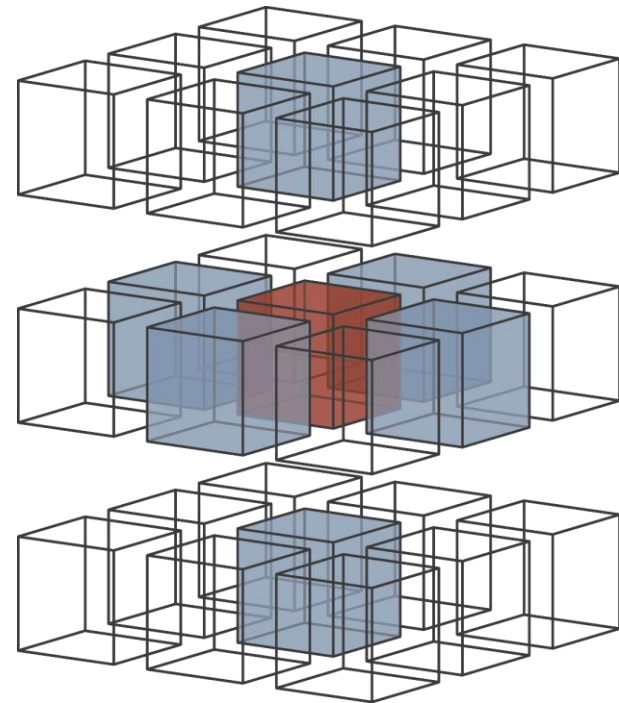
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Density-based Topology Optimization

- Filter's weights for a regular mesh
 $r_{\min}=1.3$, $q=1$ and element size is $l=1$



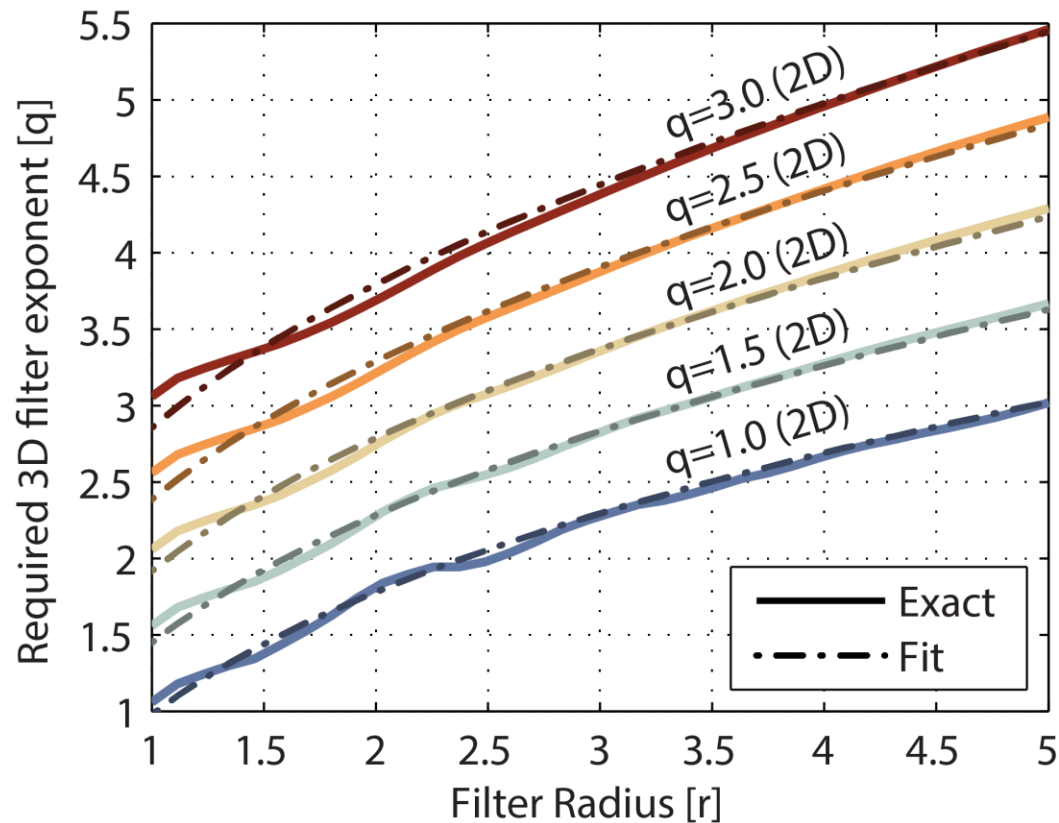
TWO-DIMENSIONS



THREE-DIMENSIONS
($H_{ii} = 0.4194$)

Density-based Topology Optimization

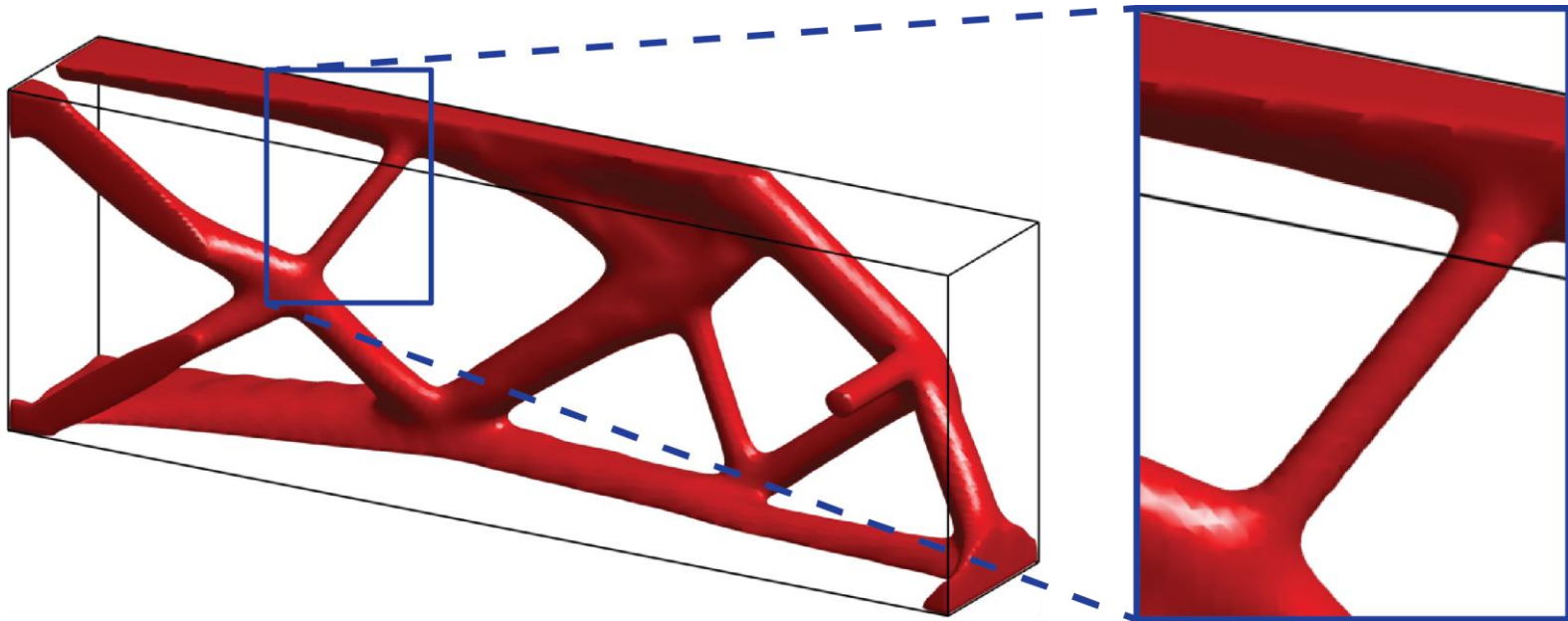
IDEA: what exponent Q makes $H_{ii}^{(2D)} = H_{ii}^{(3D)}$?



