TOPOLOGY OPTIMIZATION FOR ADDITIVE MANUFACTURING: BEYOND MATH AND NUMERICS

TOMAS ZEGARD — GLAUCIO H. PAULINO

2017 TOPOLOGY OPTIMIZATION ROUNDTABLE

Georgia Tech

SOM

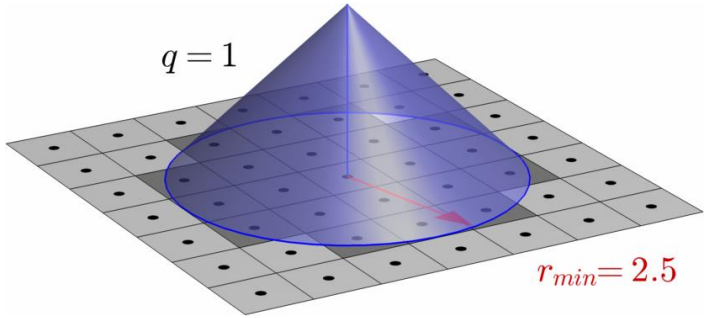
PONTIFICIA UNIVERSIDAD CATÓLICA DE CHILE

FILTER (REGULARIZATION)

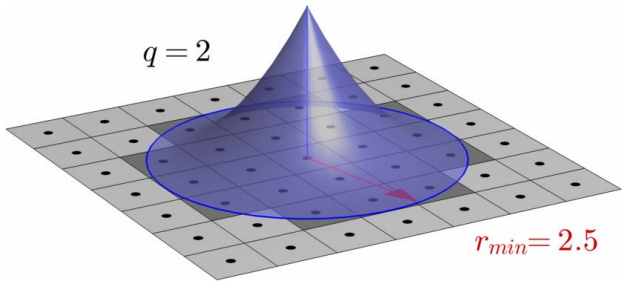
- CONVOLUTION (BLURRING) OF THE DENSITY FIELD

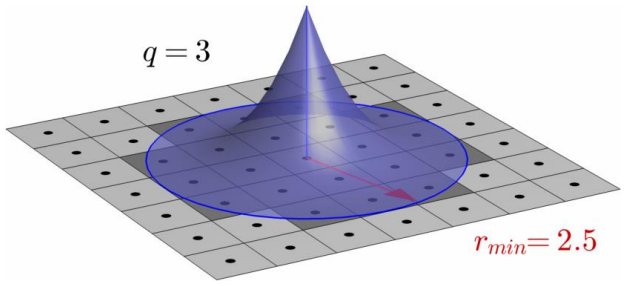
$$\overline{\boldsymbol{\rho}} = \mathbf{H}\boldsymbol{\rho}$$

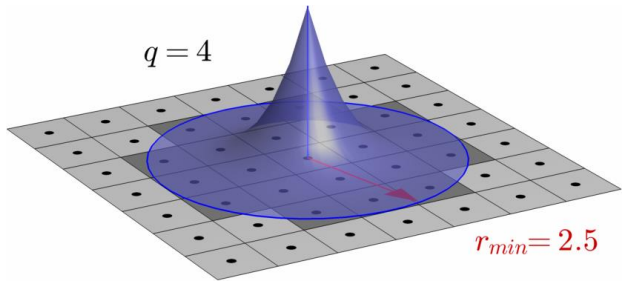
$$\text{with} \quad \mathbf{H}_{ij} = \frac{h\left(i,j\right) v_j}{\sum_k^{N_e} h\left(i,k\right) v_k}$$



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

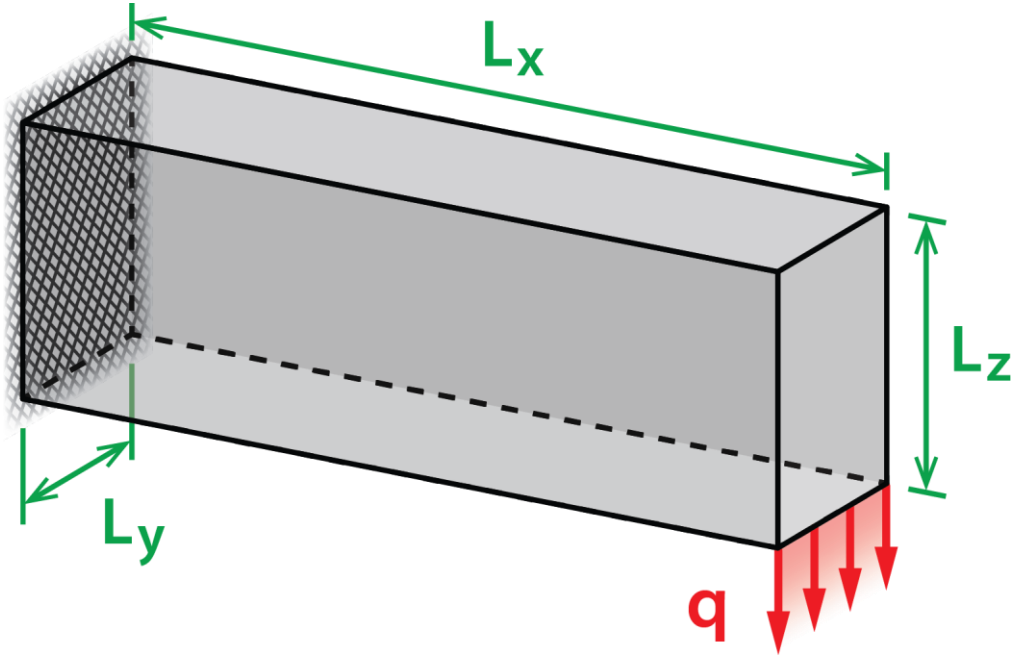






DENSITY-BASED TOP OPT

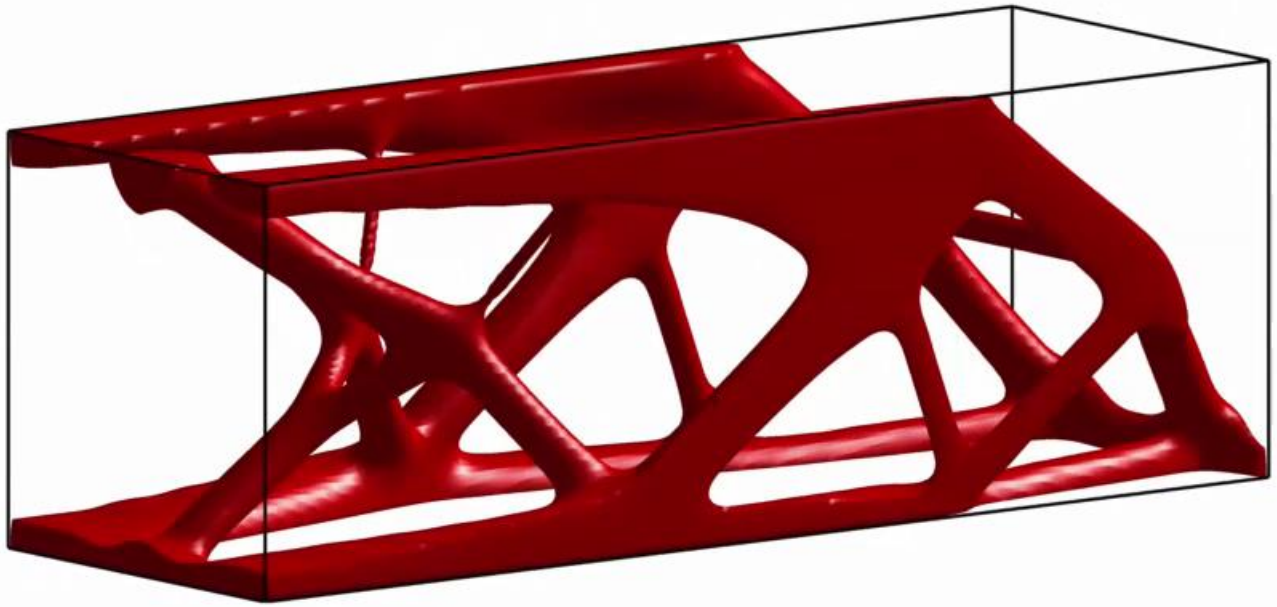
- EDGE-SUPPORTED CANTILEVER BEAM
  LX=3, LY=LZ=1, Q=1, R=5 AND VOLFRAC=10%



559,872 DVS FOR ½
(1,119,744 TOTAL)

DENSITY-BASED TOP OPT

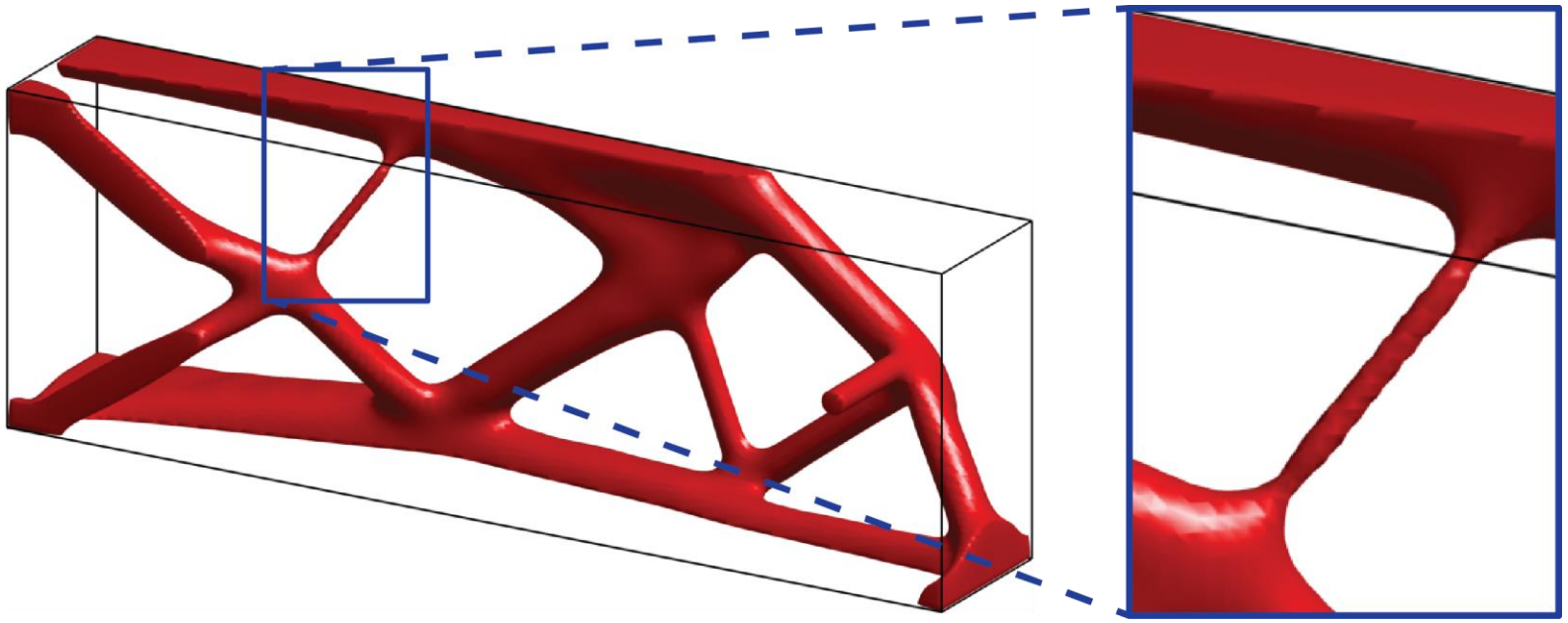
- EDGE-SUPPORTED CANTILEVER BEAM
  LX=3, LY=LZ=1, Q=1, R=5 AND VOLFRAC=10%



559,872 DVS FOR ½
(1,119,744 TOTAL)

