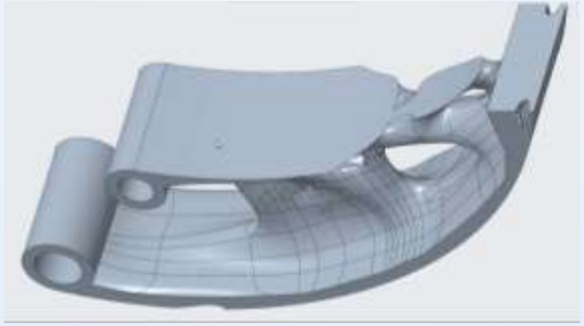
Democratization of Topology Optimization with GENESIS & CREO



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Principal at Advanced Engineering Solutions

October 2, 2018 | Plymouth, MI

What is Generative Design?

- **Generative design** (GD) is the automatic process to generate optimum feasible designs from a set of performance requirements and design rules
- Generative Design is a fundamentally disruptive **paradigm shift** . In traditional design process we build virtual or physical prototypes and then we evaluate with simulation or experiment their performance requirements. GD spawns the designs
- The emerging Generative Design technologies use algorithms to generate every possible permutation of a design solution. The designer simply enters a **range of parameters** (mass fraction, safety factor) and then chooses the *best* outcome generated by the software
- First enabler is **Topology Optimization**

Elbe Philharmonic Hall

Foam Lattice structures

1 First Enabler of GD: Topology Optimization

- Only Genesis-CREO TO automatically Reconstructs the Geometry
- Design Automation "brakes down" with all other Topology Optimization tools
- CAD reconstruction is not trivial (SC, Sub-D, PTC/Freestyle, Altair/Inspire, Dassault Systems 3DX, SANDIA)
- Why bother with **CAD/NURBS**?
  - Size optimization, morphing, post-processing
  - High quality mesh for validation step
  - In the age of MBD/MBE we need:
    - Accurate mass properties
    - Semantic GD&T
    - Automated Assembly Tolerance Analyses
    - Inspection/Verification & process definition for metrology (QIF)
    - Technical Data Package (TDP) for NASA & DOE projects
- Why bother with **Facets**/.stl
  - Validation step becomes easy (re-mesh skin and then volume)
  - File size matters (i.e. larger number lattice members)
  - Cellular Lattice generation

AUTODESK

Altair

VR&D

DASSAULT SYSTEMES

ANSYS

ptc

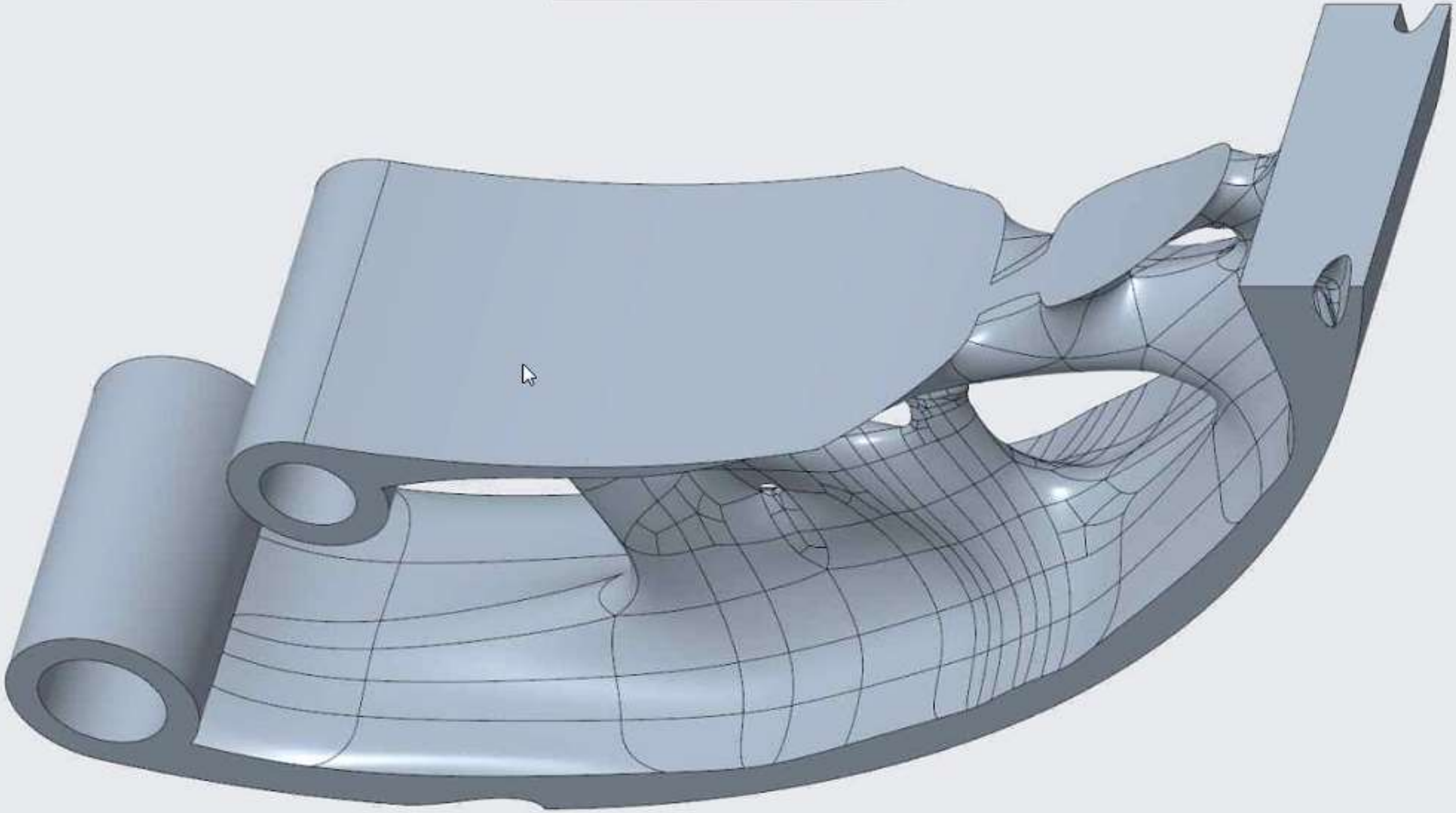
Sandia National Laboratories

Topology Optimization Output

1

CAD Reconstruction can be automated with CREO 5

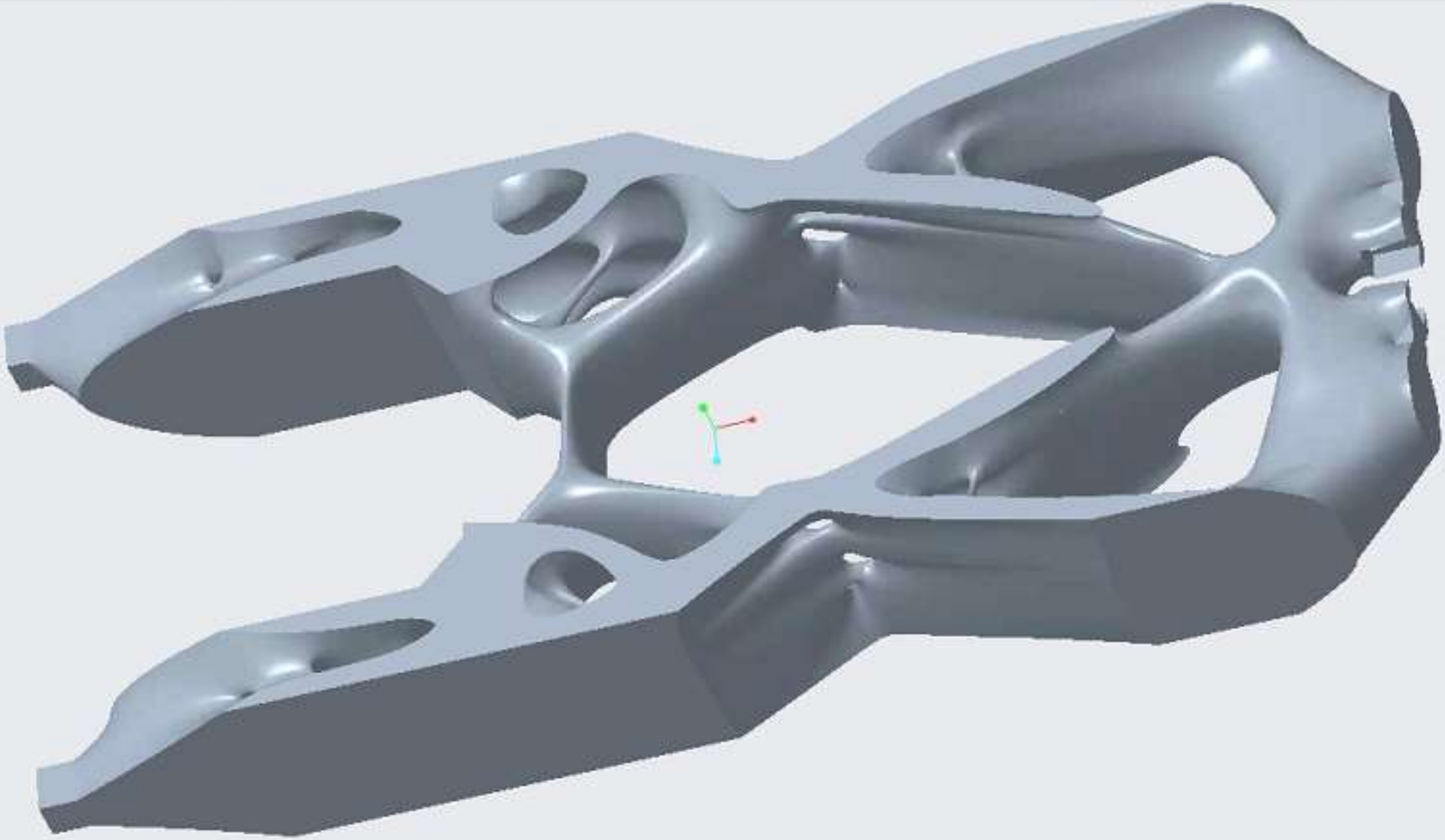
1 Sub-Divisional Surface Modeling with free-style feature