Density-based Topology Optimization

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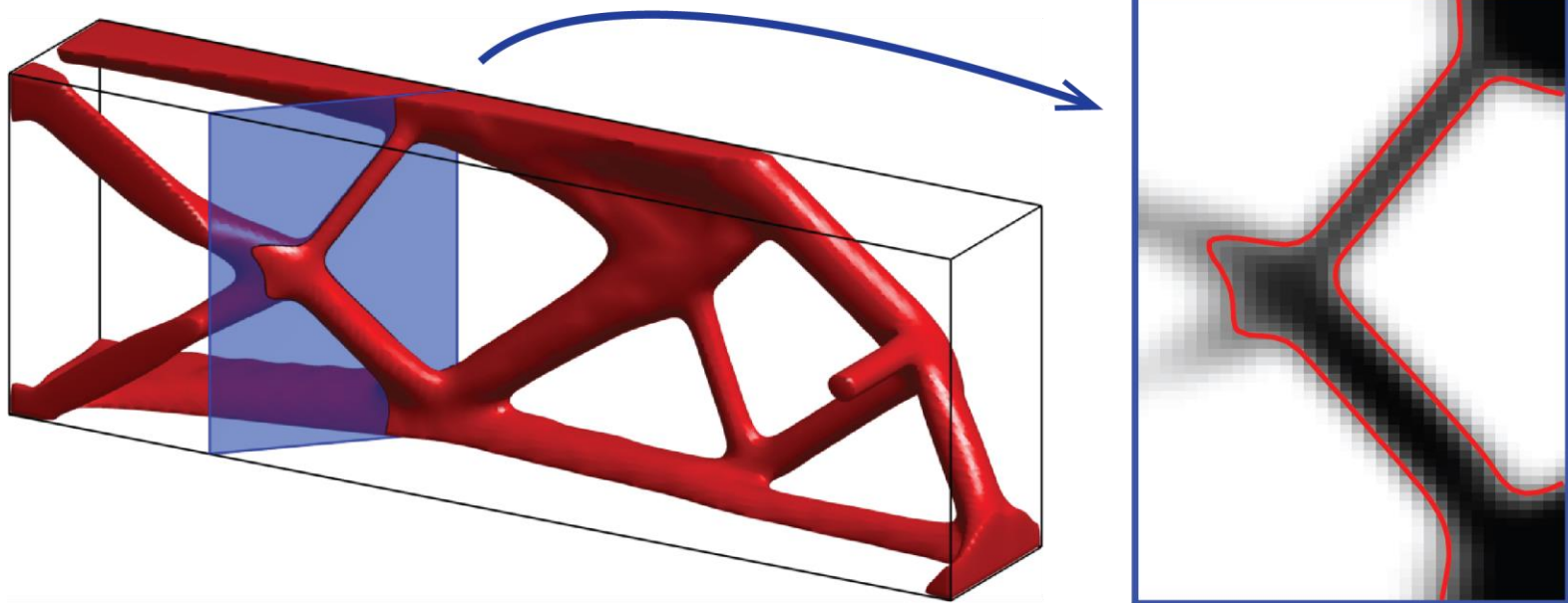


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Density-based Topology Optimization

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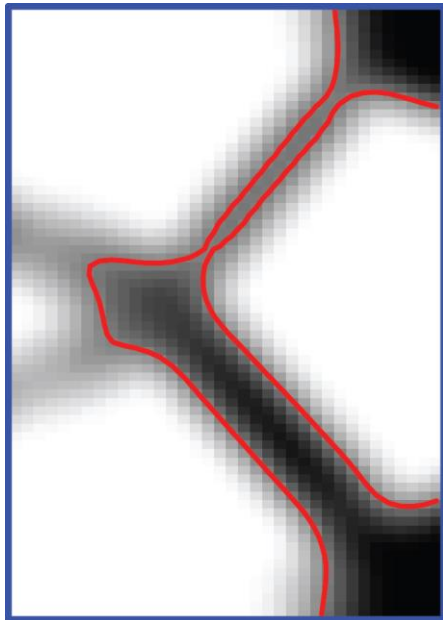
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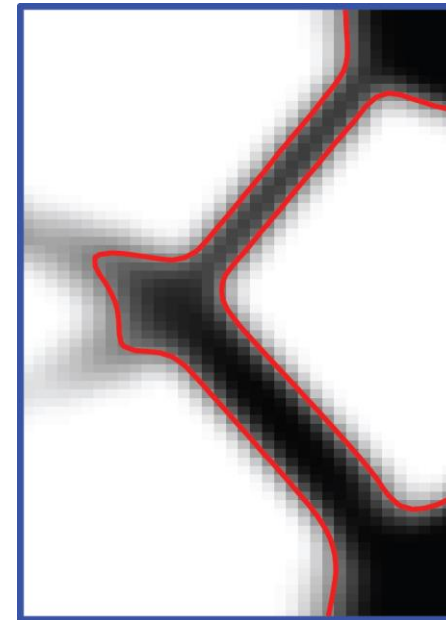
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Density-based Topology Optimization