DENSITY-BASED TOP OPT

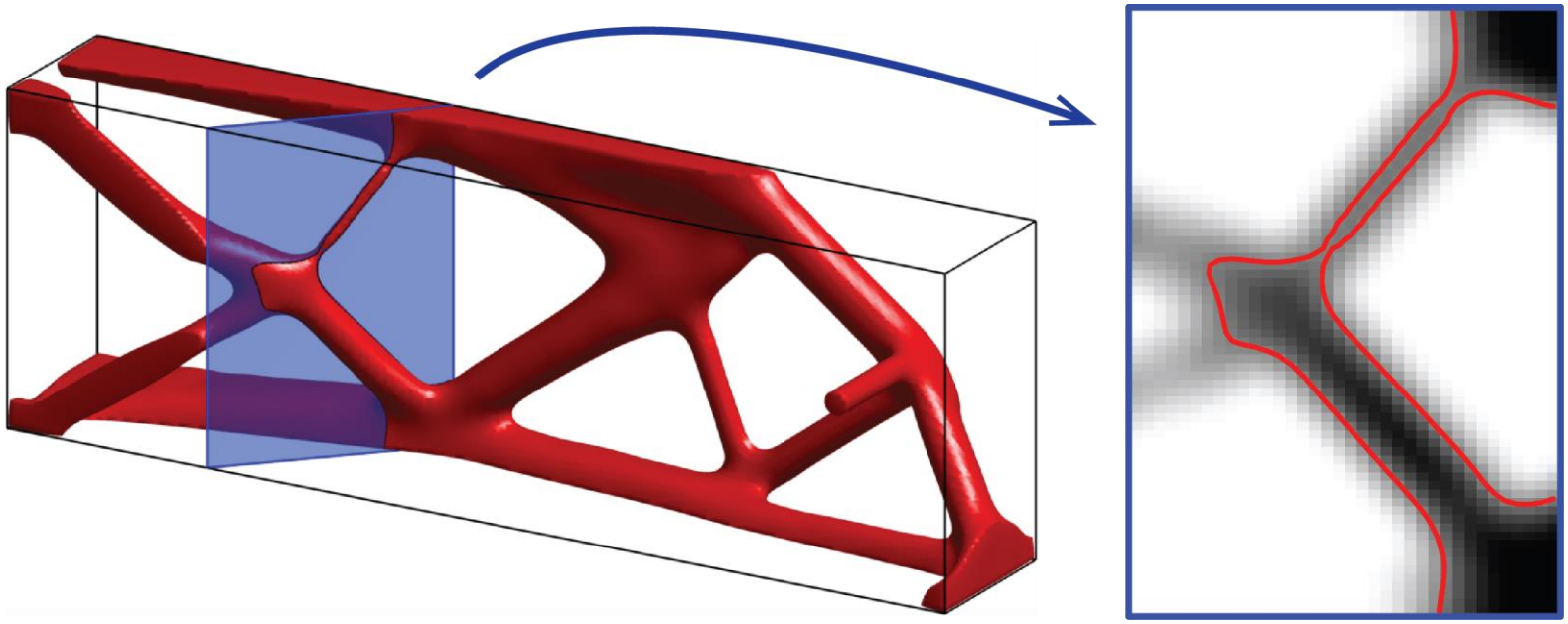
- EDGE-LOADED CANTILEVER BEAM
  LX=3, LY=LZ=1, VOLFRAC=10%, R=6, Q=1 AND P=3.0



559,872 DVS FOR ½
(1,119,744 TOTAL)

DENSITY-BASED TOP OPT

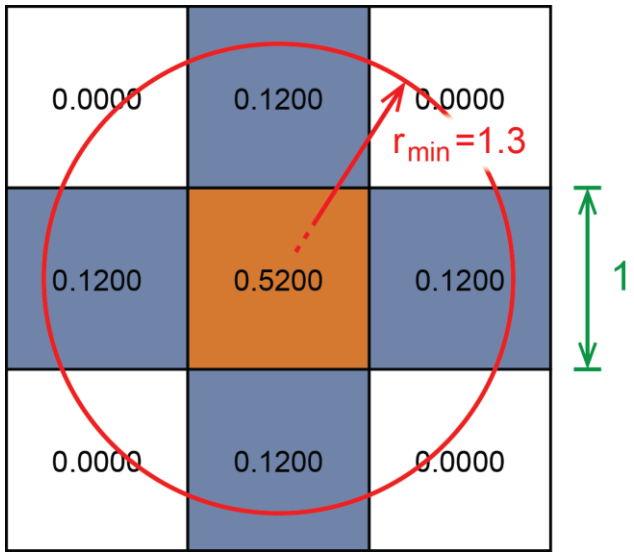
- EDGE-LOADED CANTILEVER BEAM
  LX=3, LY=LZ=1, VOLFRAC=10%, R=6, Q=1 AND P=3.0



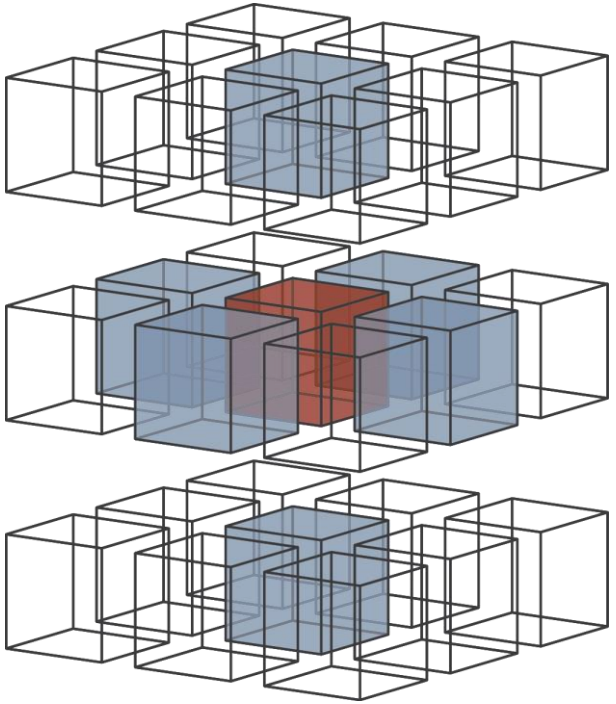
559,872 DVS FOR ½
(1,119,744 TOTAL)

DENSITY-BASED TOP OPT

- FILTER'S WEIGHTS FOR A REGULAR MESH
  R_{MIN}=1.3, Q=1 AND ELEMENT SIZE IS L=1



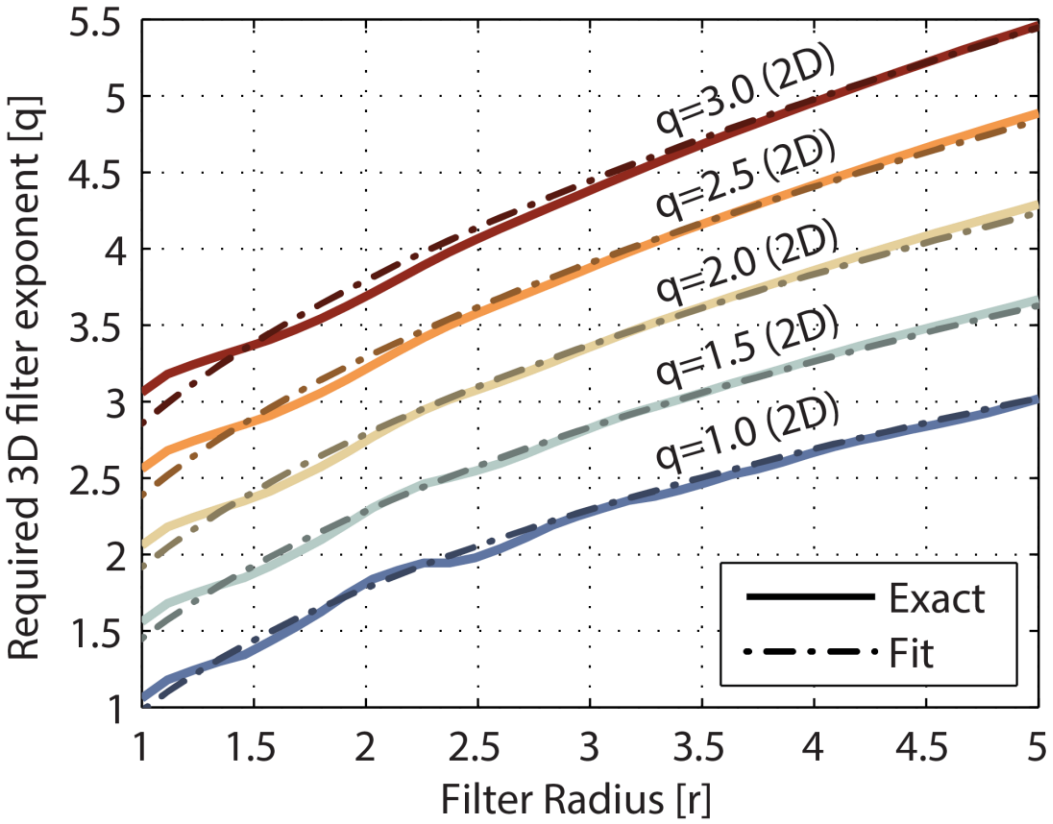
TWO-DIMENSIONS



THREE-DIMENSIONS
(H_{ii} = 0.4194)

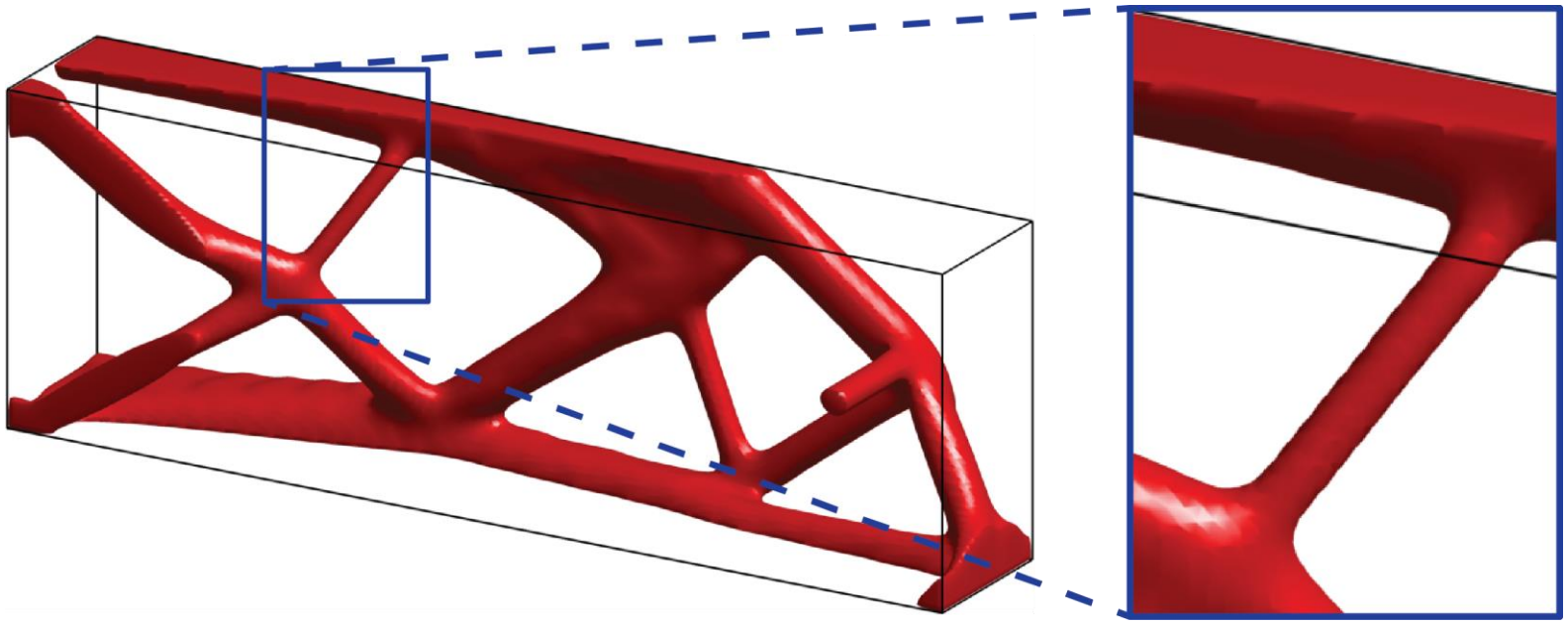
DENSITY-BASED TOP OPT

IDEA: WHAT EXPONENT Q MAKES $H_{||}^{(2D)} = H_{||}^{(3D)}$?