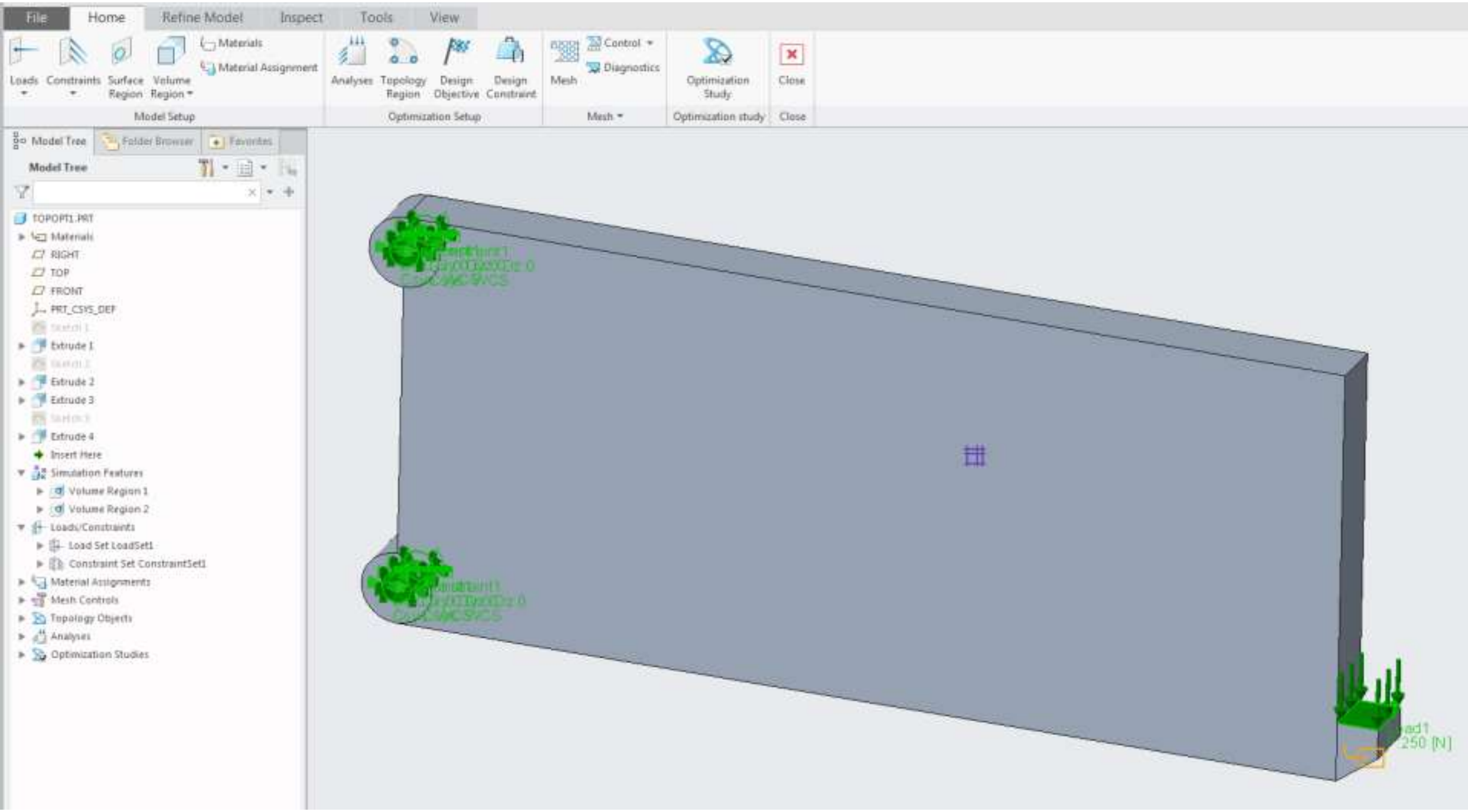
Sub-D models are great for:

Geometry morphing, MBD and Meshing for Validation
Compliance mechanism with automatic CAD reconstruction

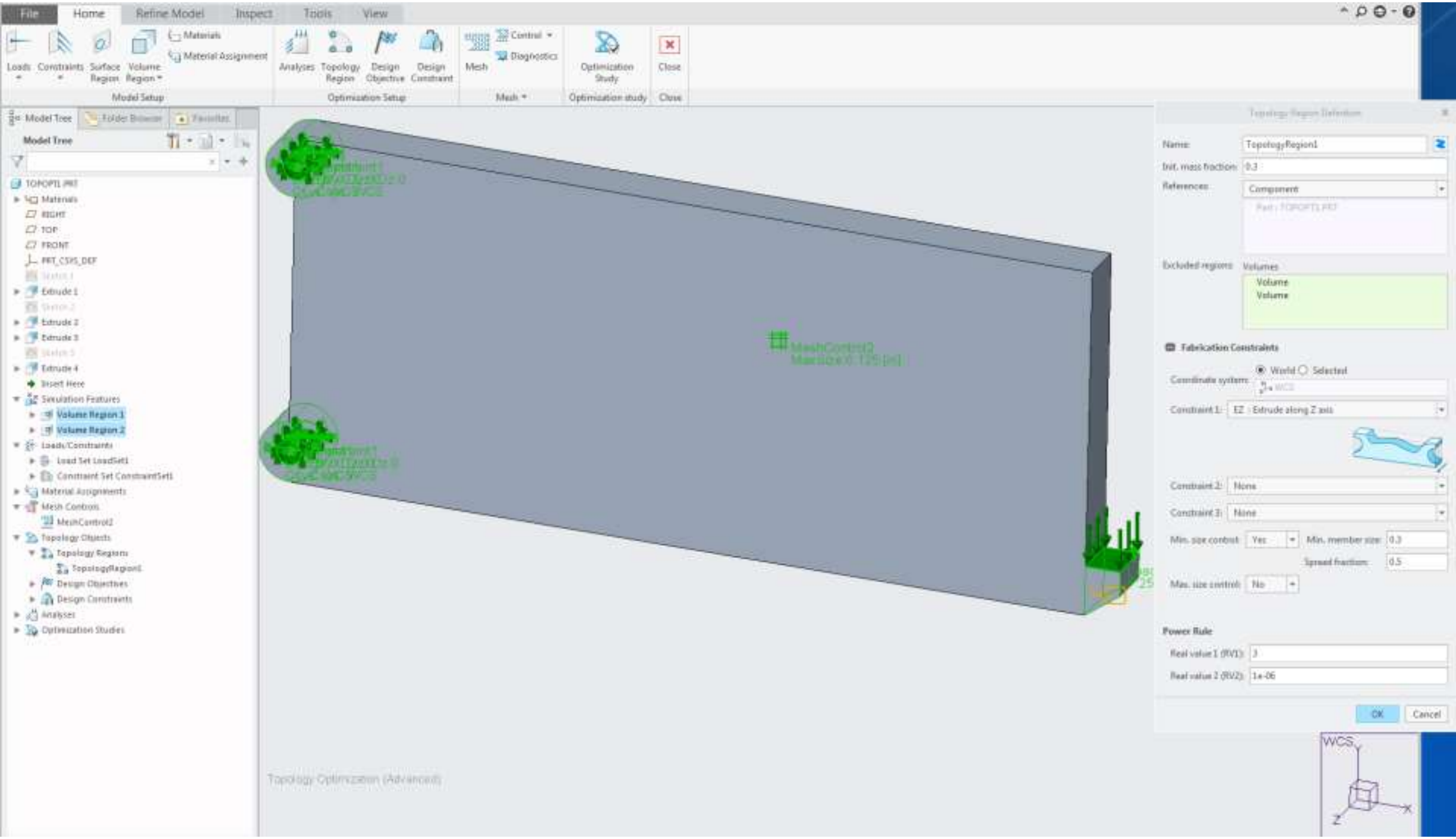
1



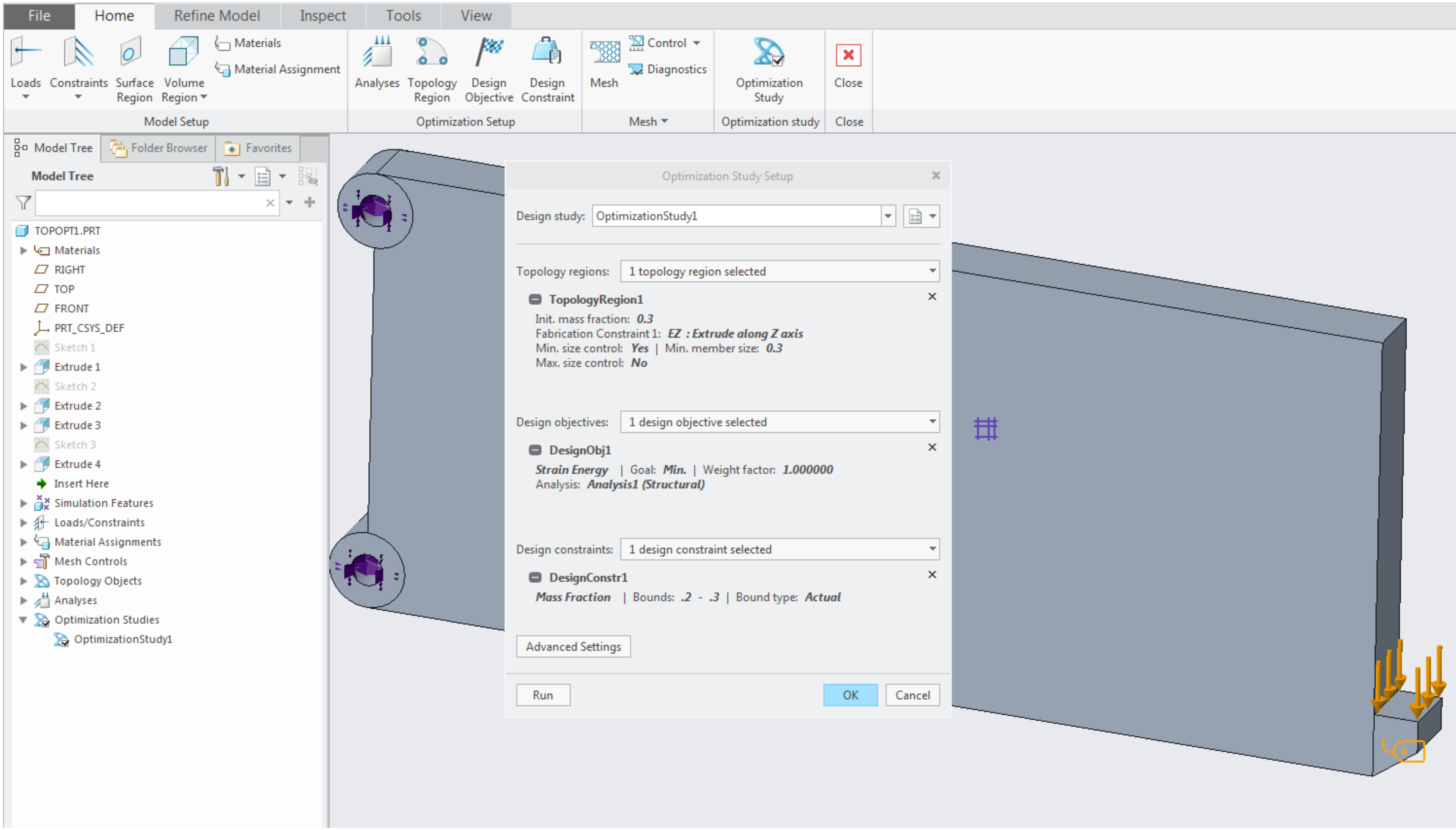
Simple setup of Topology Optimization Regions Loading, BC and Volume Regions within CREO