- Edge-loaded cantilever
density filter: $R=6$



LINEAR DENSITY FILTER



CUBIC DENSITY FILTER

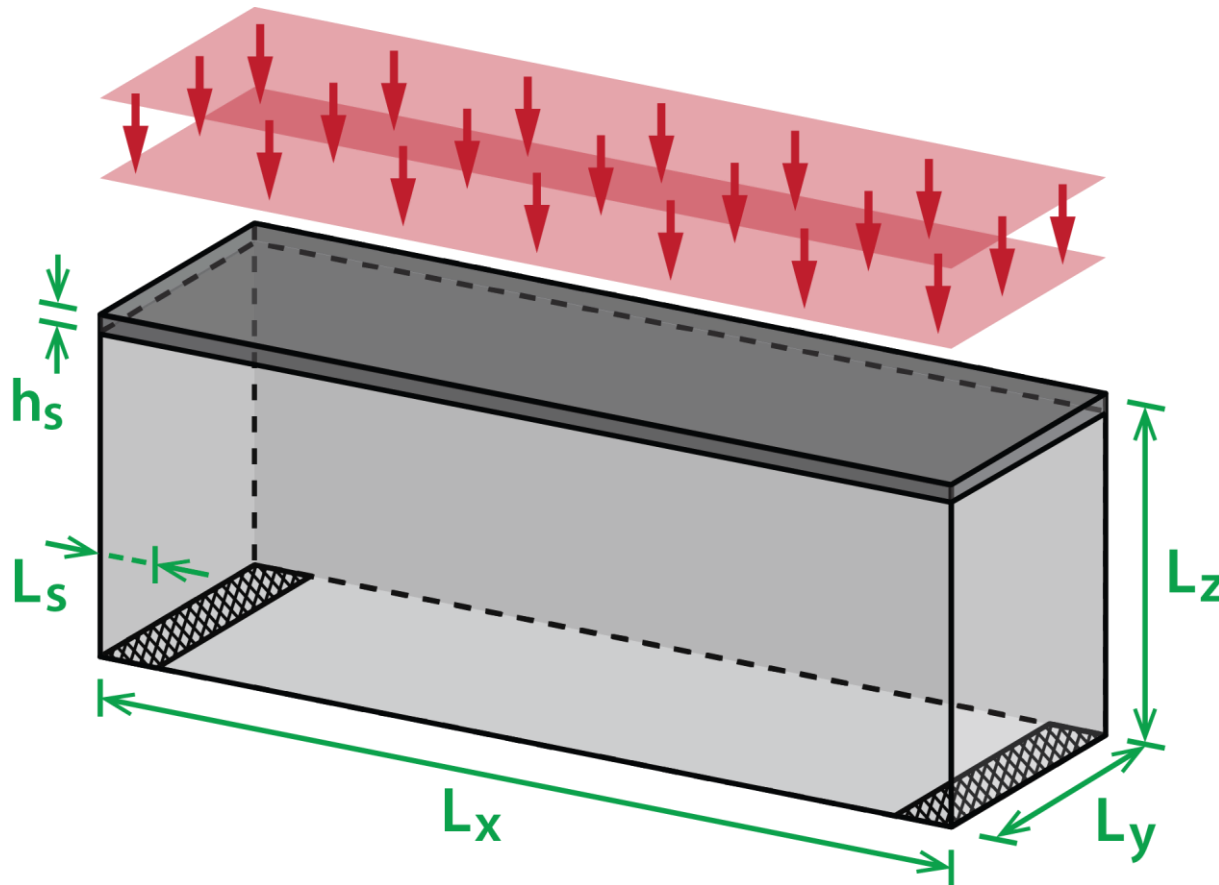
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Density-based Topology Optimization

□ Bridge problem

$l_x=25$, $l_y=l_z=5$, $\text{volfrac}=10\%$, $r=5$, $q=3$ and $p=[\text{contin.}]$