DENSITY-BASED TOP OPT

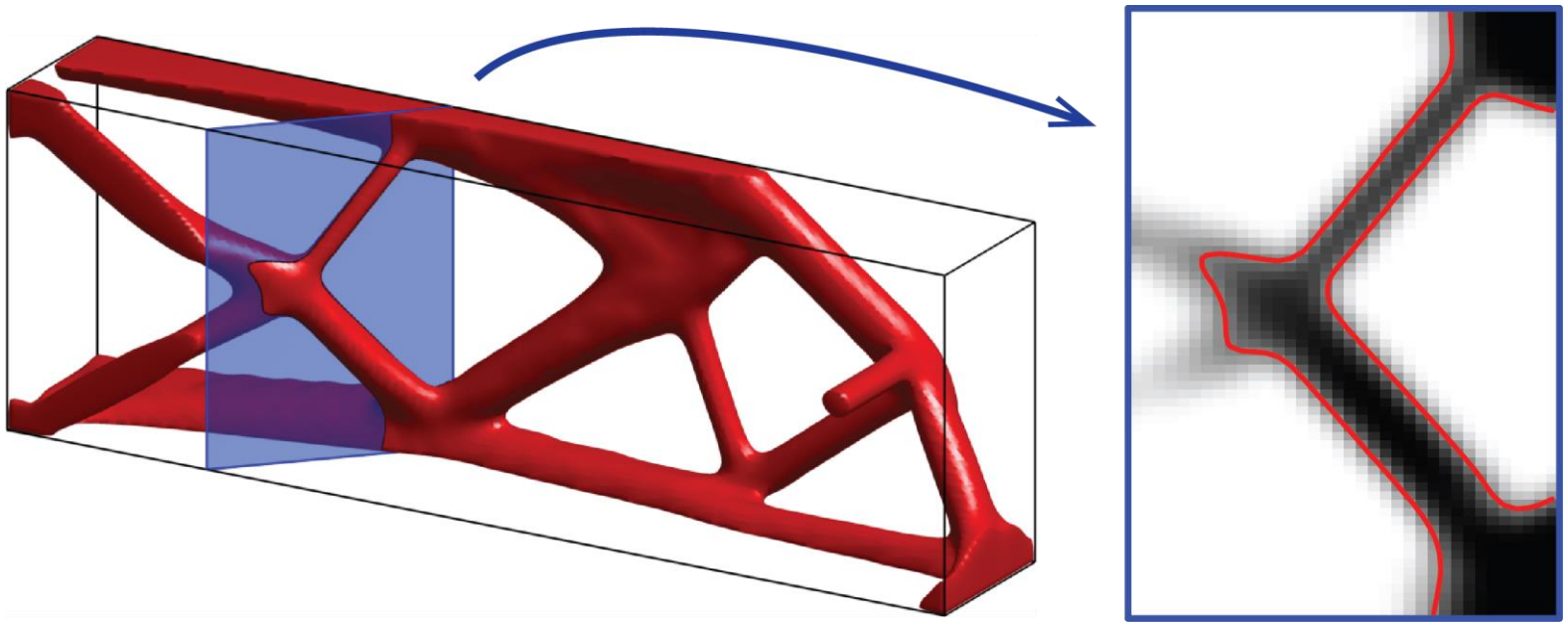
- EDGE-LOADED CANTILEVER BEAM
  LX=3, LY=LZ=1, VOLFRAC=10%, R=6, Q=3 AND P=3.0



559,872 DVS FOR ½
(1,119,744 TOTAL)

DENSITY-BASED TOP OPT

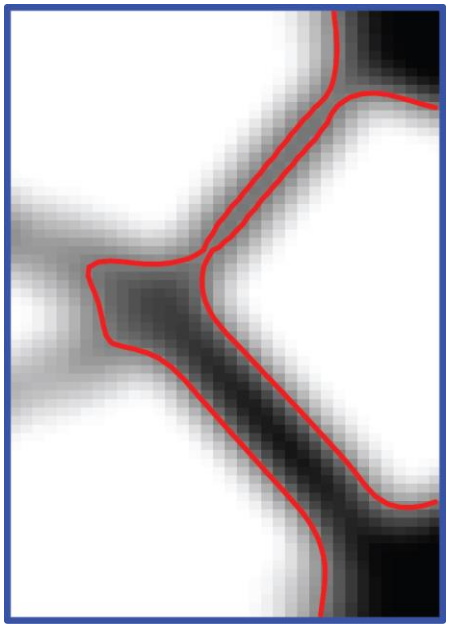
- EDGE-LOADED CANTILEVER BEAM
  LX=3, LY=LZ=1, VOLFRAC=10%, R=6, Q=3 AND P=3.0



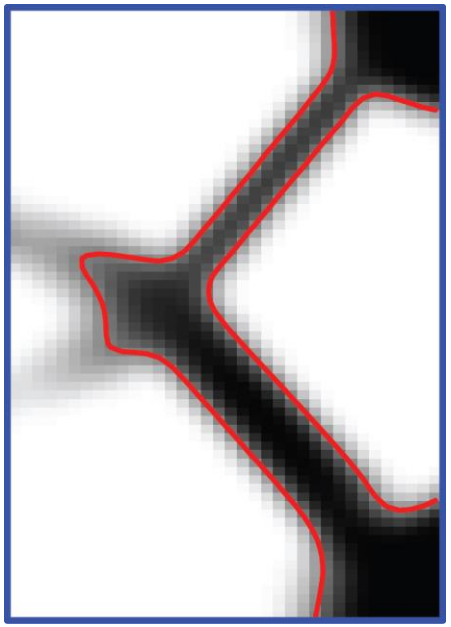
559,872 DVS FOR ½
(1,119,744 TOTAL)

DENSITY-BASED TOP OPT

- EDGE-LOADED CANTILEVER
  DENSITY FILTER: **R=6**



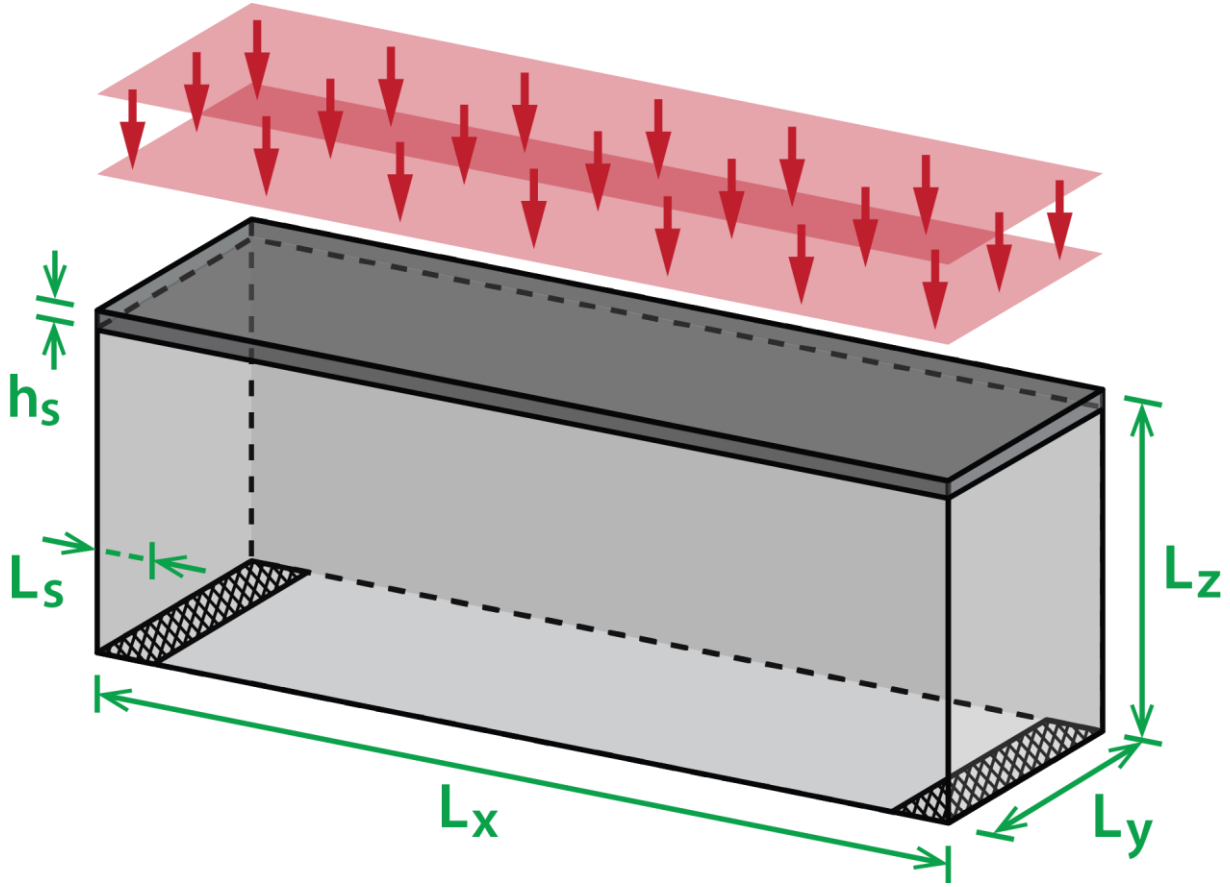
LINEAR DENSITY FILTER



CUBIC DENSITY FILTER

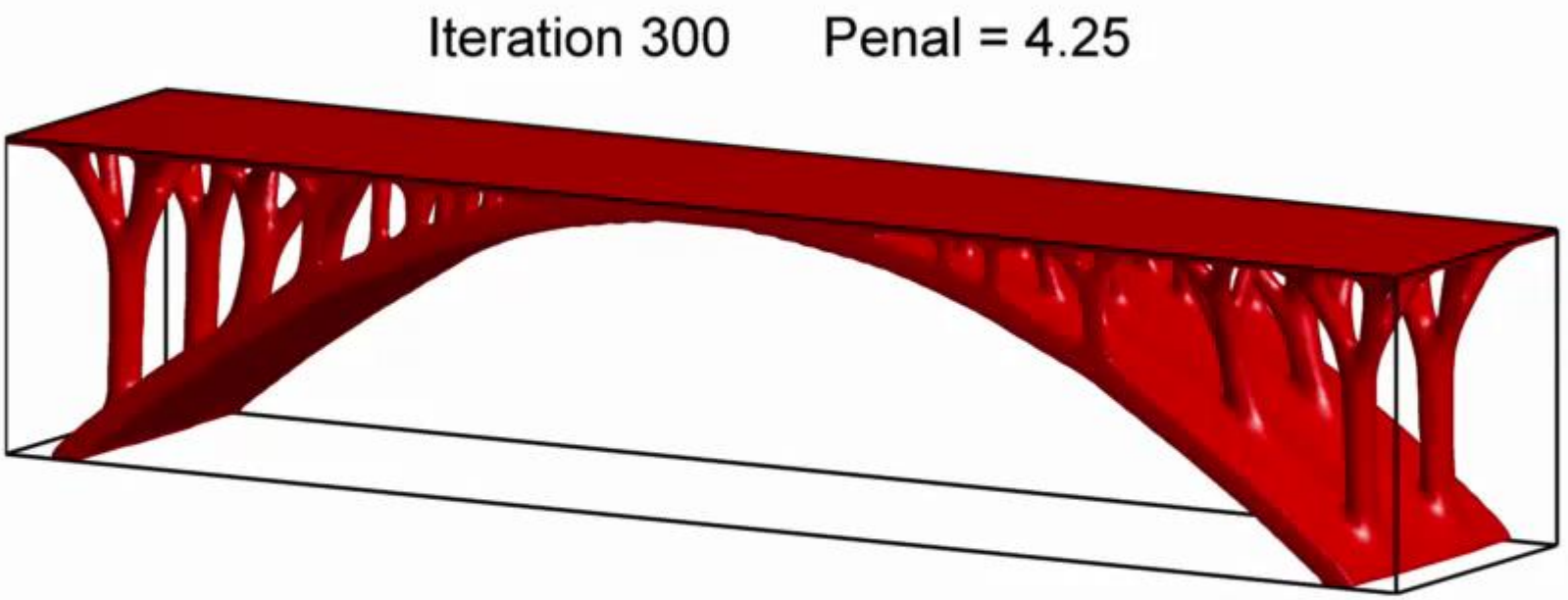
DENSITY-BASED TOP OPT

- BRIDGE PROBLEM
  LX=25, LY=LZ=5, VOLFRAC=10%, R=5, Q=3 AND P=[CONTIN.]