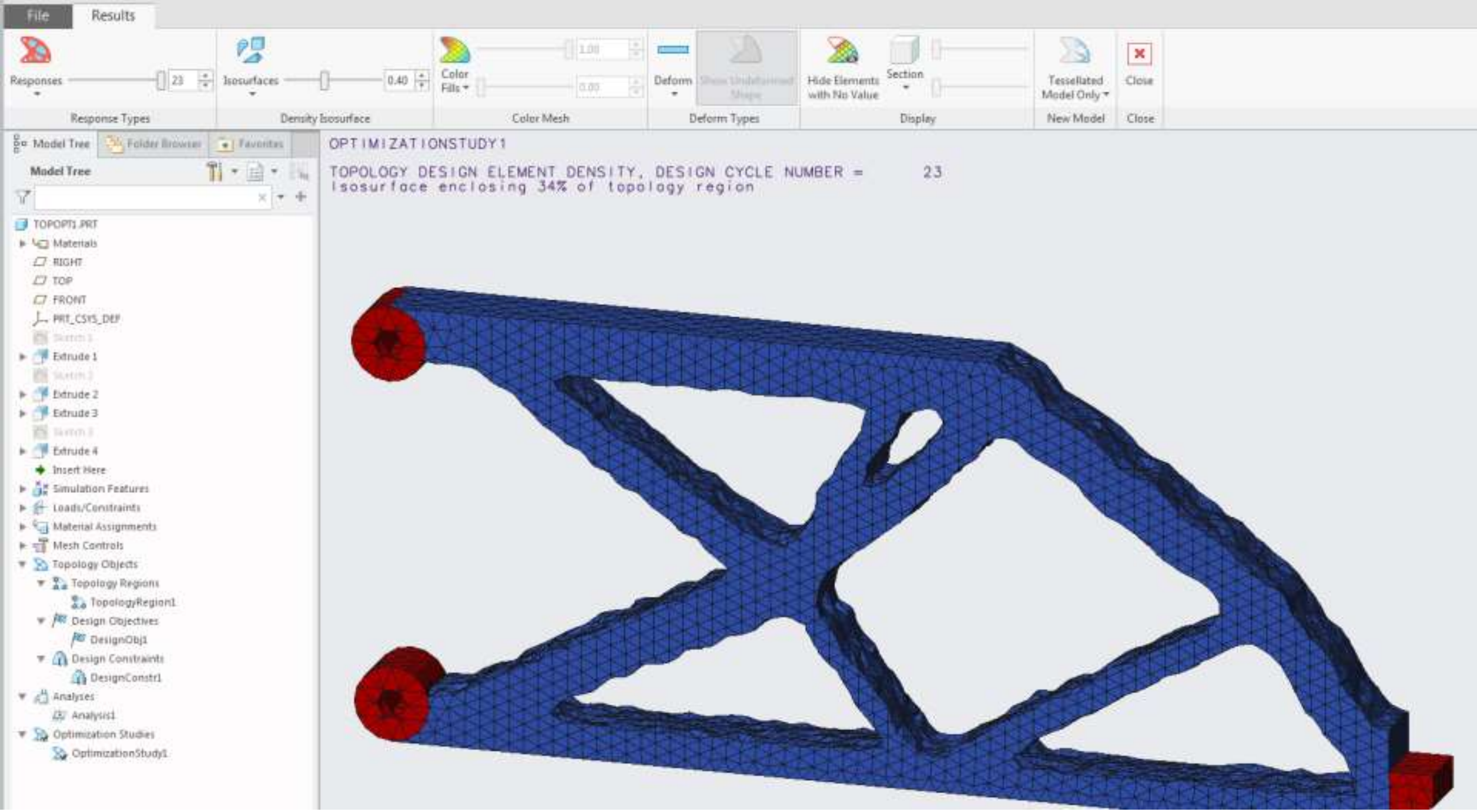


Simple Definition of Fabrication Constraints

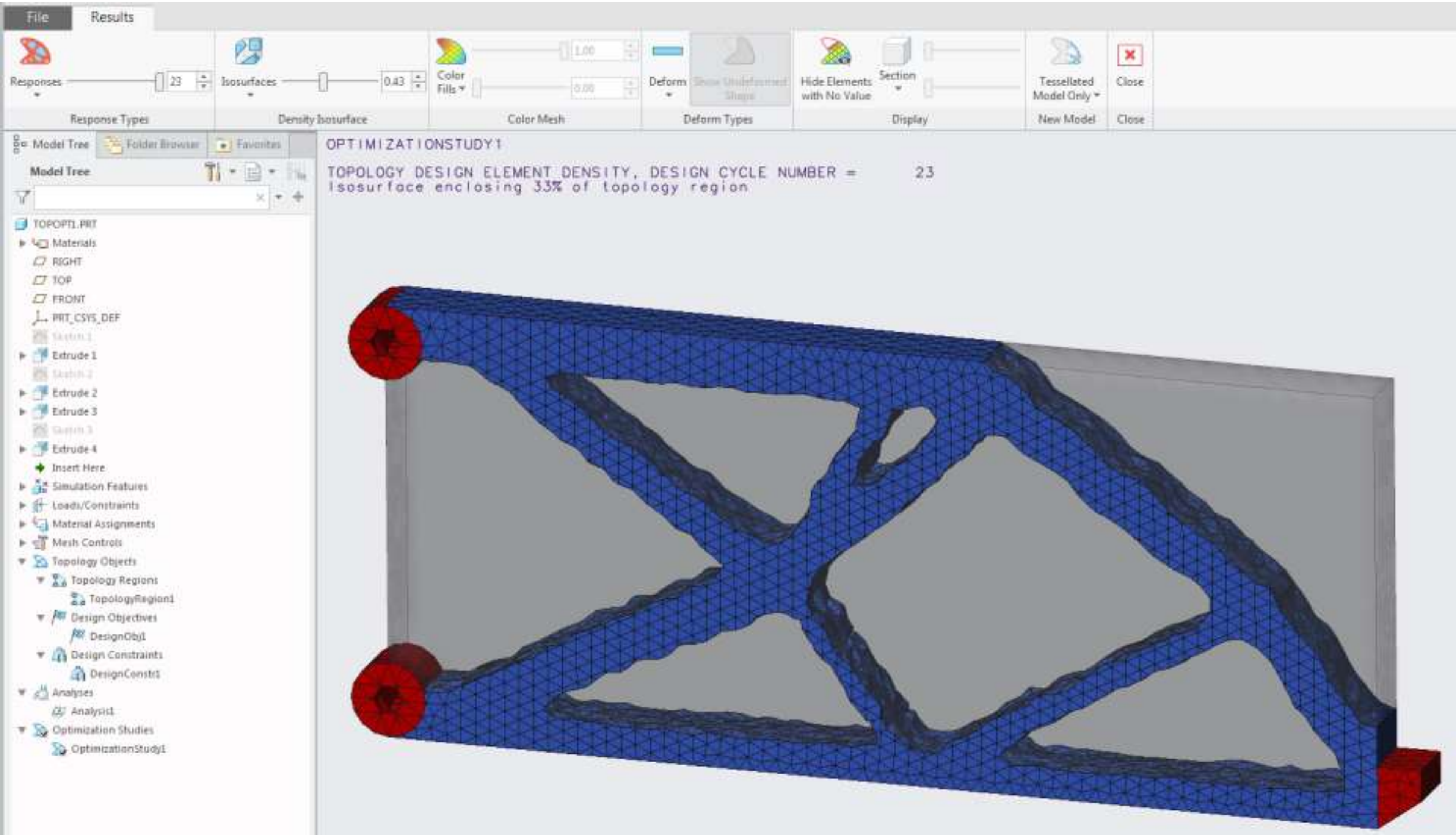


Simple Optimization Study setup



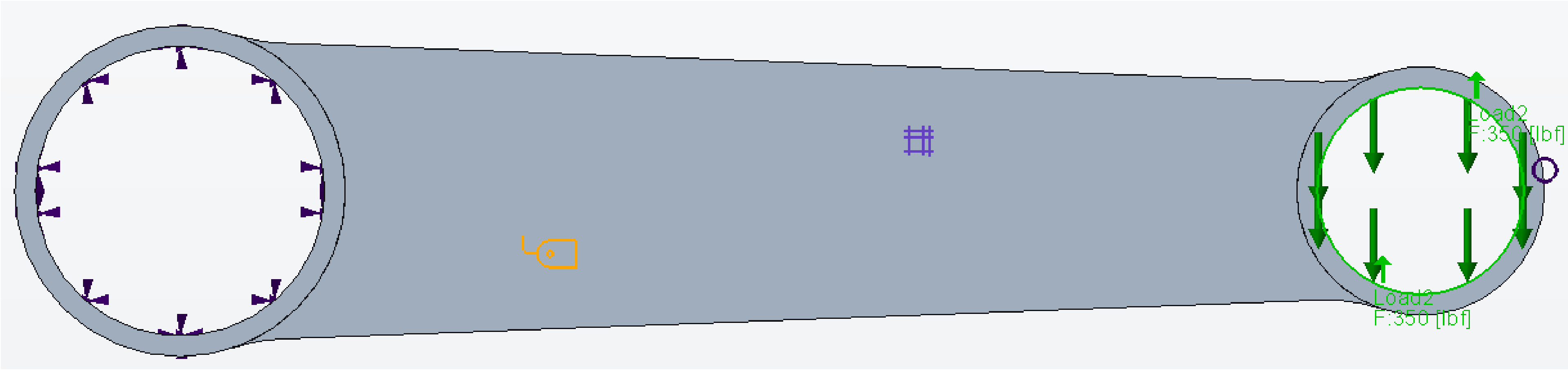

File
Results
Responses
Isosurfaces
Color Fills
Deform
Hide Elements with No Value
Section
Tessellated Model Only
Close
Response Types
Density Isosurface
Color Mesh
Deform Types
Display
New Model
Close
Model Tree
OPTIMIZATIONSTUDY1
TOPOLOGY DESIGN ELEMENT DENSITY, DESIGN CYCLE NUMBER = 23
Isosurface enclosing 34% of topology region
TOPOPT1.PRT
Materials
RIGHT
TOP
FRONT
PRT_CSYS_DEF
Extrude 1
Extrude 2
Extrude 3
Extrude 4
Insert Here
Simulation Features
Loads/Constraints
Material Assignments
Mesh Controls
Topology Objects
Topology Regions
TopologyRegion1
Design Objectives
DesignObj1
Design Constraints
DesignConstr1
Analyses
Analysis1
Optimization Studies
OptimizationStudy1

Design Region and Topology Optimization Results



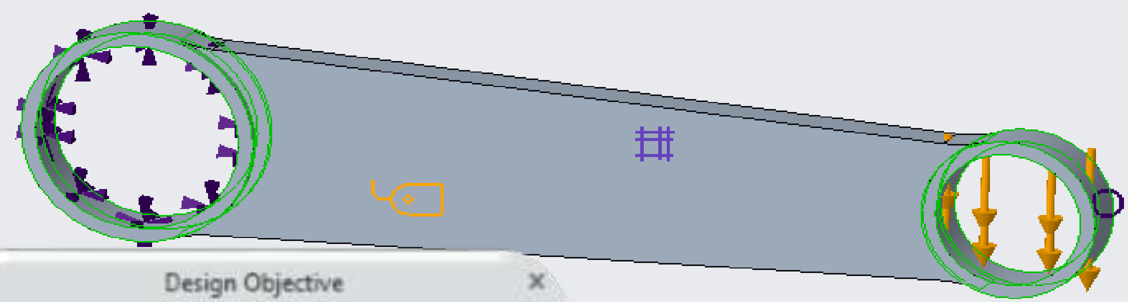
Example 2 Robotic Arm Link

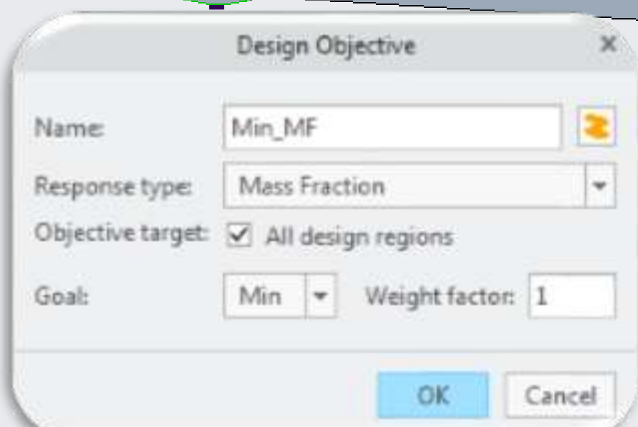
- Objective: Minimize Mass
- Constraints:
  - Maximum Von Mises Stress < 36 ksi
  - Maximum Vertical Displacement < 0.04 in
  - First Natural Frequency (out of Plane Mode) > 75 Hz
  - Third Natural Frequency (in Plane Mode) > 400 Hz

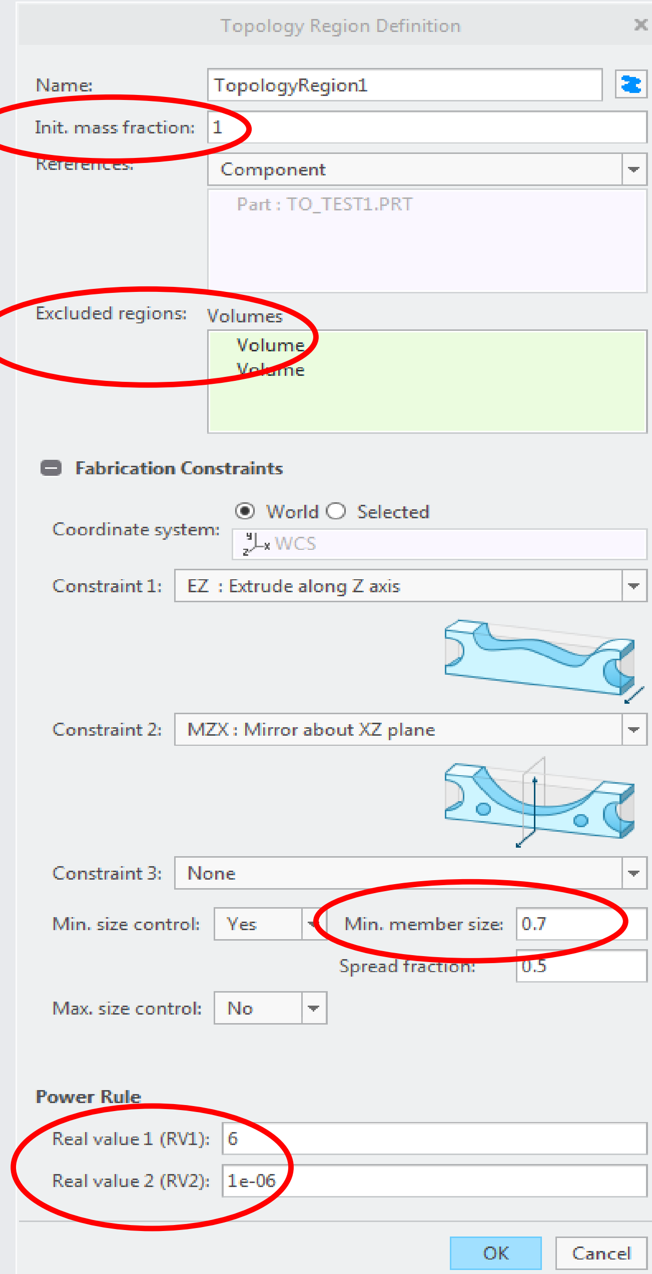


Topology Region & Design Objective Setup

- Topology Region
  - Initial mass fraction 1.0
  - Volume Regions are excluded
  - Fabrication Constraint 1 Extrude along Z axis
  - Fabrication Constraint 2 Mirror about XZ plane
  - Minimum Member Size 0.7 in
  - Power Rule RV1 8
- Design Objective
  - Minimize mass Fraction