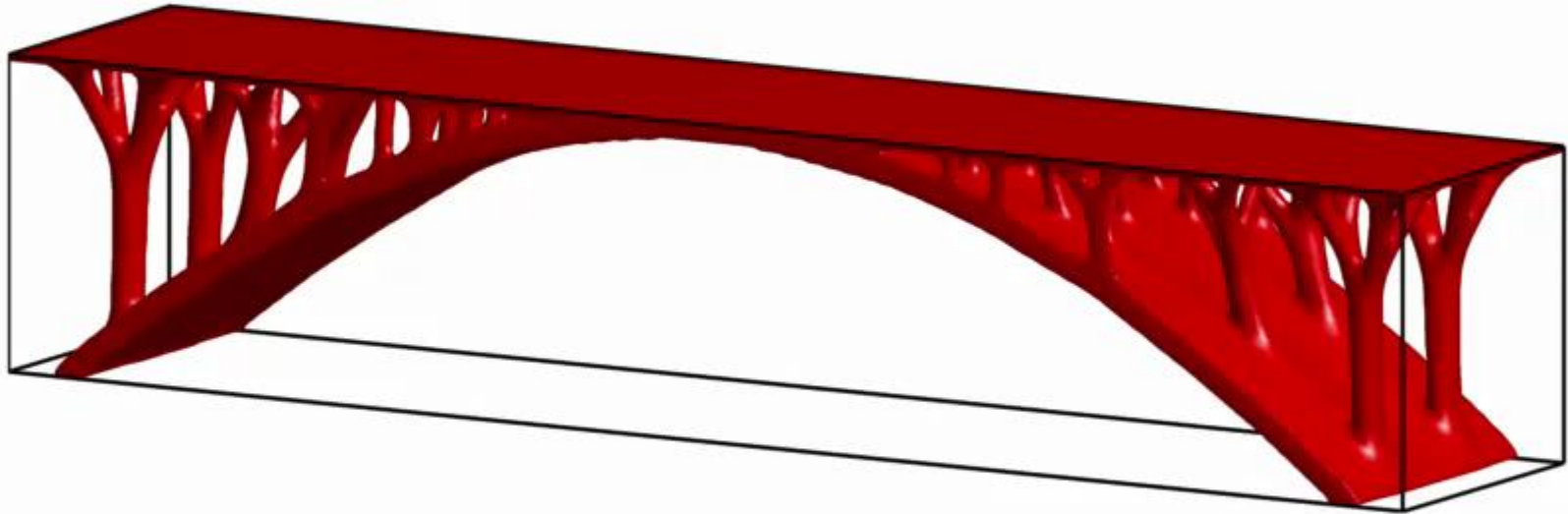


Density-based Topology Optimization

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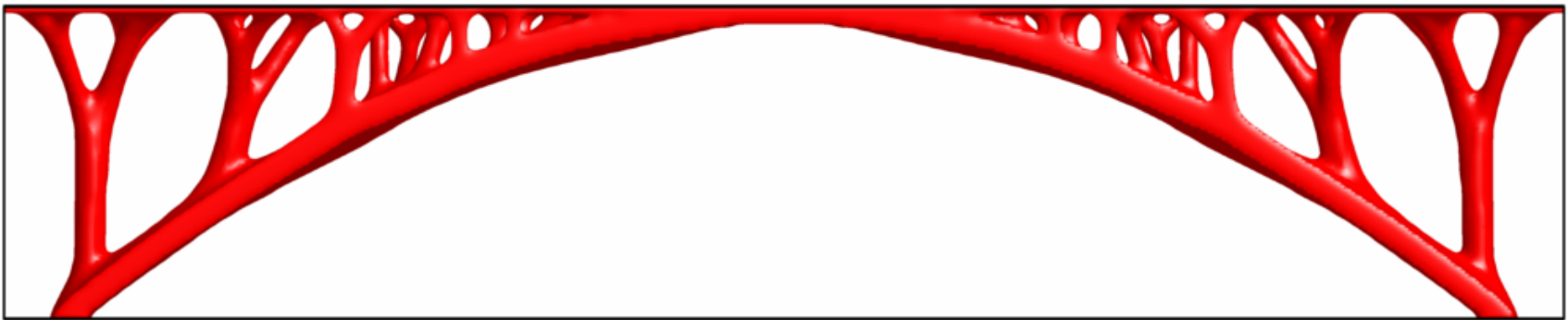
Iteration 300 Penal = 4.25



Density-based Topology Optimization

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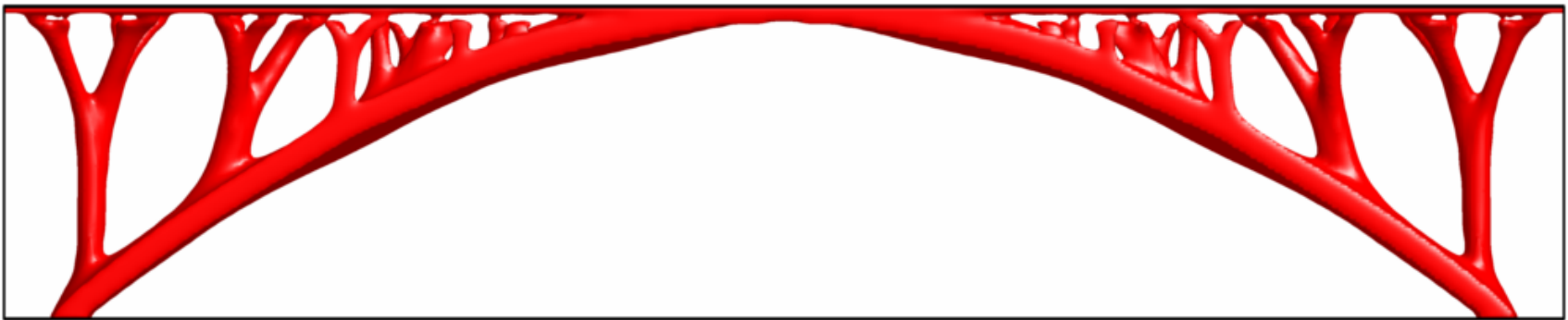


851,840 DVs for $\frac{1}{4}$
(3,407,360 total)

Density-based Topology Optimization

□ Need for a continuation scheme

$l_x=25$, $l_y=l_z=5$, $\text{volfrac}=10\%$, $r=5$, $q=3$ and $p=3$

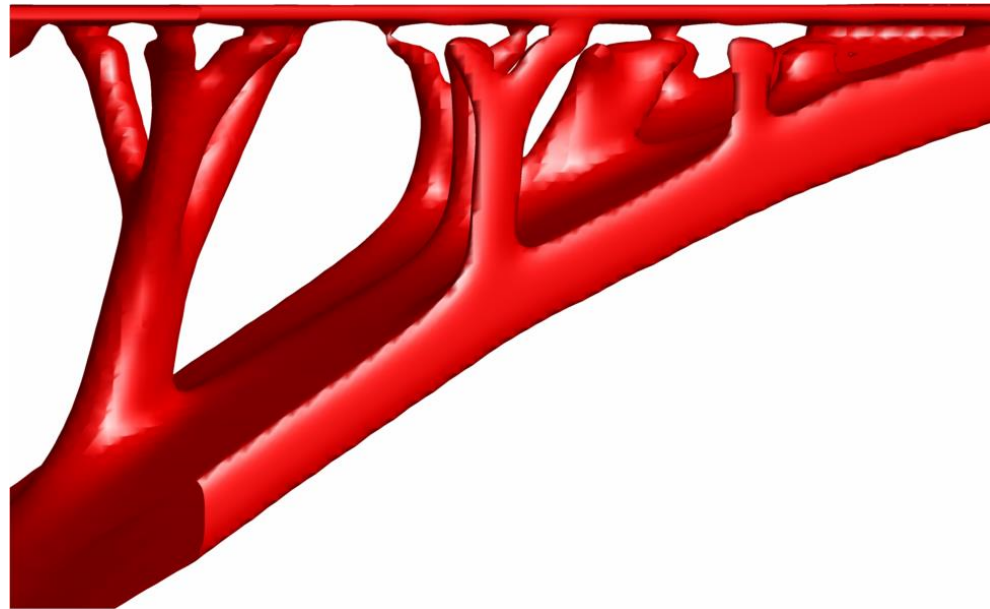


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Density-based Topology Optimization