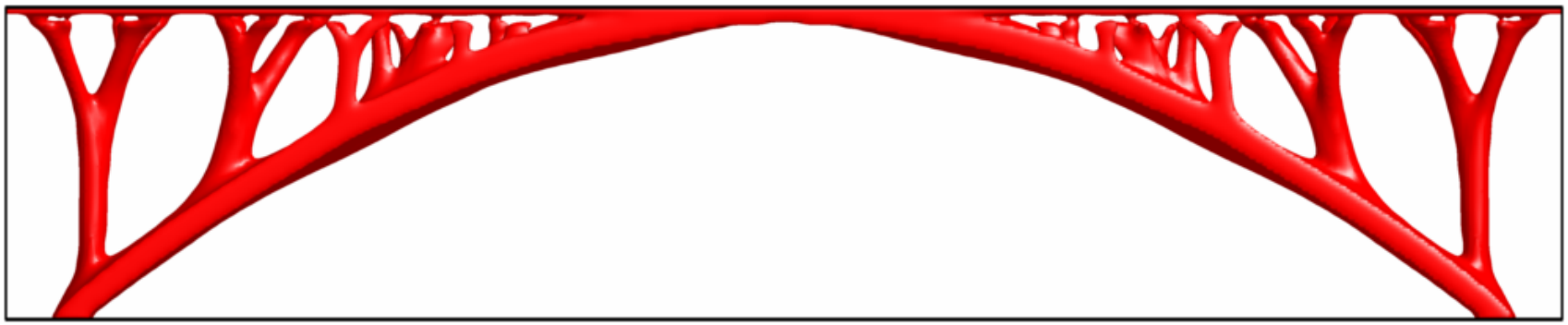
DENSITY-BASED TOP OPT

- BRIDGE PROBLEM
  LX=25, LY=LZ=5, VOLFRAC=10%, R=5, Q=3 AND P=[CONTIN.]



DENSITY-BASED TOP OPT

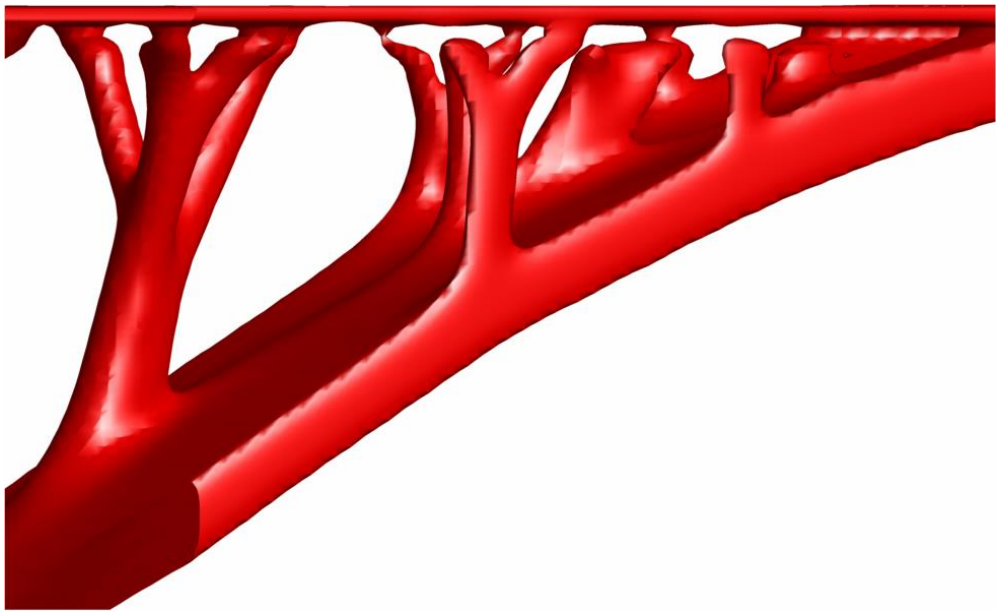
- NEED FOR A CONTINUATION SCHEME
  LX=25, LY=LZ=5, VOLFRAC=10%, R=5, Q=3 AND P=3



851,840 DVS FOR ¼
(3,407,360 TOTAL)

DENSITY-BASED TOP OPT

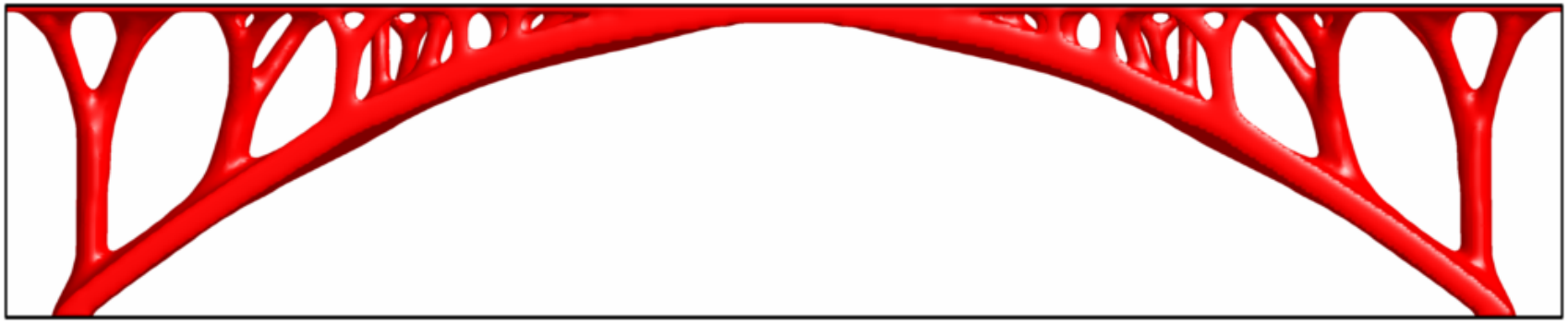
- NEED FOR A CONTINUATION SCHEME
  LX=25, LY=LZ=5, VOLFRAC=10%, R=5, Q=3 AND P=3



851,840 DVS FOR ¼
(3,407,360 TOTAL)

DENSITY-BASED TOP OPT

- BRIDGE PROBLEM
  LX=25, LY=LZ=5, VOLFRAC=10%, R=5, Q=3 AND P=[CONTIN.]



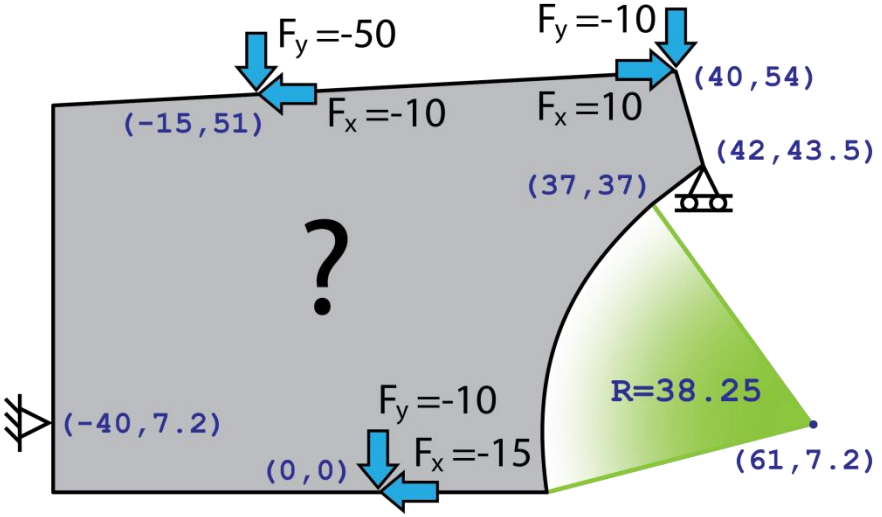
851,840 DVS FOR ¼
(3,407,360 TOTAL)

WHY UNSTRUCTURED?

- DENSITY-BASED TOPOLOGY OPTIMIZATION

HTTP://WWW.CANNONDALE.COM

CANNONDALE CAPO
(URBAN COMMUTER BIKE)

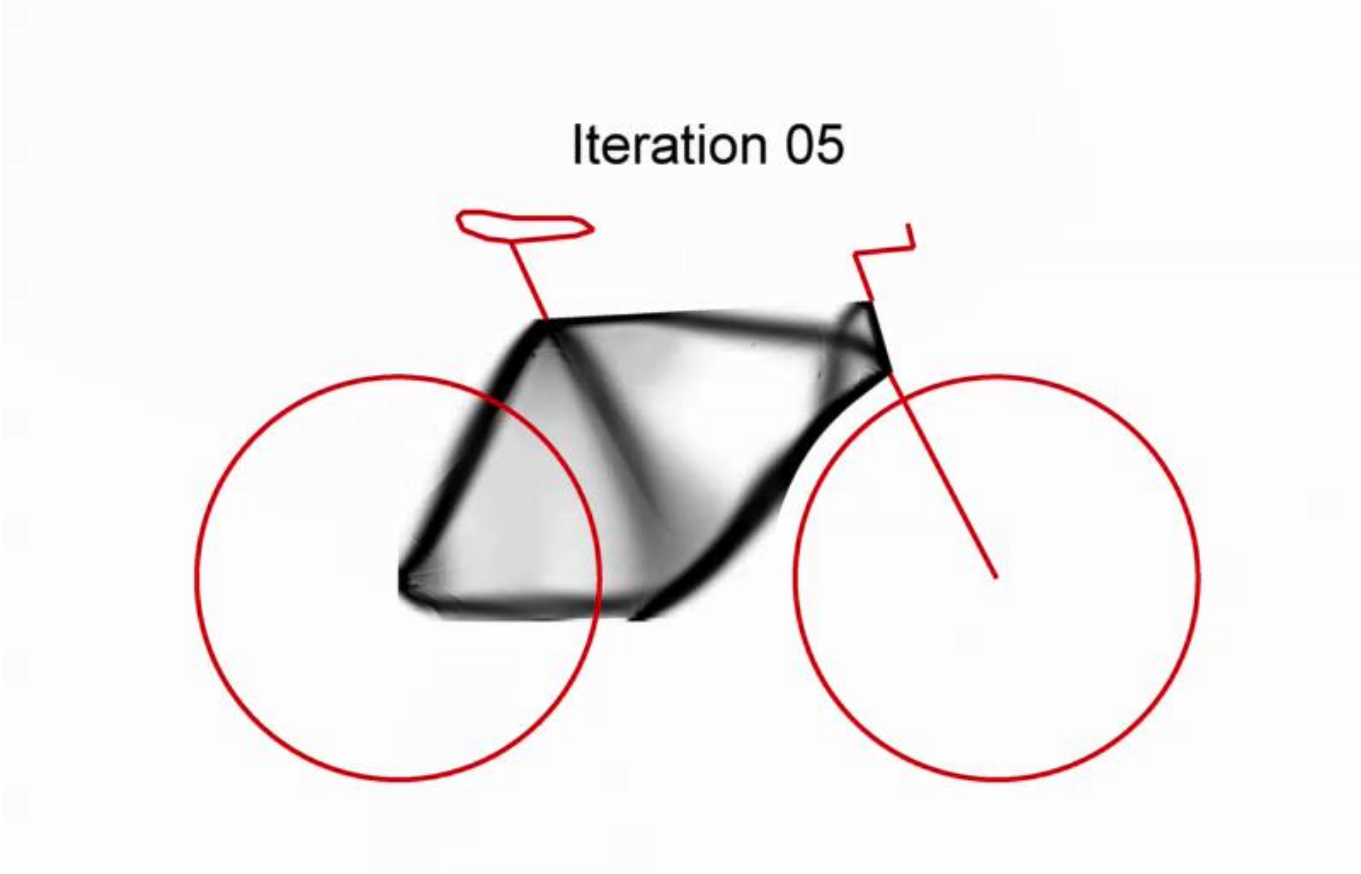


BIKE DOMAIN AND LOADS

ZEGARD T, PAULINO GH (2013) "TOWARD GPU ACCELERATED TOPOLOGY OPTIMIZATION ON UNSTRUCTURED MESHES." STRUCTURAL AND MULTIDISCIPLINARY OPTIMIZATION, 48(3):473-485

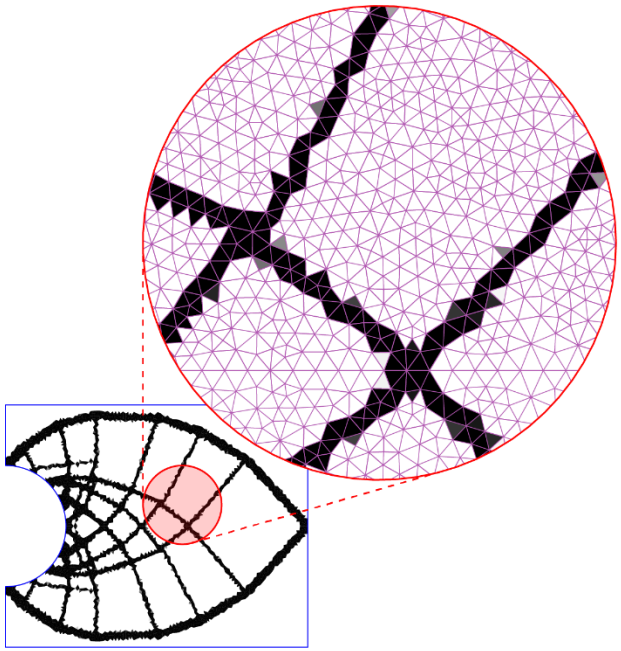
WHY UNSTRUCTURED?