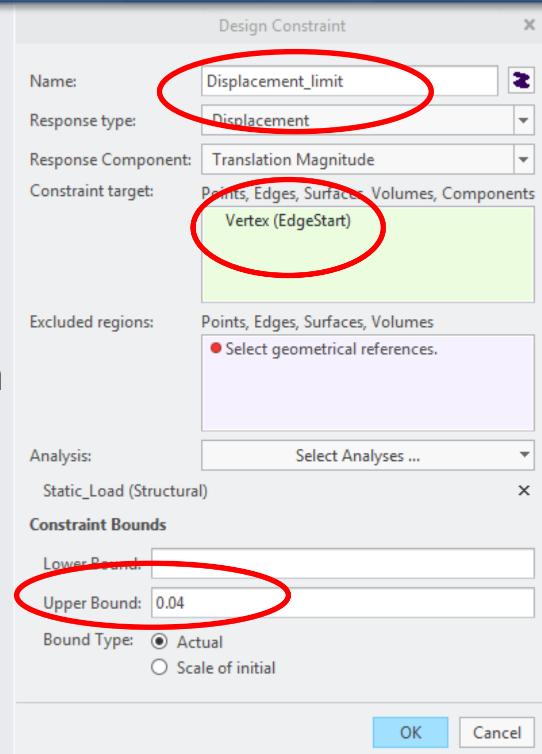


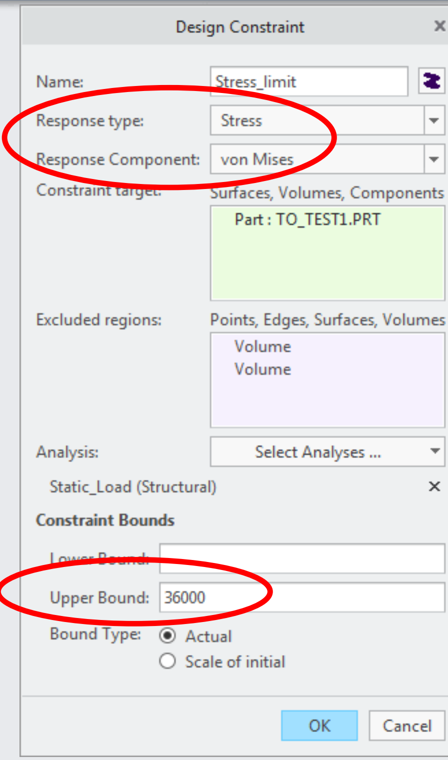


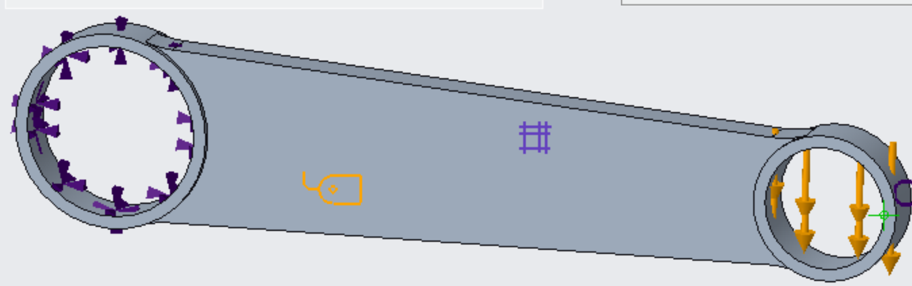


Design Constraints Setup

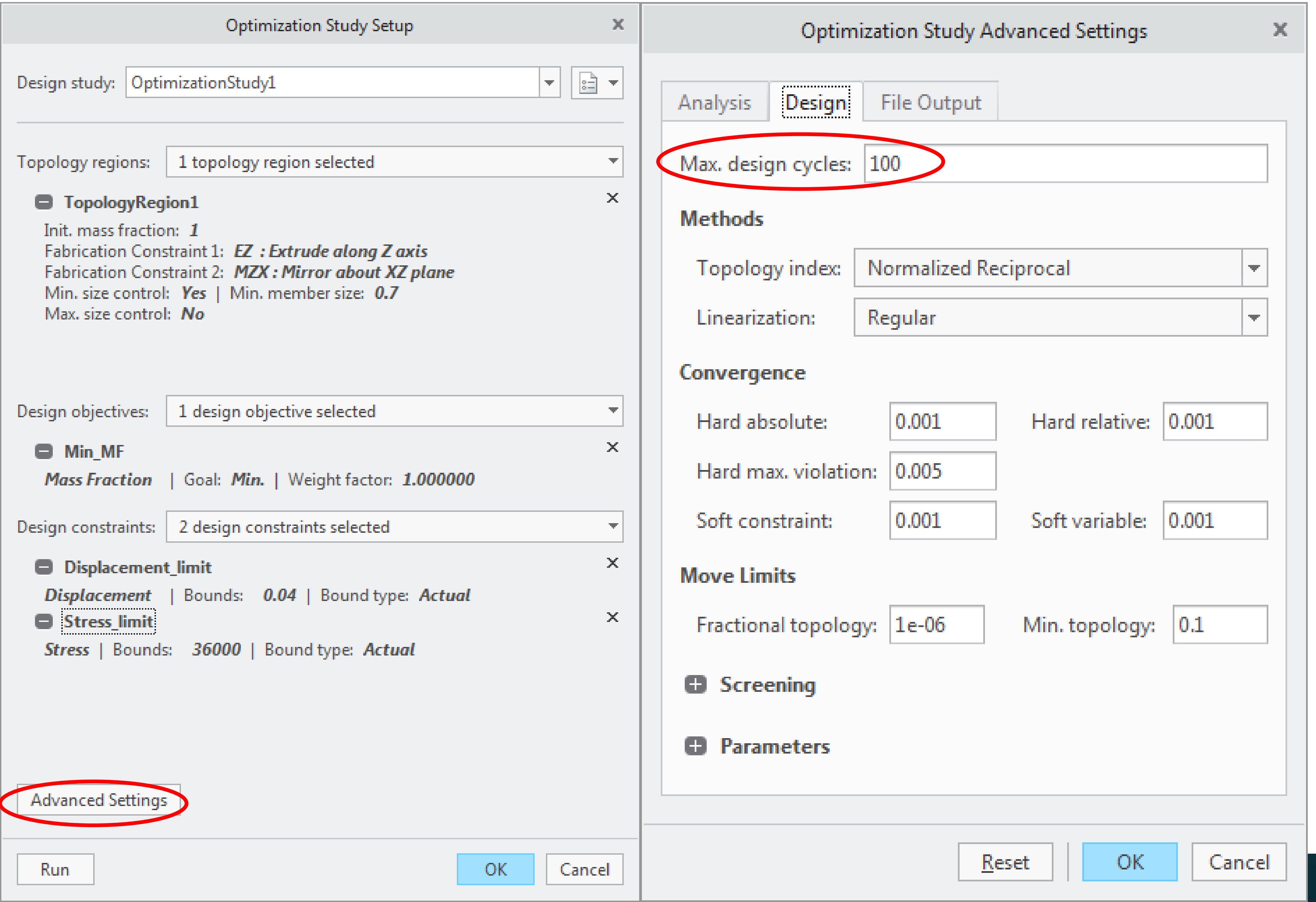
- Design Constraint #1
  - Maximum displacement less than 0.4 in
- Design Constraint #2
  - Maximum Stress less than 36,000 psi







Optimization Study Setup



Convergence Monitoring & Results Viewing during execution

Optimization Status (OptimizationStudy1)