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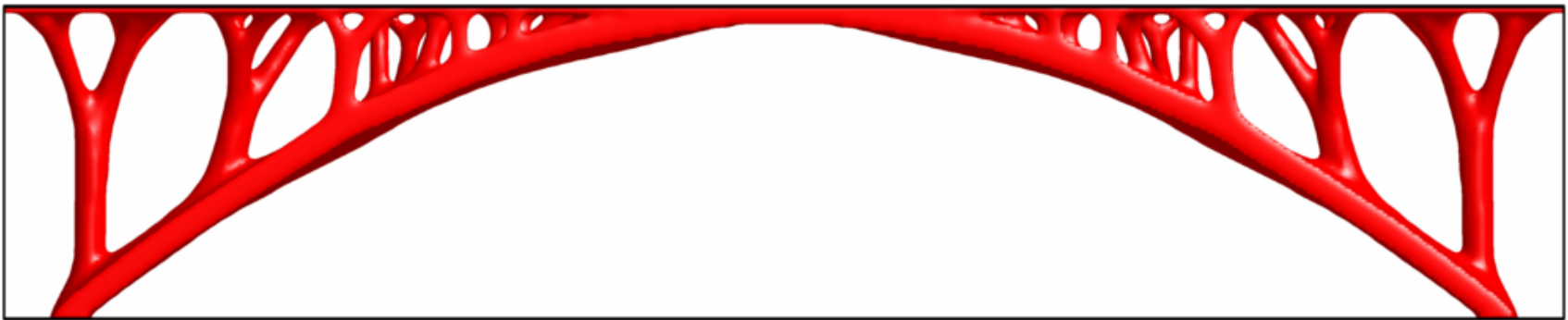


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Examples

- Bridge — achieving larger scales?