- DENSITY-BASED TOPOLOGY OPTIMIZATION

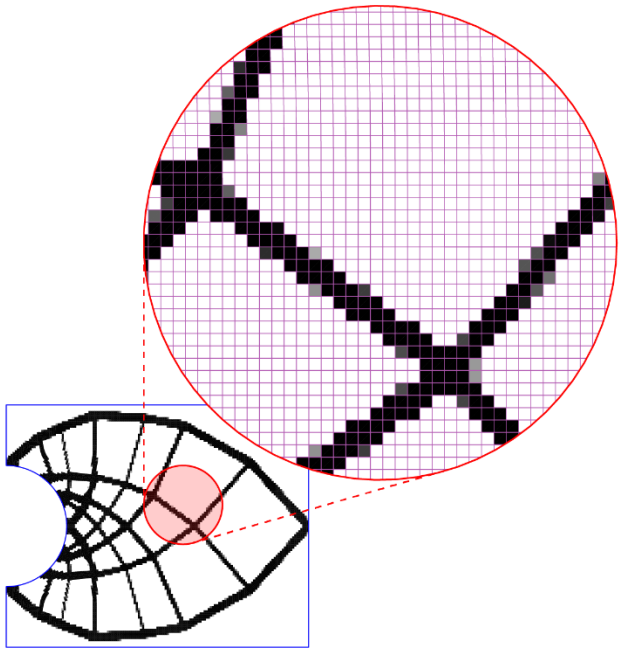


ZEGARD T, PAULINO GH (2013) "TOWARD GPU ACCELERATED TOPOLOGY OPTIMIZATION ON UNSTRUCTURED MESHES." STRUCTURAL AND MULTIDISCIPLINARY OPTIMIZATION, 48(3):473–485

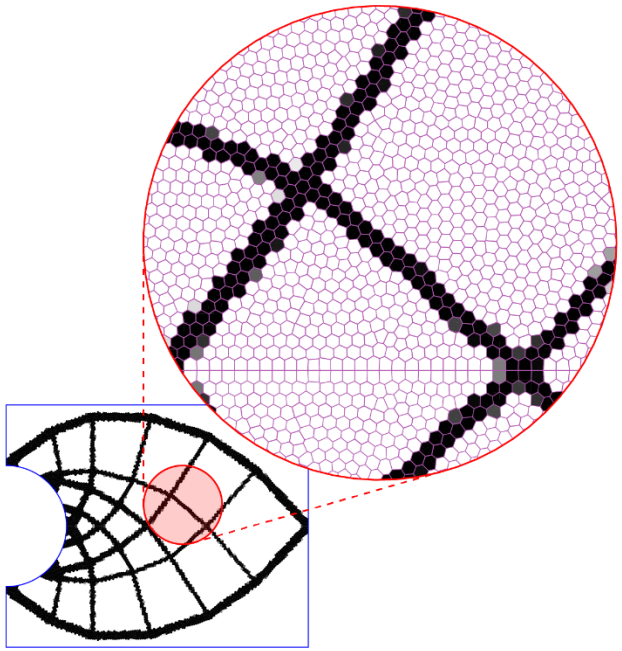
WHY POLYGONS/POLYTOPES?



16000 ELEMS



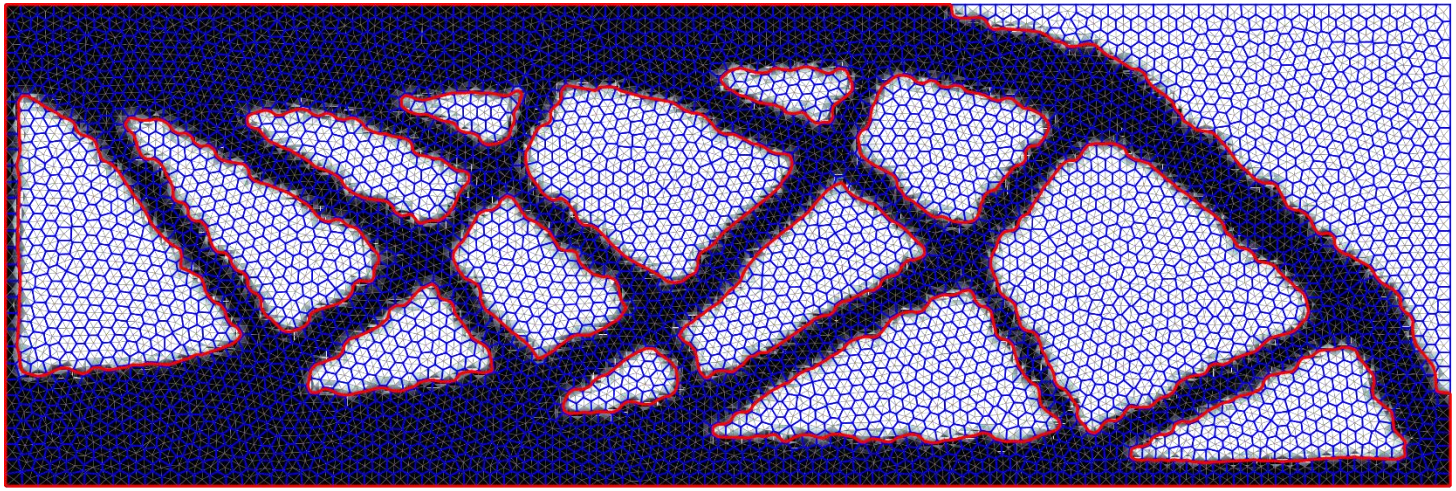
16016 ELEMS

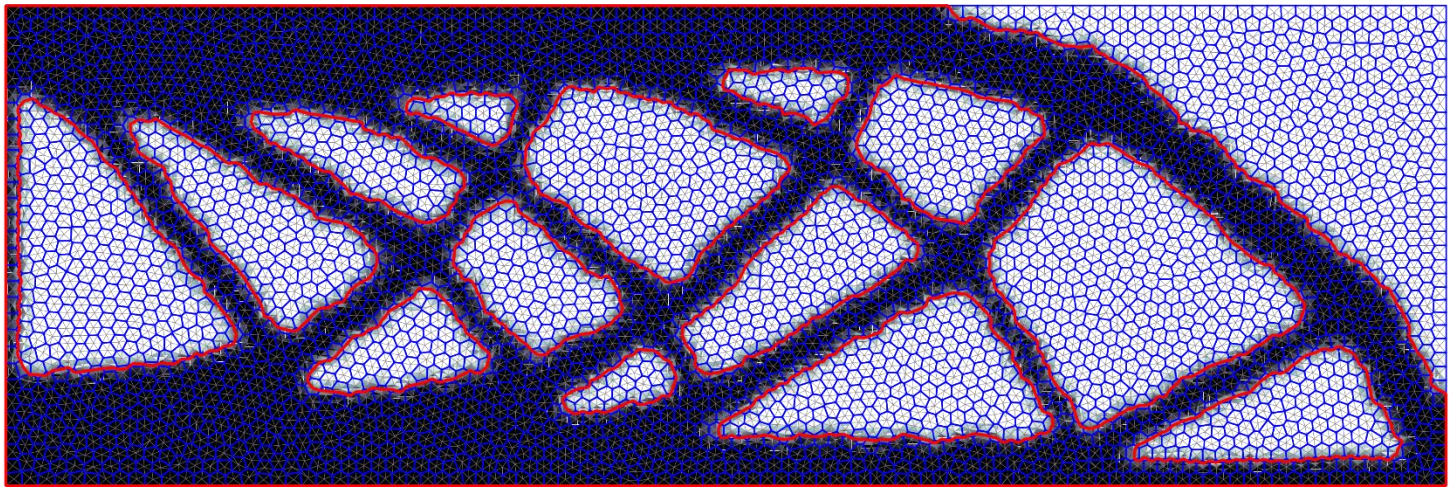


16000 ELEMS

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." JOURNAL OF STRUCTURAL AND MULTIDISCIPLINARY OPTIMIZATION. VOL. 45, NO. 3, PP. 329–357. 2012.

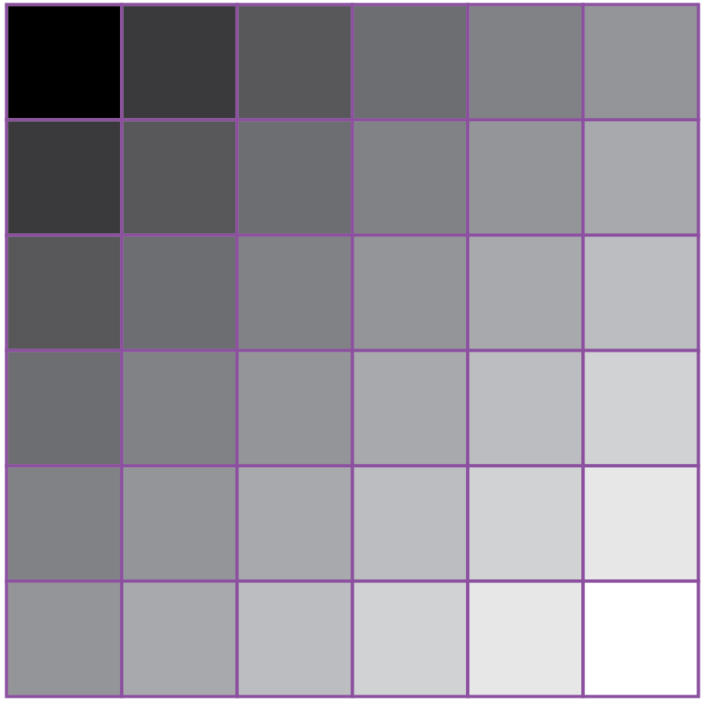
WHY POLYGONS/POLYTOPES?