Optimization Status

Design Cycle	:	49
Objective	:	5.183537E-01
Maximum Violation	:	0.0%
Time Elapsed	:	00:14:45
Status	:	Hard Convergence

```
  10      7.5113E-01          0.0%
  11      7.3786E-01          0.0%
  12      7.2498E-01          0.0%
  13      7.1265E-01          0.0%
  14      7.0133E-01          0.1%
  15      6.9269E-01          0.2%
  16      6.8717E-01          0.1%
  17      6.8360E-01          0.0%
  18      6.8068E-01          0.0%
  19      6.7793E-01          0.0%
  20      6.7513E-01          0.0%
  21      6.7194E-01          0.0%
  22      6.6828E-01          0.0%
  23      6.6387E-01          0.0%
  24      6.5859E-01          0.0%
  25      6.5252E-01          0.0%
  26      6.4579E-01          0.0%
  27      6.3844E-01          0.0%
  28      6.3050E-01          0.0%
  29      6.2220E-01          0.0%
  30      6.1353E-01          0.0%
  31      6.0458E-01          0.0%
  32      5.9542E-01          0.0%
  33      5.8613E-01          0.0%
  34      5.7667E-01          0.0%
  35      5.6715E-01          0.0%
  36      5.5749E-01          0.0%
  37      5.4780E-01          0.0%
  38      5.4264E-01          0.0%
  39      5.3795E-01          0.0%