Examples

□ AMIE v1.0

Oak Ride National Laboratory

Skidmore, Owings & Merrill LLP

University of Tennessee

Clayton Homes

Alcoa/Kawneer

NanoPore

GE Appliances

Cincinnati Inc

Mach Fuels

KUB

Techmer ES

Tru-Design

Axalta Coating Systems

DowAksa

Hexagon Lincoln

Johnson Controls

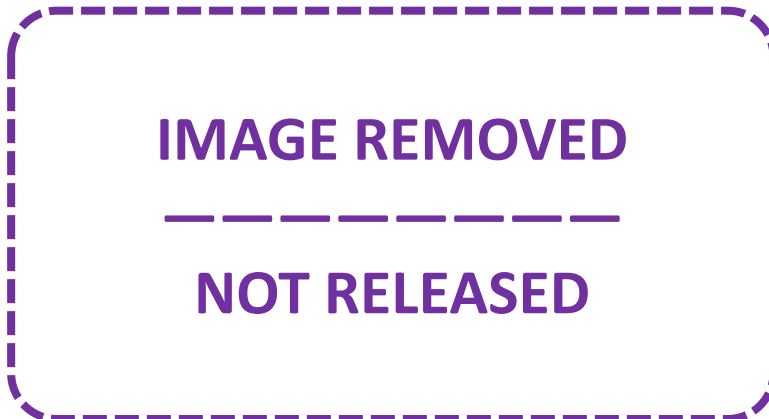
Liberty Utilities

Spiers New Technologies

IACMI The Composites Institute

Line-X

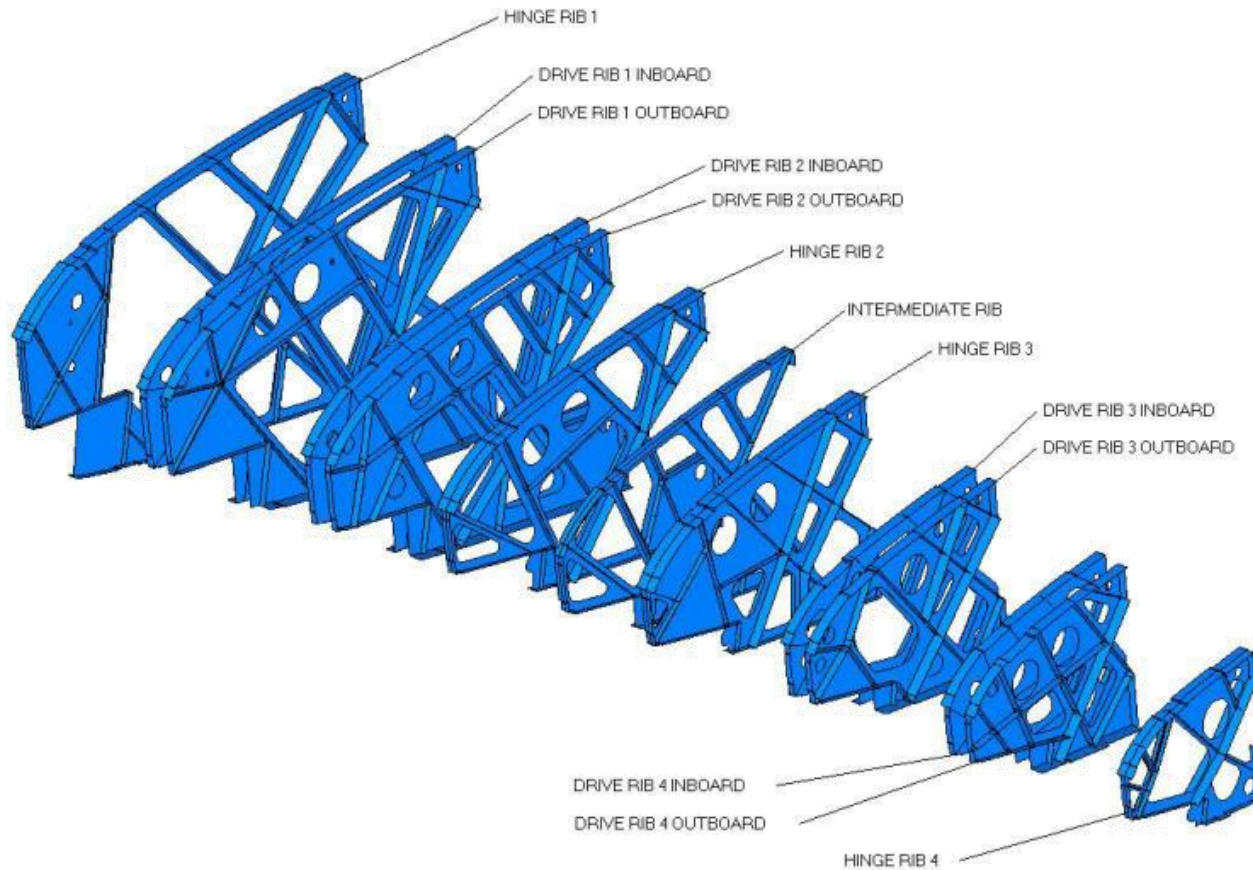