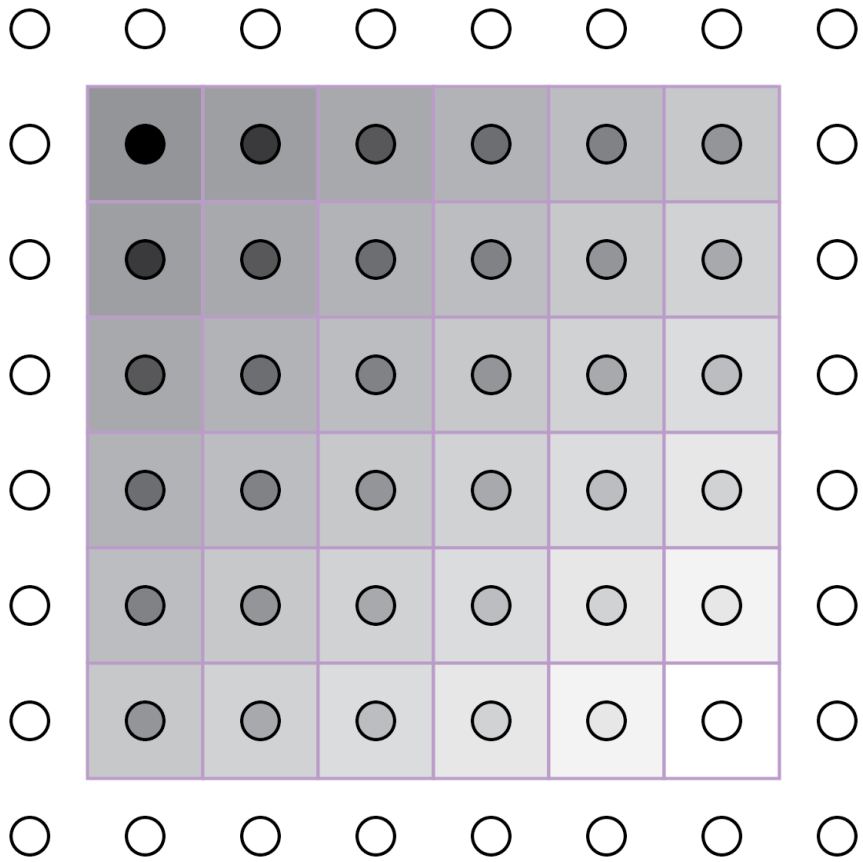
WHY POLYGONS/POLYTOPES

- NOT A PROBLEM IN GRID-STRUCTURED MESH



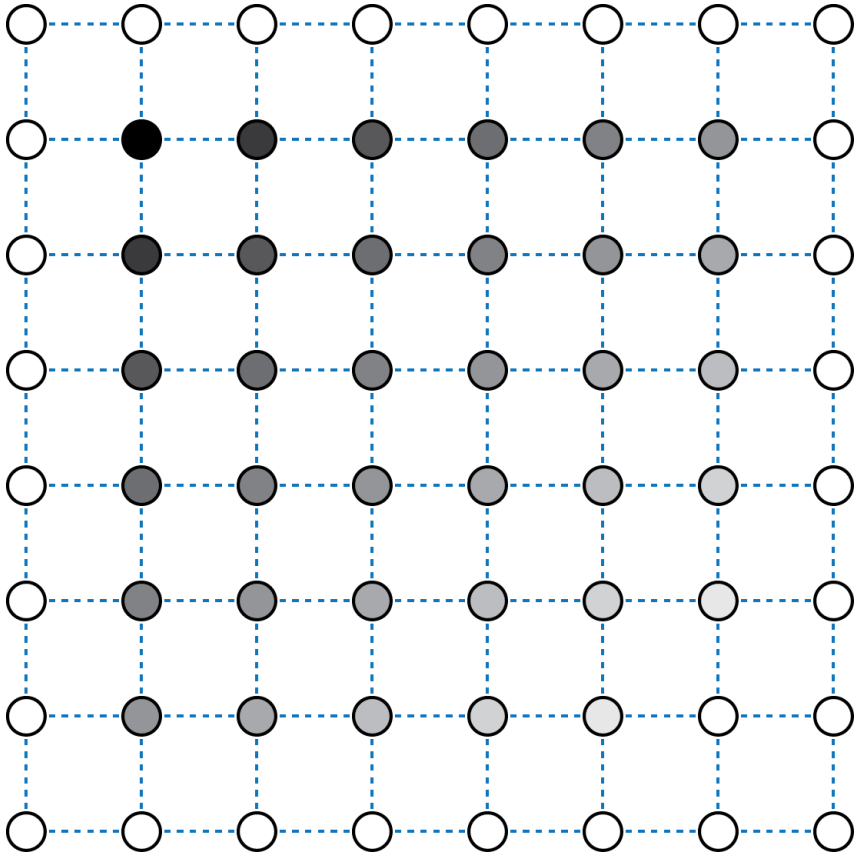
WHY POLYGONS/POLYTOPES

- NOT A PROBLEM IN GRID-STRUCTURED MESH



WHY POLYGONS/POLYTOPES

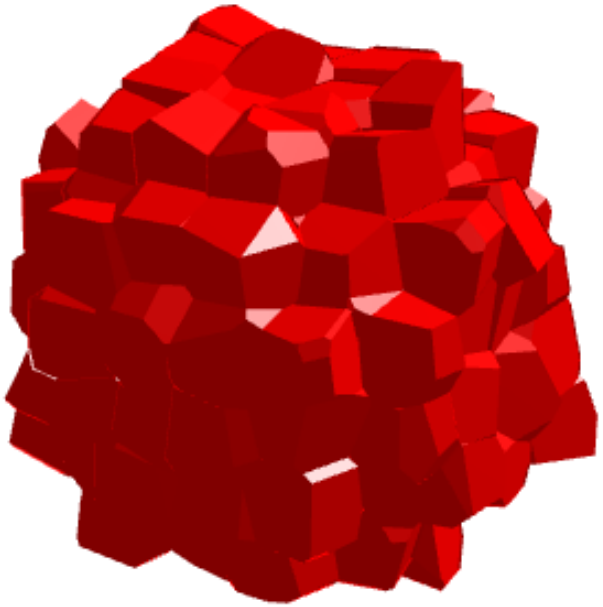
- NOT A PROBLEM IN GRID-STRUCTURED MESH



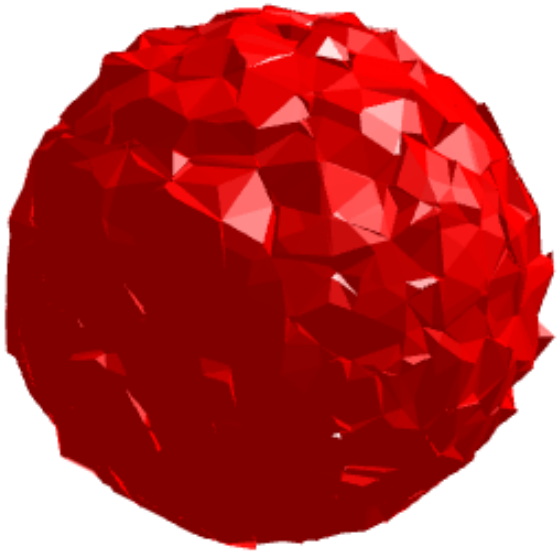
SAME AS CAMD!

INTERPRETATION / RACIONALIZATION

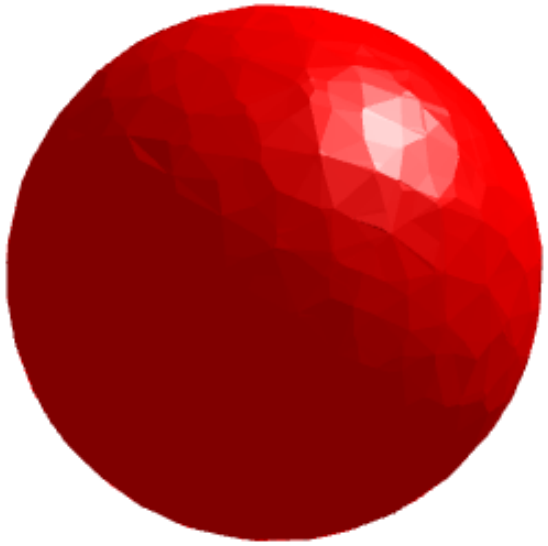
- IS THERE AN OPTIMAL RECOVERY METHOD?
  HOW CLOSE CAN WE GET TO THE SOLUTION ON THE RIGHT?



ELEMENT CUTOFF



MARCHING POLYTOPES
W/ NODAL AVERAGING



MARCHING POLYTOPES
(EXACT SOLUTION)

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." JOURNAL OF STRUCTURAL AND MULTIDISCIPLINARY OPTIMIZATION. VOL. 45, NO. 3, PP. 329–357. 2012.

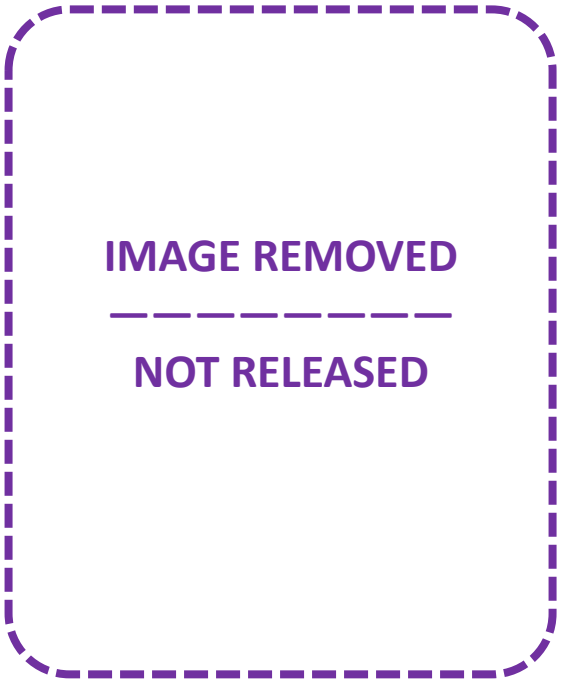
LARGER IMPACT

- BRIDGE — ACHIEVING LARGER SCALES?