  40      5.3392E-01          0.0%
  41      5.3084E-01          0.0%
  42      5.2816E-01          0.0%
  43      5.2564E-01          0.0%
  44      5.2382E-01          0.0%
  45      5.2229E-01          0.0%
  46      5.2086E-01          0.0%
  47      5.1959E-01          0.0%
  48      5.1878E-01          0.0%
  49      5.1835E-01          0.0%
 COMPLETION CODE: 1
CPU TIME SPENT IN MODULE HCONVG =    49.06 SEC, IN TOTAL =      842. SEC
  ELAPSED TIME IN MODULE HCONVG =    49.00 SEC, IN TOTAL =      884. SEC
CPU TIME SPENT IN MODULE TSURF  =     0.78 SEC, IN TOTAL =      843. SEC
  ELAPSED TIME IN MODULE TSURF  =     1.00 SEC, IN TOTAL =      885. SEC
CPU TIME SPENT IN MODULE FINISH =     0.08 SEC, IN TOTAL =      843. SEC
  ELAPSED TIME IN MODULE FINISH =     0.00 SEC, IN TOTAL =      885. SEC
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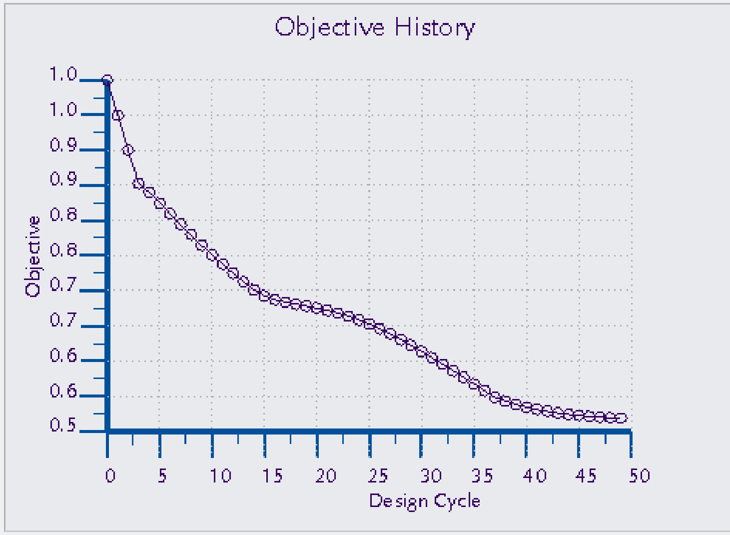
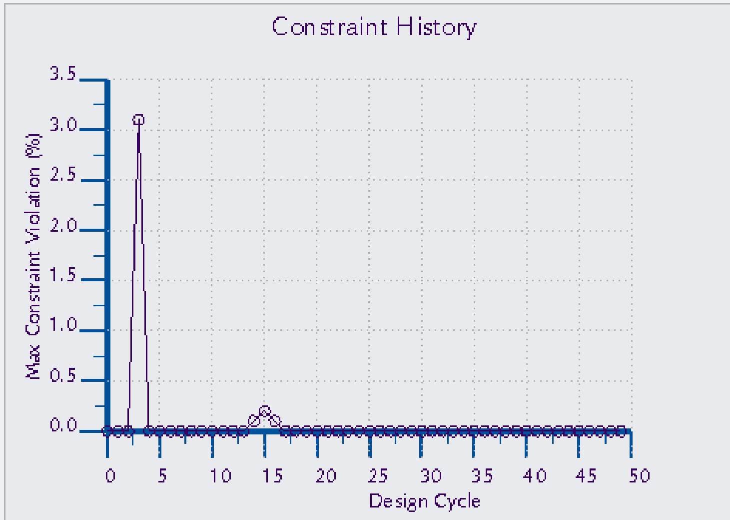


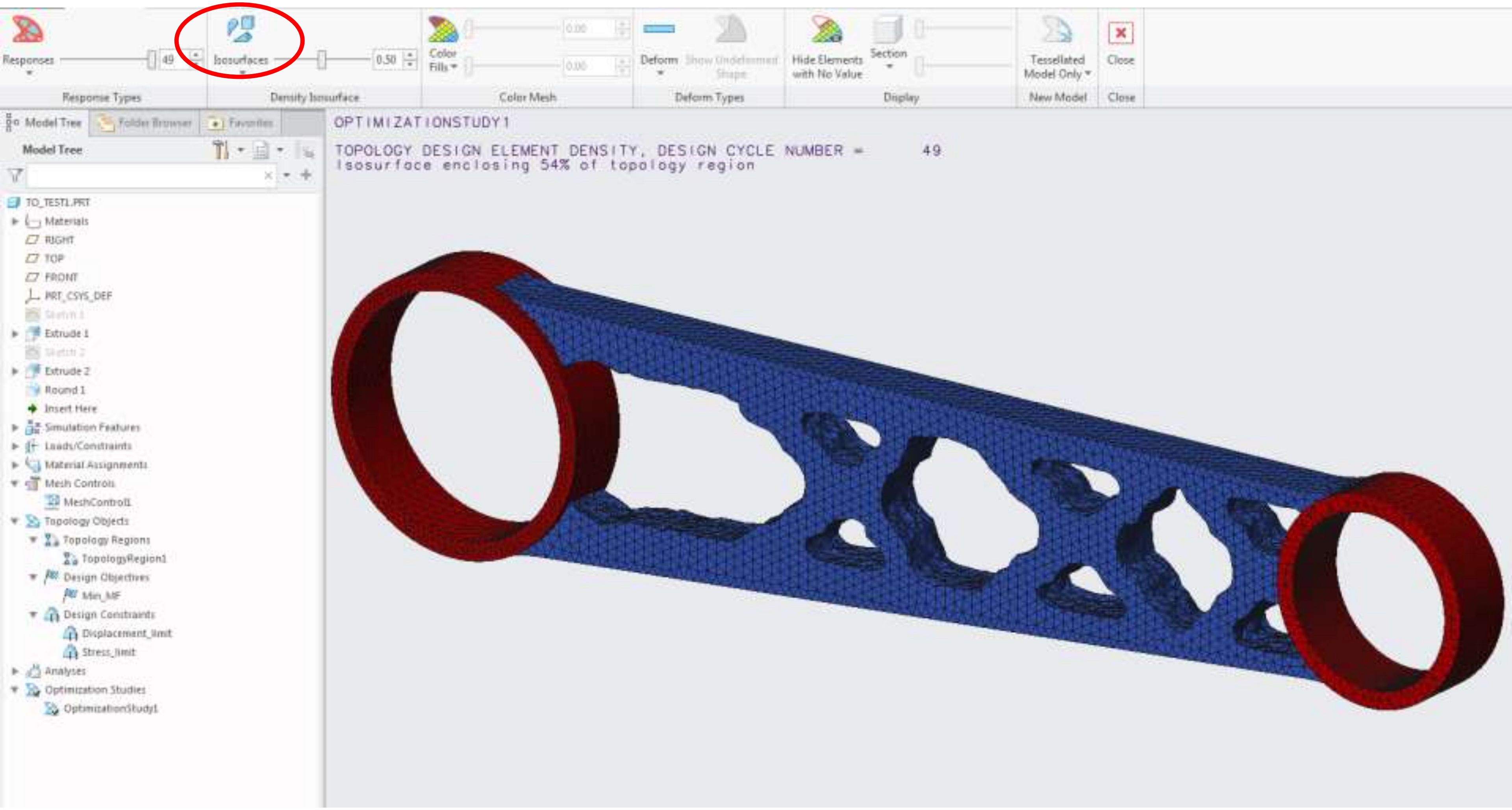


Show Results

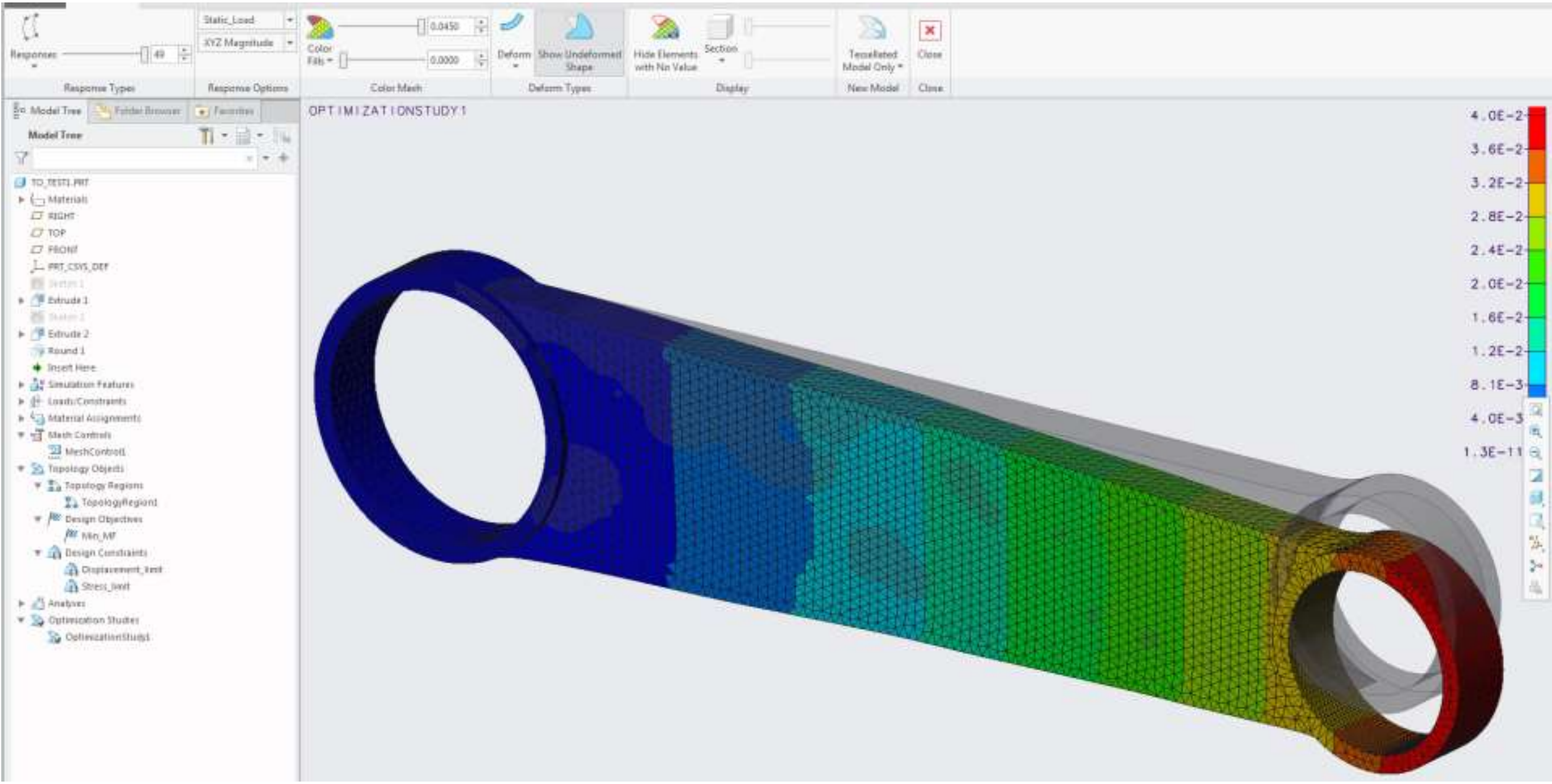
Abort

Close

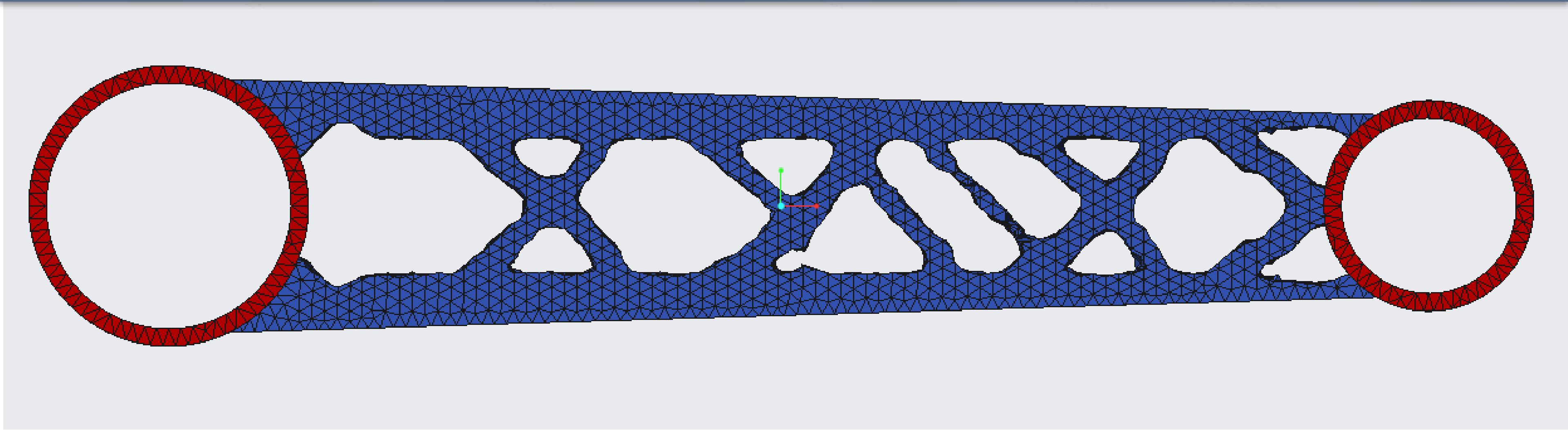
Isosurface Enclosing 54% of Topology Region



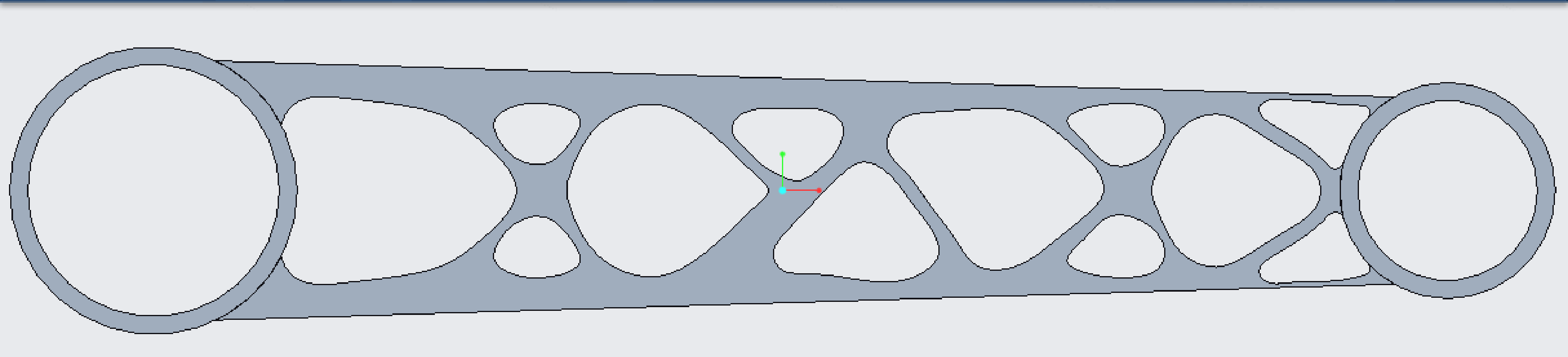