EPB



Examples

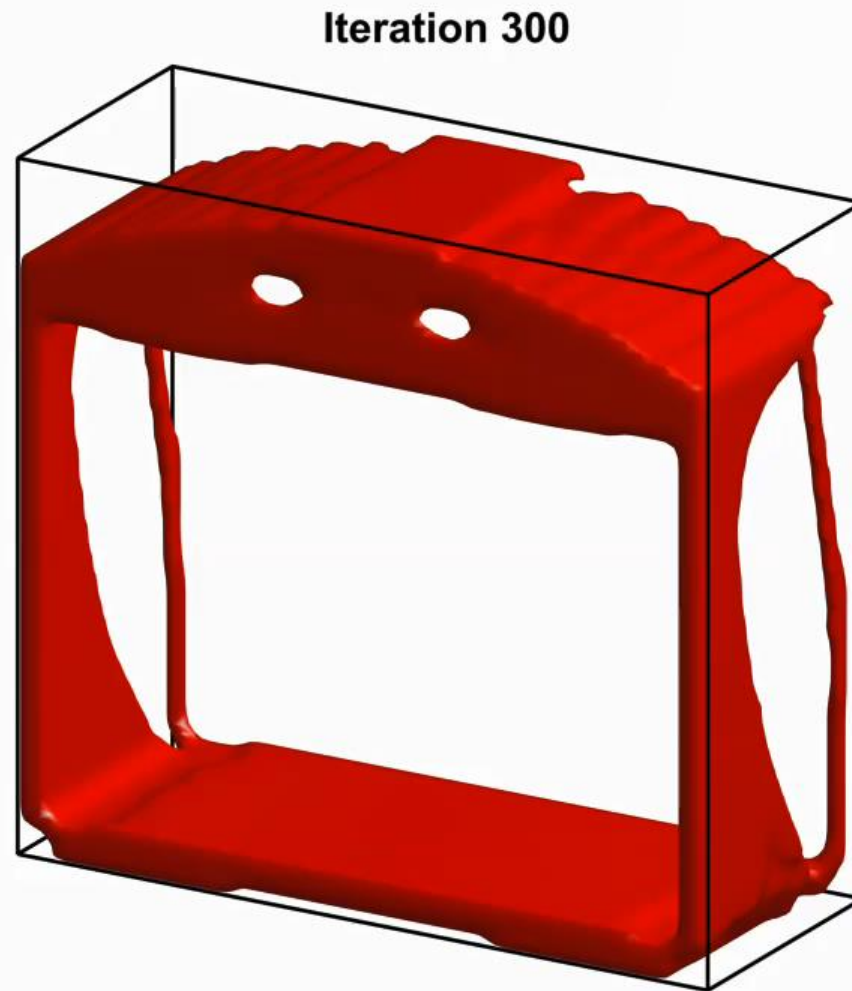
□ AMIE v1.0

ALTAIR ENGINEERING



Examples

□ AMIE v1.0



Examples

□ AMIE v1.0



Examples

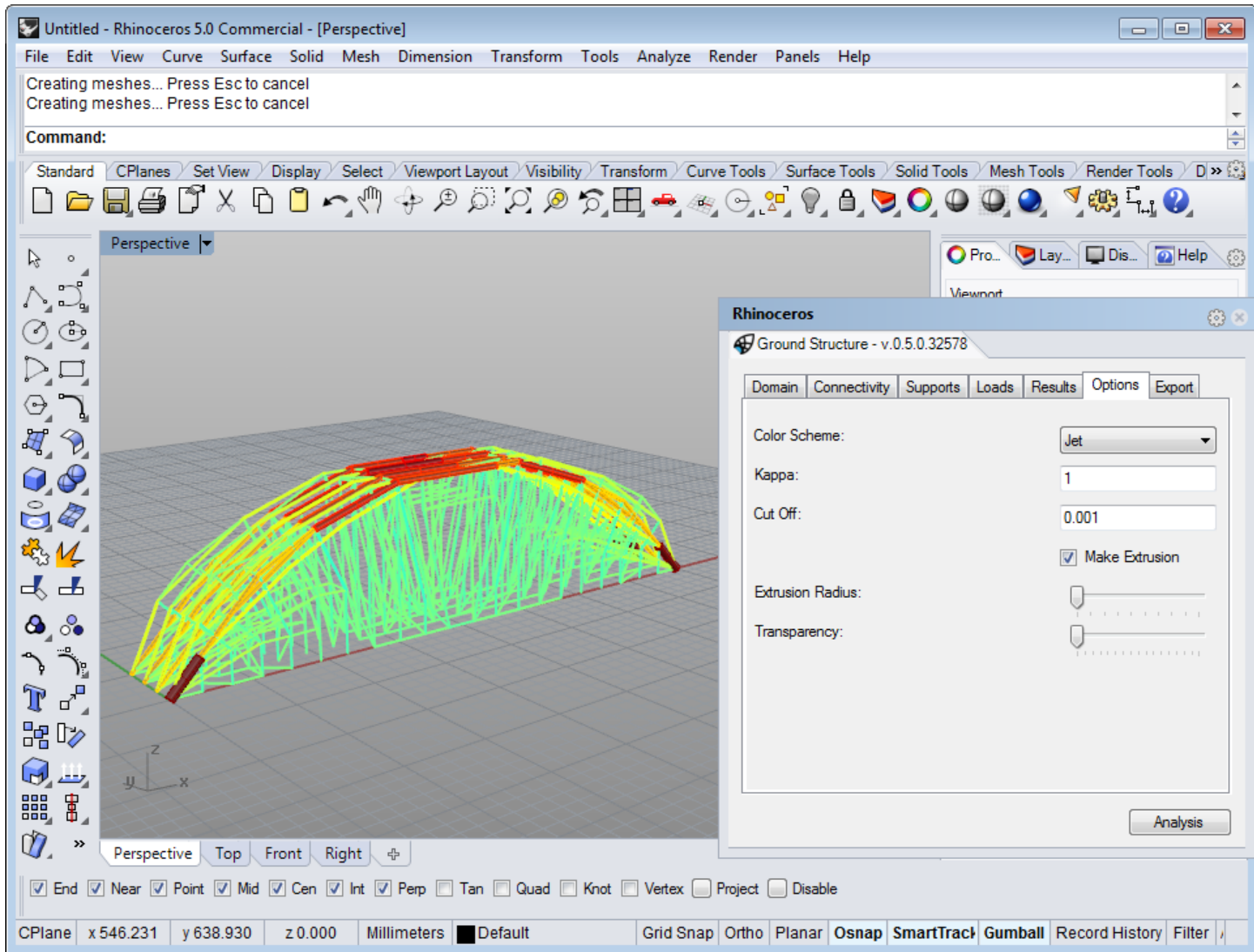
□ AMIE v1.0



Outline

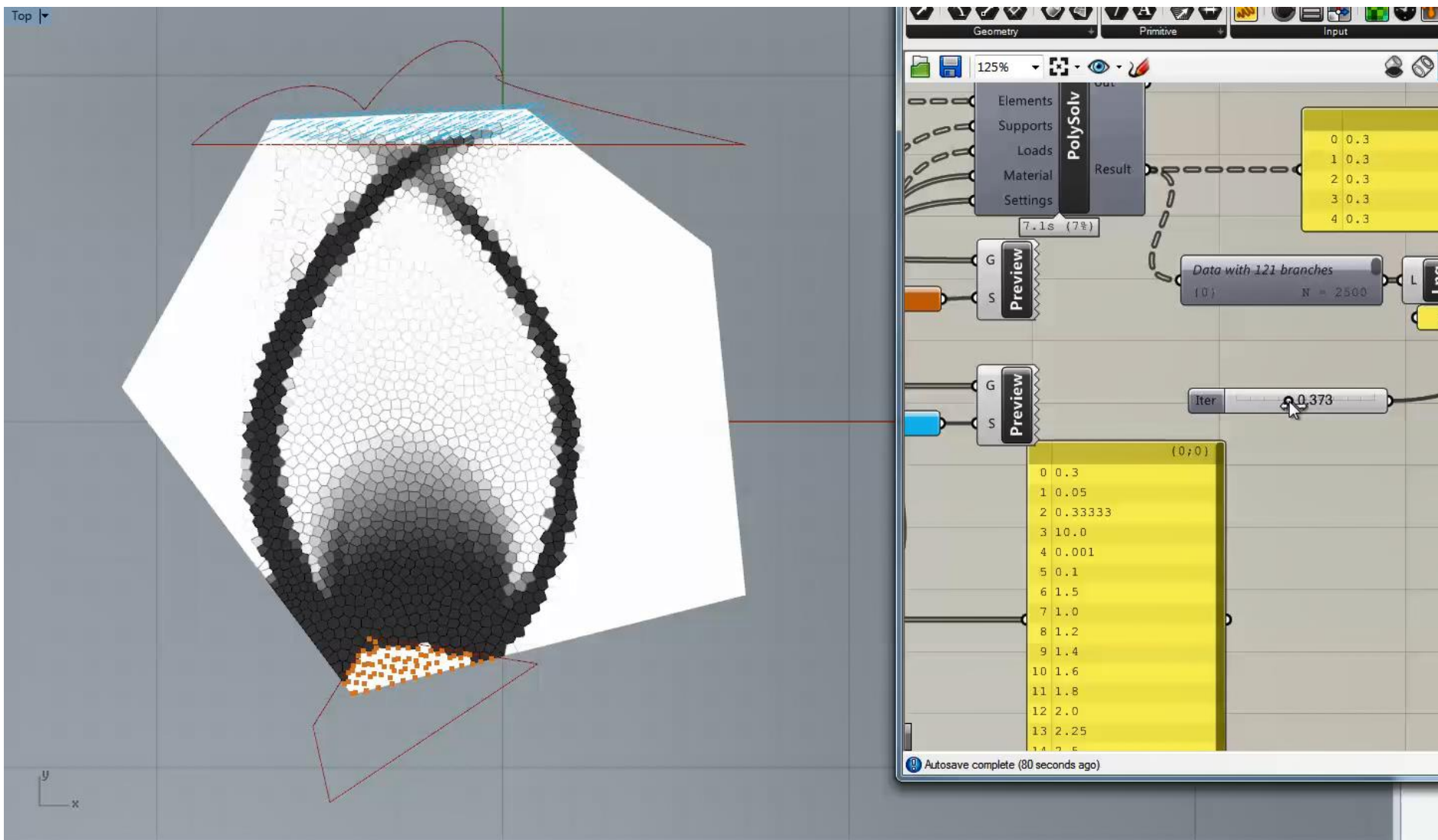
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Conclusions



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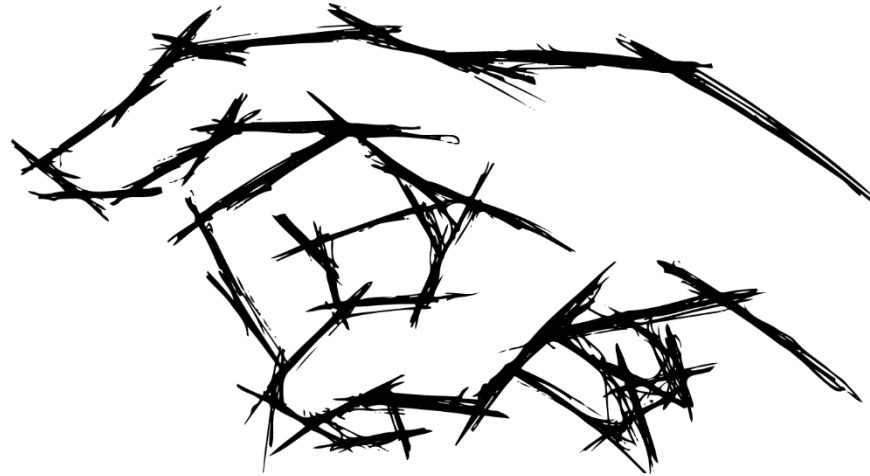
Conclusions