LARGER IMPACT

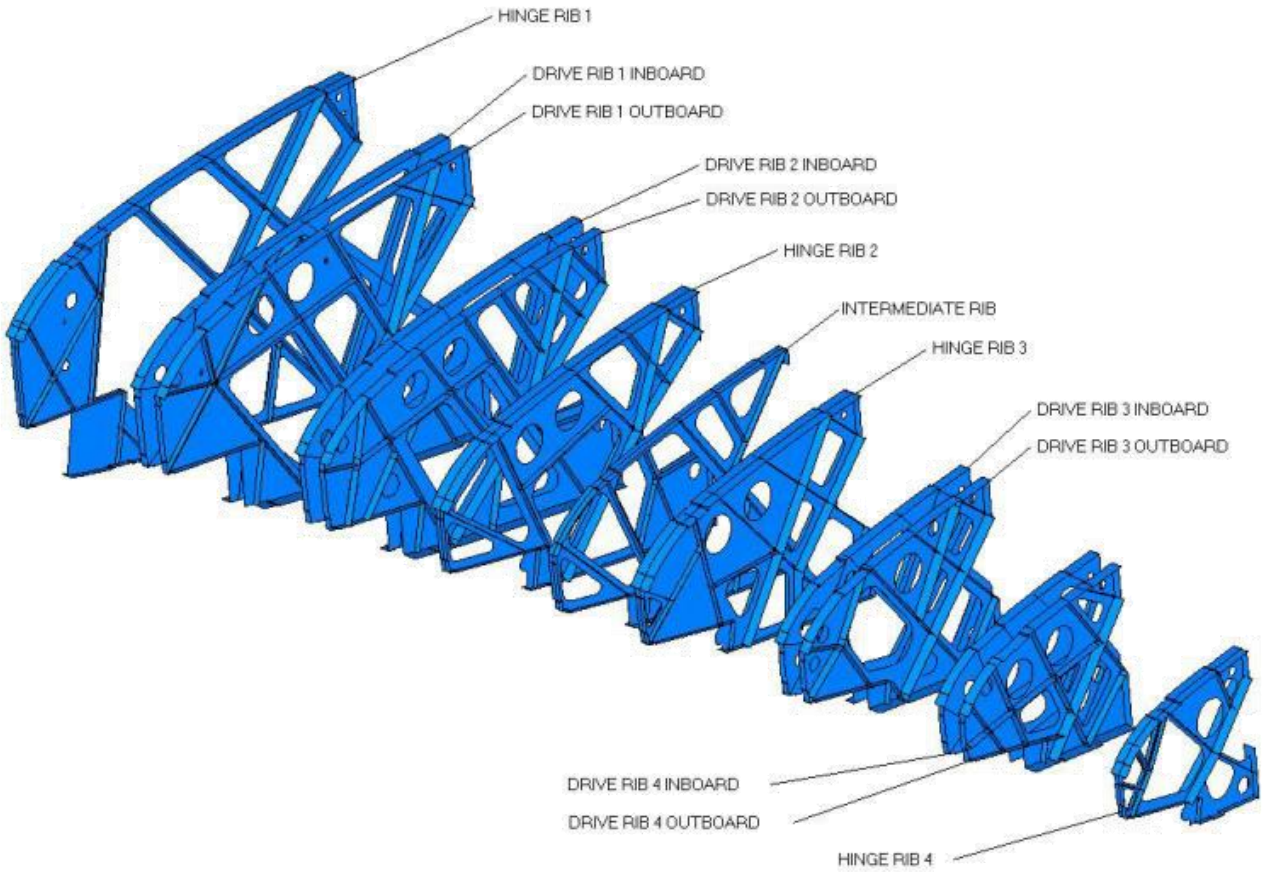
- AMIE V1.0

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



LARGER IMPACT

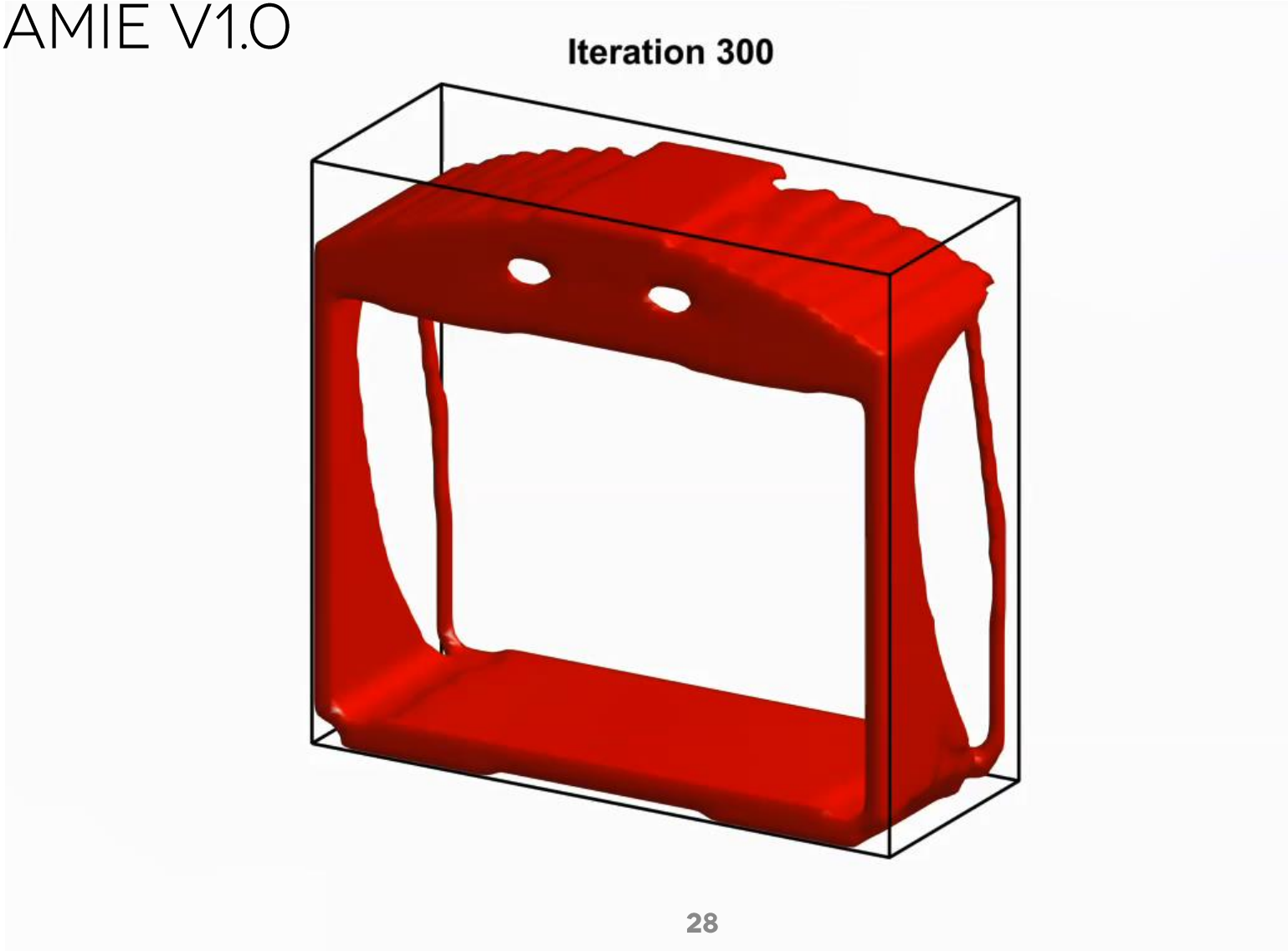
- AMIE V1.0



ALTAIR ENGINEERING

LARGER IMPACT

- AMIE V1.0



LARGER IMPACT

- AMIE V1.0

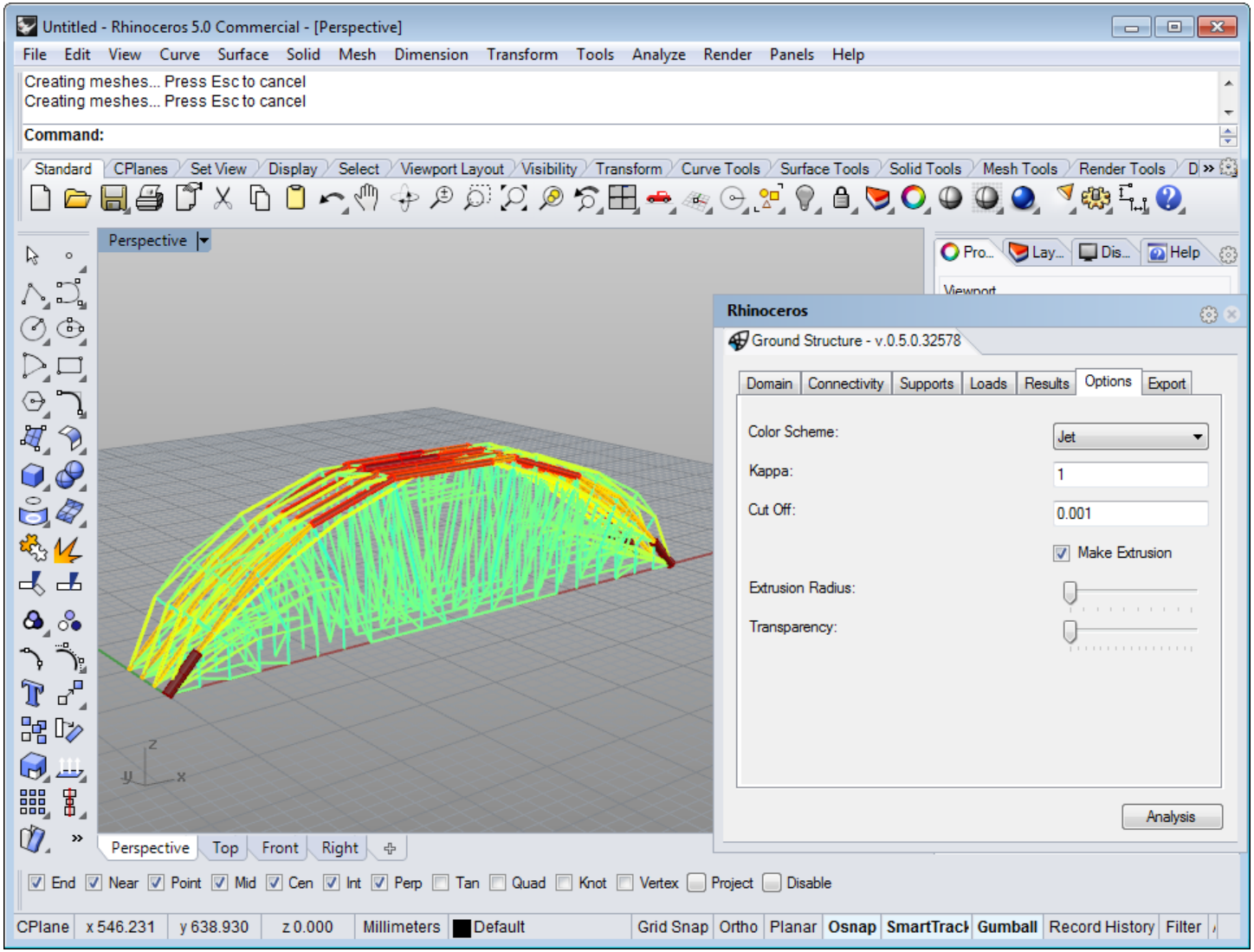
SKIDMORE, OWINGS & MERRILL LLP

LARGER IMPACT

- AMIE V1.0

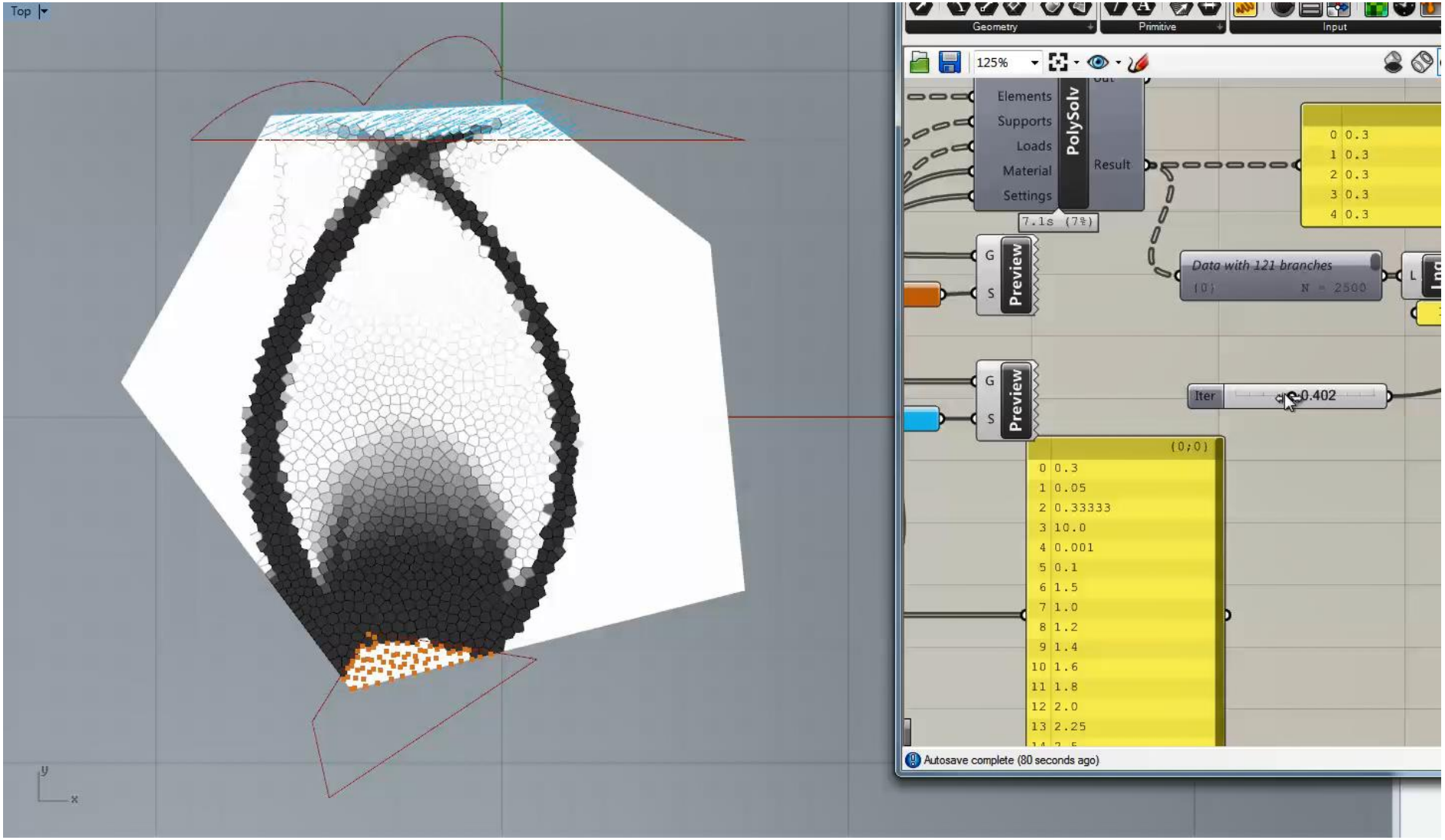
SKIDMORE, OWINGS & MERRILL LLP

TOOLS FOR BETTER DESIGN



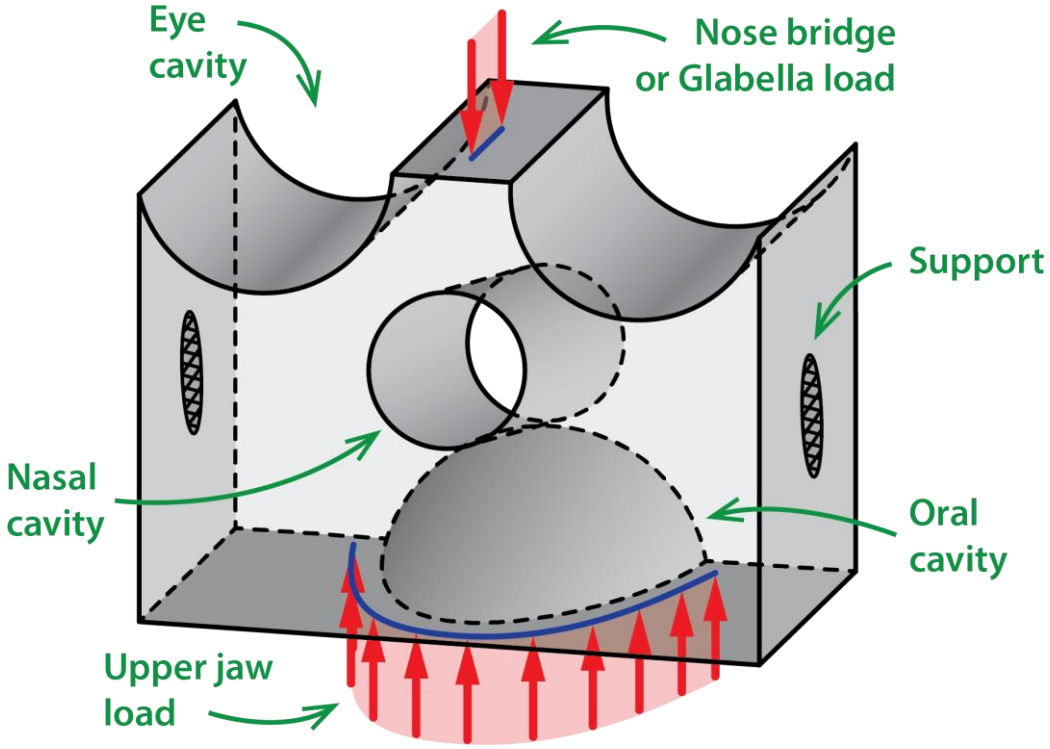
TOMAS ZEGARD & CHRISTIAN HARTZ | SOM LLP 2016

TOOLS FOR BETTER DESIGN



NEW APPLICATIONS FIELDS