Deformed and Un-deformed Shape
Topology Optimization Model



CREO Topology tessellated output

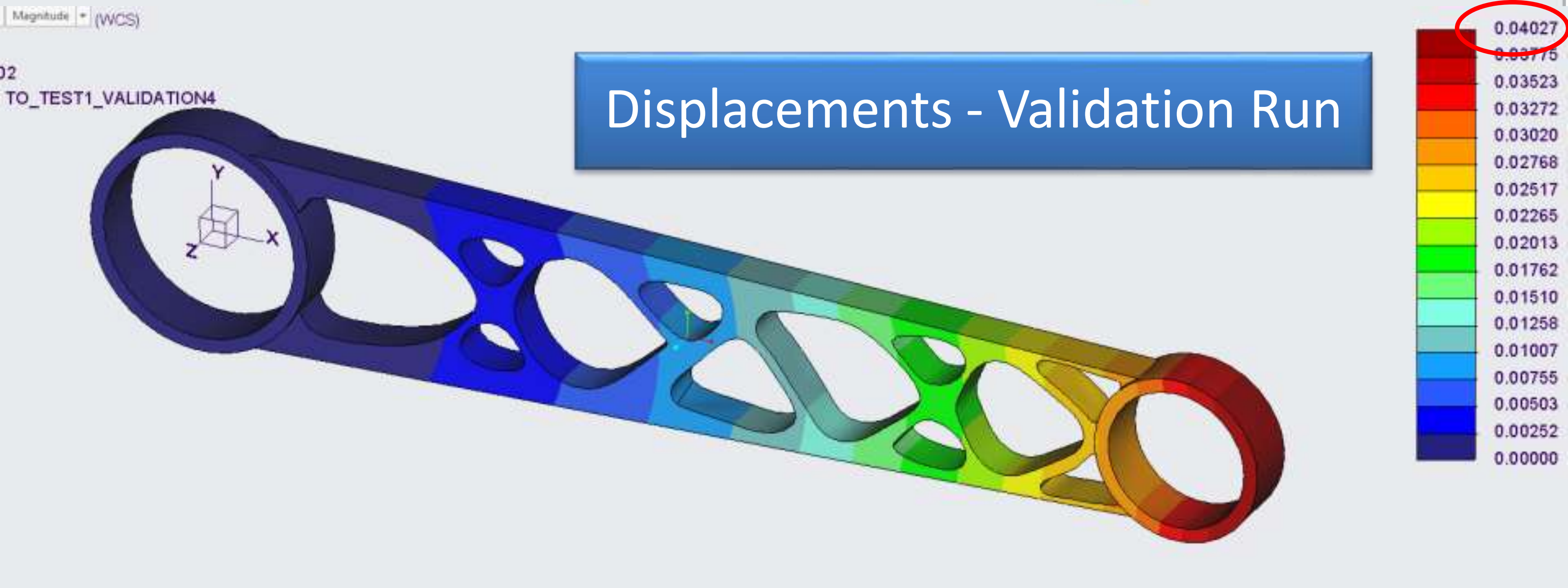


Simple Manual Reconstruction

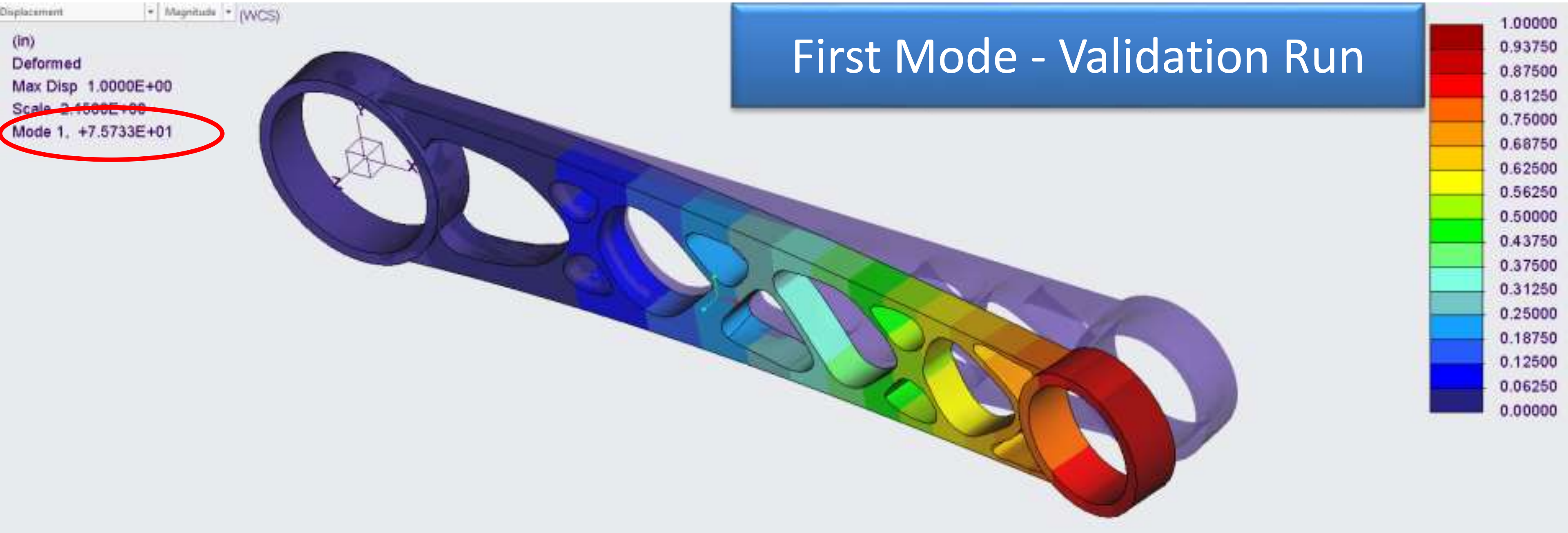


Von Mises Stress Validation Run Fully Stress Part!

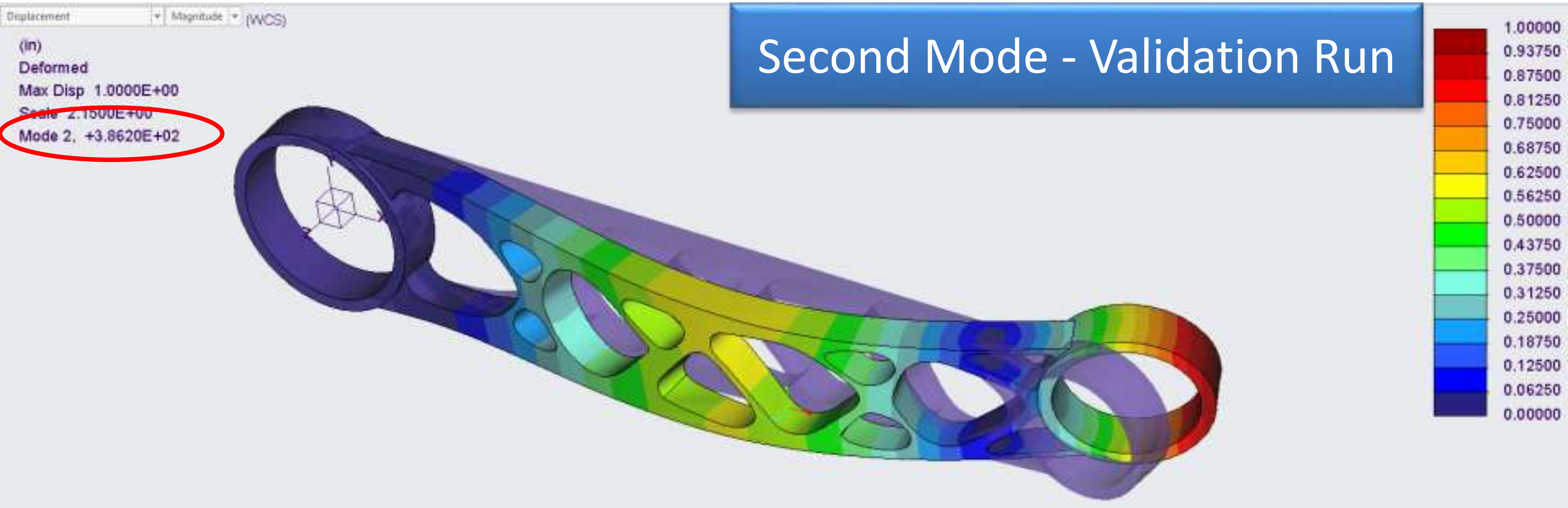
Displacements - Validation Run



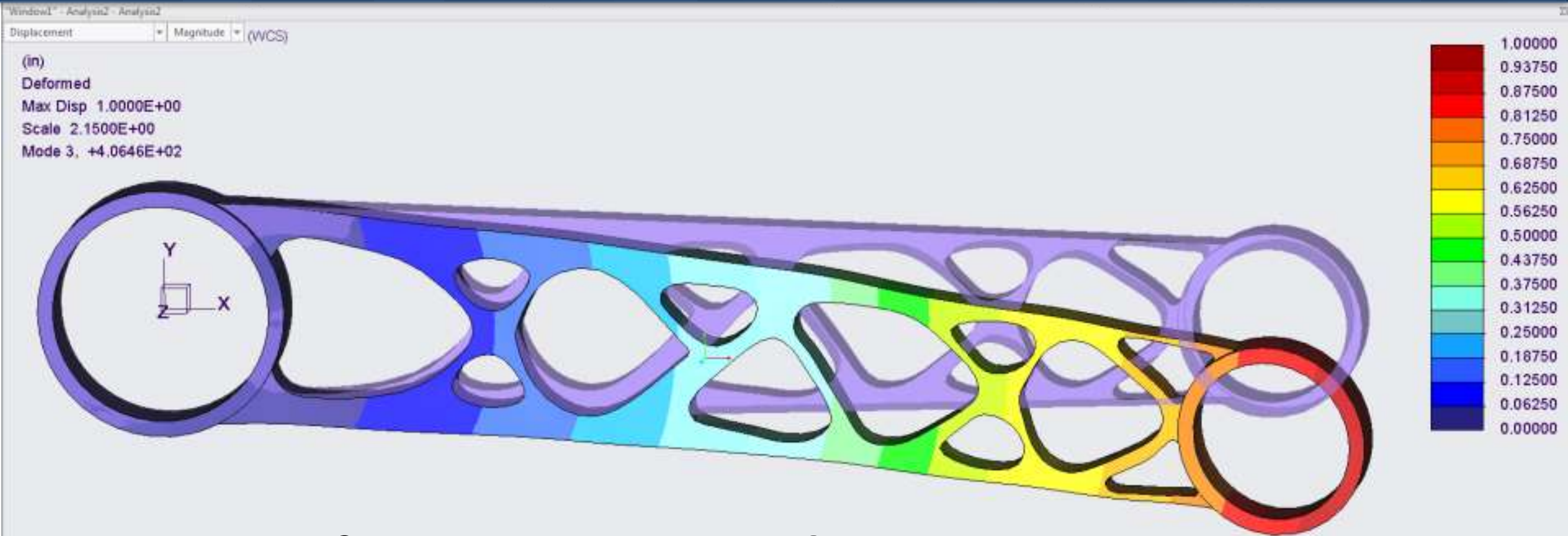
First Mode - Validation Run



Second Mode - Validation Run



Third Mode Shape (in Plane Mode) – Validation Run

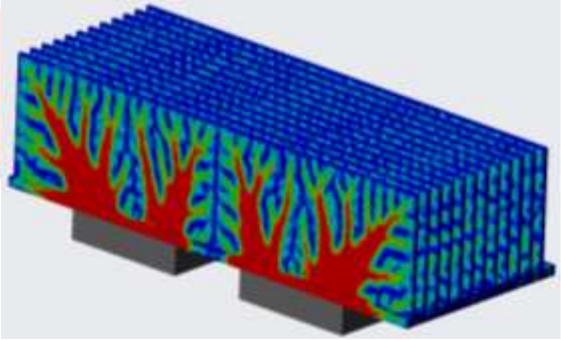


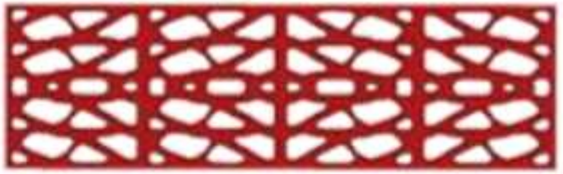
Summary of Optimization Study

- Objective: Weight Reduction about 50%
- Constraints:
  - Maximum Von Mises Stress 6 ksi < 36 ksi
  - Maximum Vertical Displacement 0.04 < 0.05 in
  - First Natural Frequency (out of Plane Mode) 76 Hz > 75 Hz
  - Third Natural Frequency (in Plane Mode) 406 Hz > 400 Hz

1 Useful Topology Optimization Features

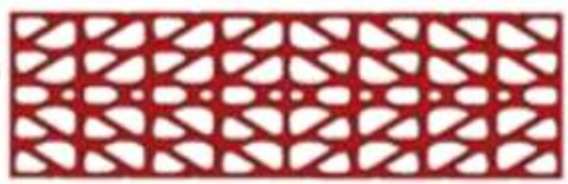
- Manufacturing constraints
  - Symmetry / pattern grouping / **periodic patterns**
  - Minimum /Maximum Member Size Control
  - Draw direction constraints for **AM**, extrusion, casting, stamping, radial filling, machining, etc.