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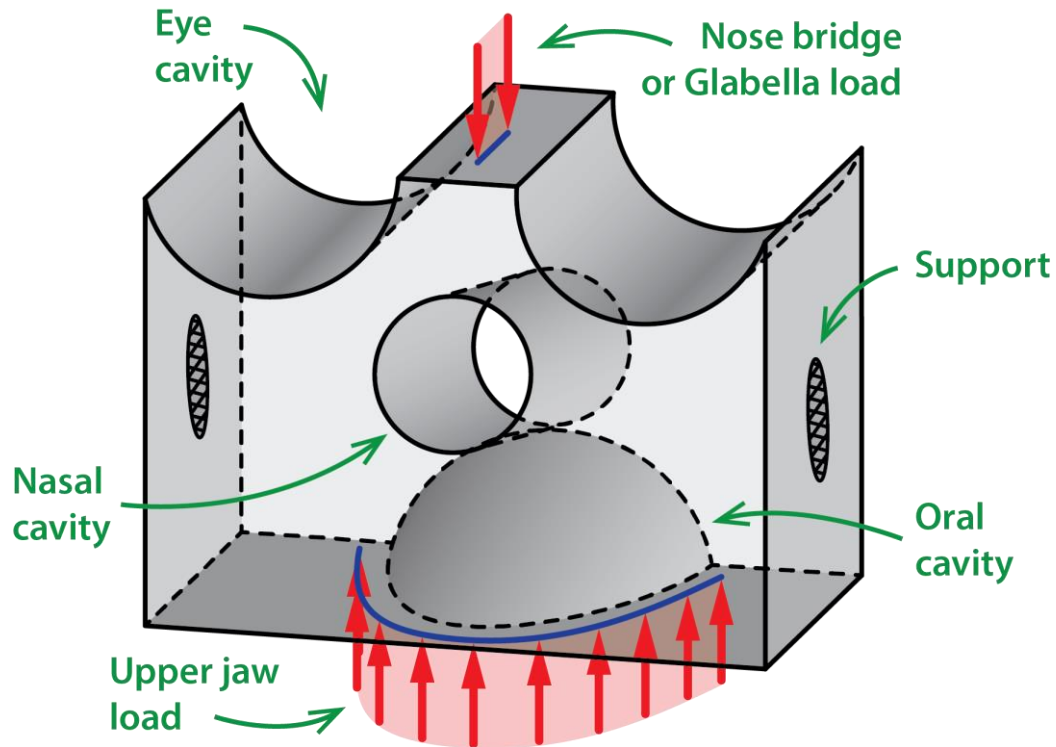
C. Talischi, G. H. Paulino, A. Pereira, and I. F. M. Menezes. "PolyTop: a Matlab implementation of a general topology optimization framework using unstructured polygonal finite element meshes." *JSMO* Vol. 45, No. 3, pp. 329-357. 2012.

Information — Not complete designs



Examples

□ Craniofacial Reconstruction

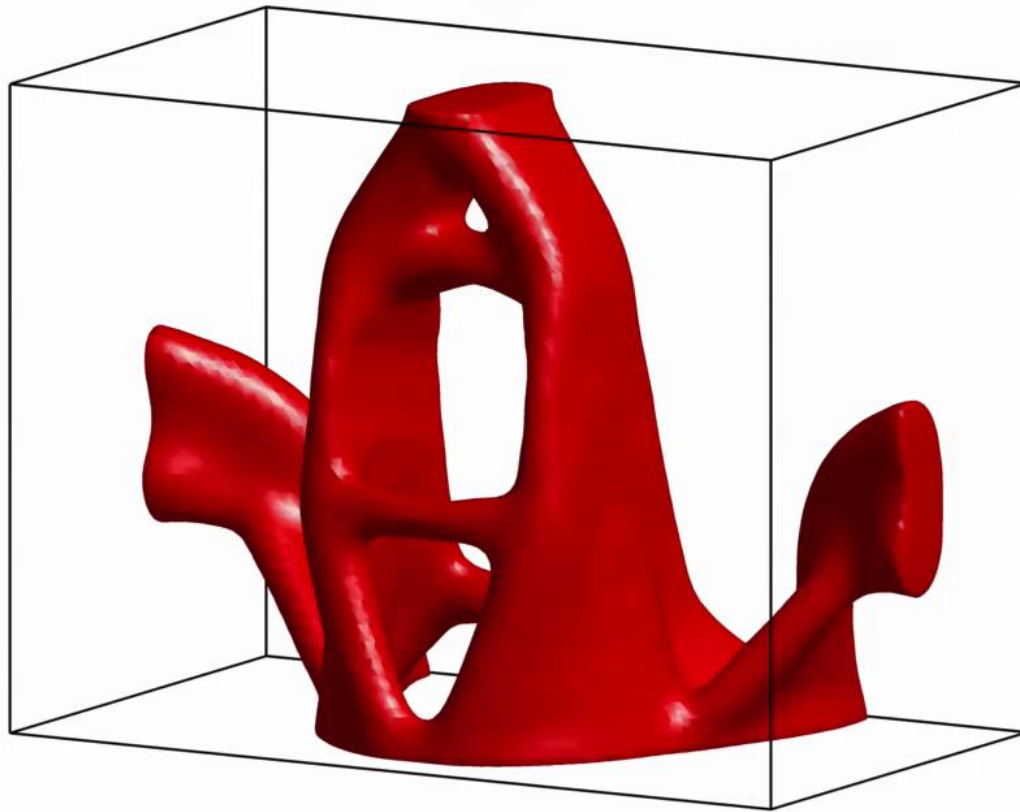


Sutradhar A, Paulino GH, Miller MJ, Nguyen TH (2010) "Topological optimization for designing patient-specific large craniofacial segmental bone replacements." PNAS, 107(30):13222-13227

Examples

□ Craniofacial Reconstruction

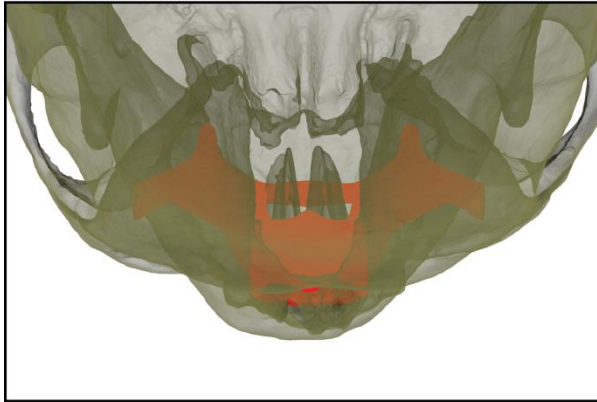
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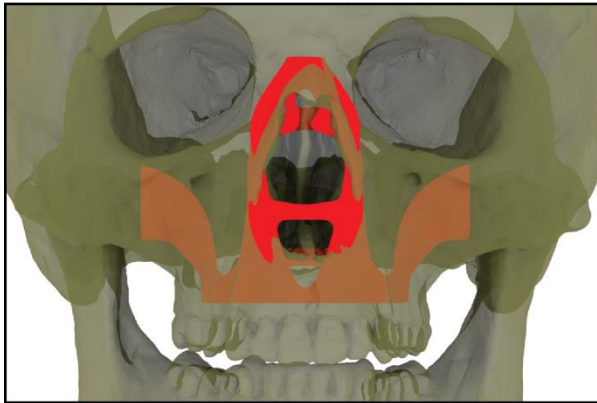
Examples

□ Craniofacial reconstruction

Top view



Iso view



Front view



Side view

Examples

□ Craniofacial reconstruction