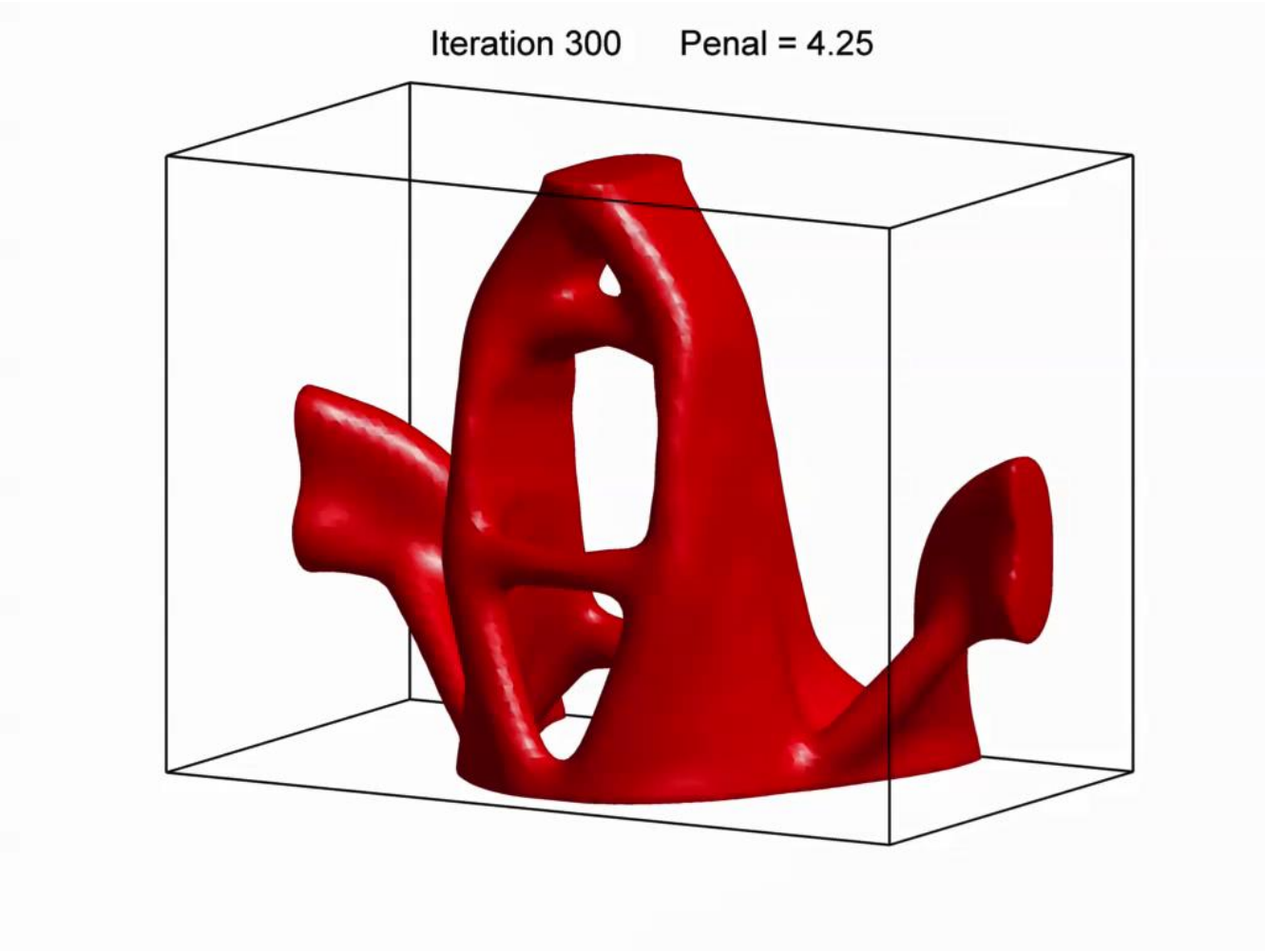
- CRANIOFACIAL RECONSTRUCTION



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

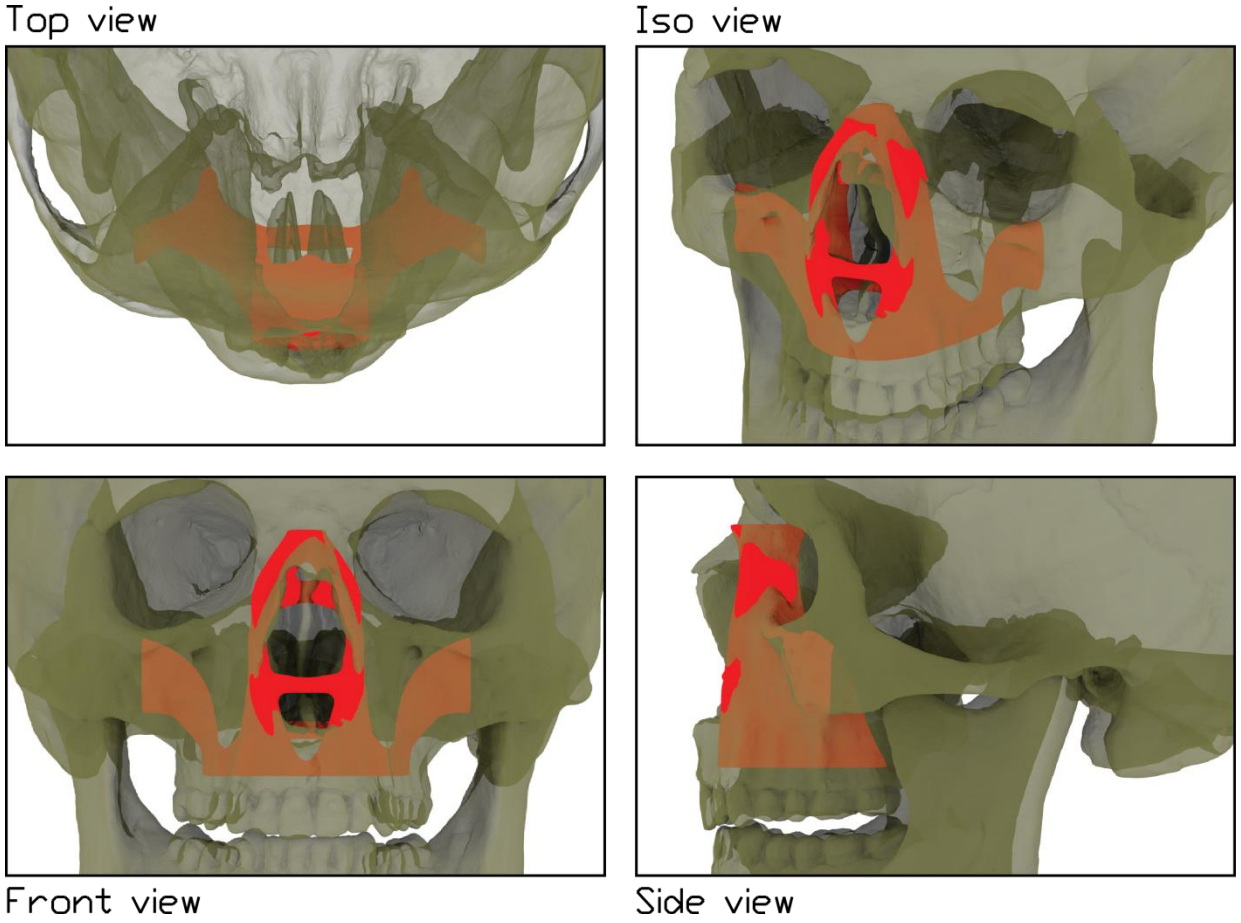
NEW APPLICATIONS FIELDS

- CRANIOFACIAL RECONSTRUCTION



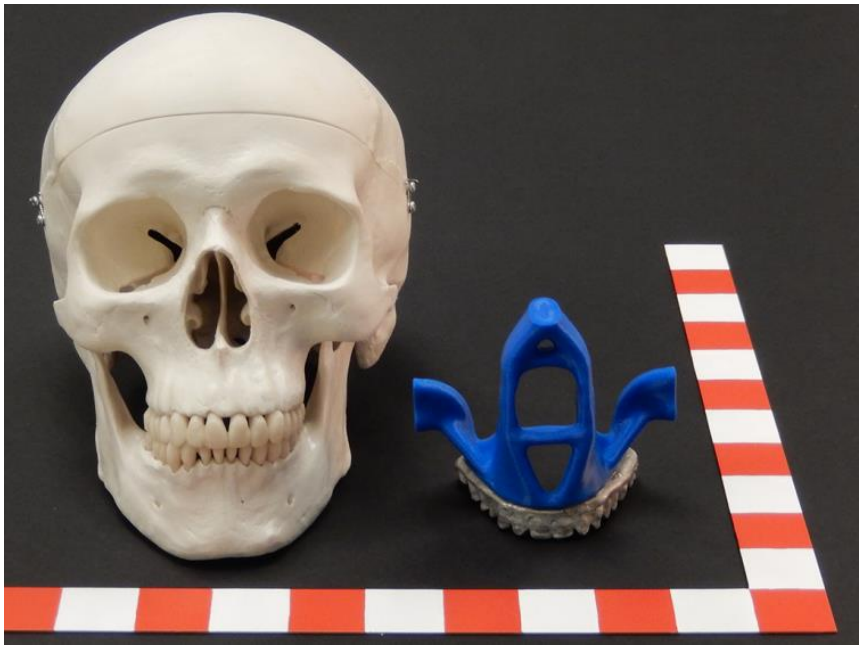
NEW APPLICATIONS FIELDS

- CRANIOFACIAL RECONSTRUCTION



NEW APPLICATIONS FIELDS

- CRANIOFACIAL RECONSTRUCTION



THINGS TO TAKE AWAY

- USE HIGHER-ORDER FILTERS
- USE CONTINUATION
  - MUST WITH DISTRIBUTED LOADS
- BETTER SURFACE INTERPOLATION
  - NODAL DENSITY RECOVERY
- TOOL DEVELOPMENT AND INTEGRATION
  - BRANCH OUT TO OTHER FIELDS

THE END