  - Sheet metal
  - Additive manufacturing (slopes for support-less elements)
- Multiphysics
  - Structural, **Thermal, Fluid**, Electromagnetics
- Optimization Constraints
  - Stress, deflection, natural frequency, temperature
  - Global and local buckling (lattice elements)
- **Robustness evaluation**
  - Load magnitude uncertainties (μ, σ)
  - Load Orientation uncertainties (μ, σ)
  - Material properties uncertainties (μ, σ)
- **No Design Space Required**, only Loads and BC





Optimum using New P0X+P0Z
4x4 = 16 Patterns repeated

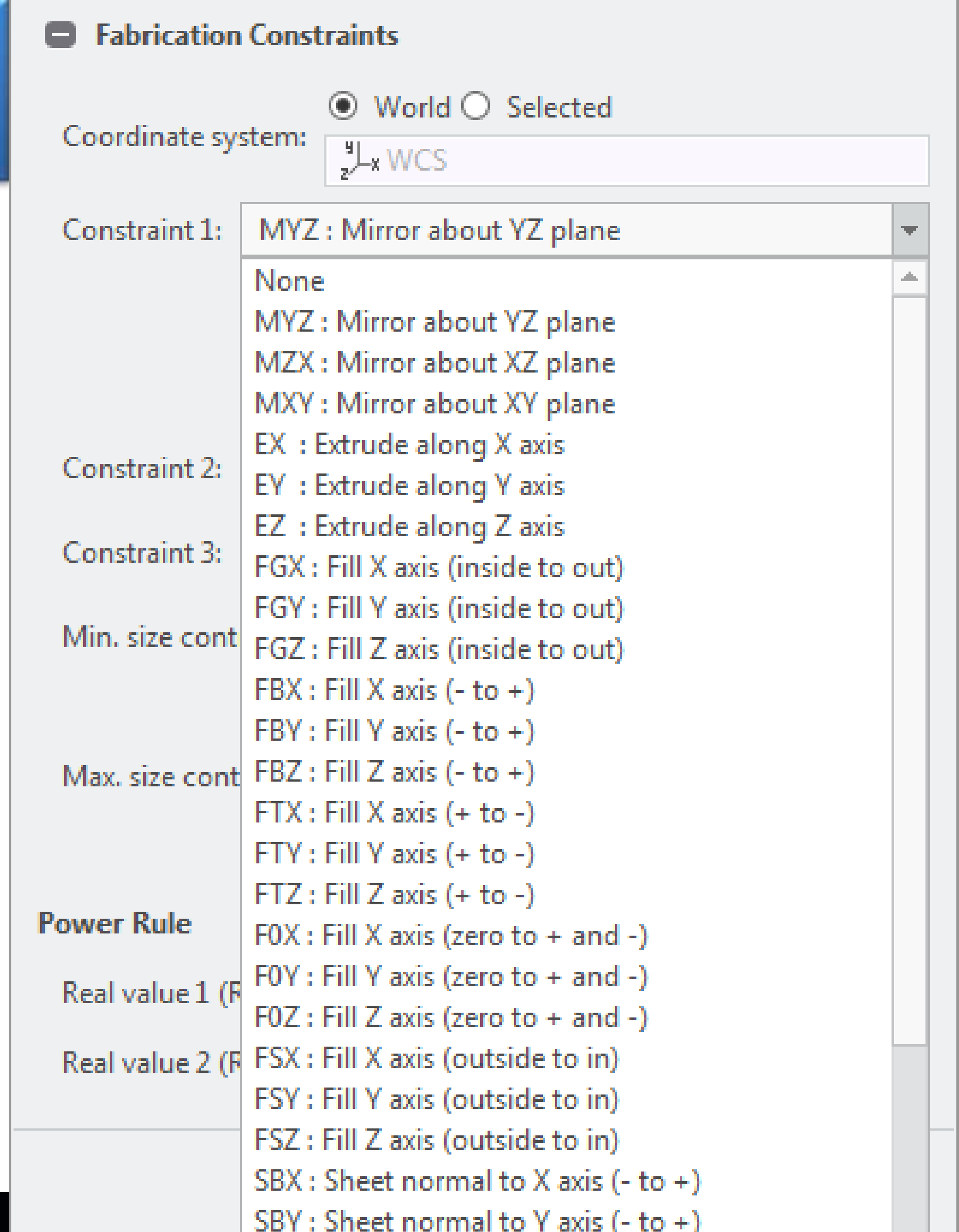
Optimum using New P0X + P0Z
8x2=16 Patterns repeated



Fabrication Constraints in CREO TO

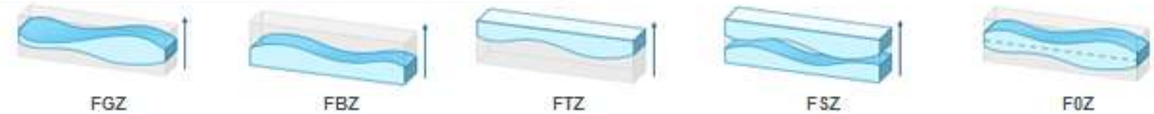
- Symmetry
- Extrusion
- Filling and Filling Symmetric
- Stamping
- Uniform
- Radial Filling and Spokes
- Periodic

- Can impose up to 3 fabrication constraints
- Min/Max Member Size

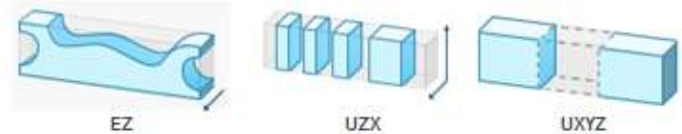


Visualization of Fabrication Constraints in CREO TO

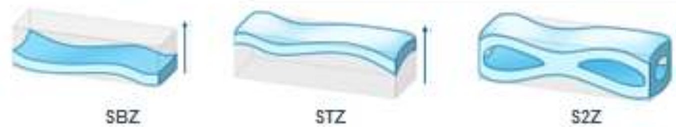
Filling (Castings)



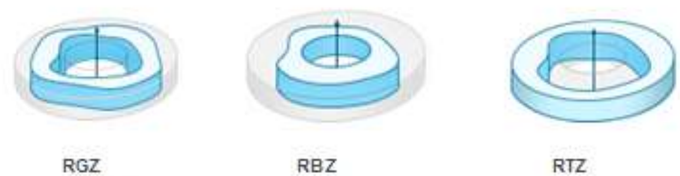
Extrusion and Uniforms



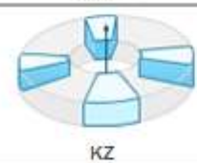
Stamping



Radial Filling



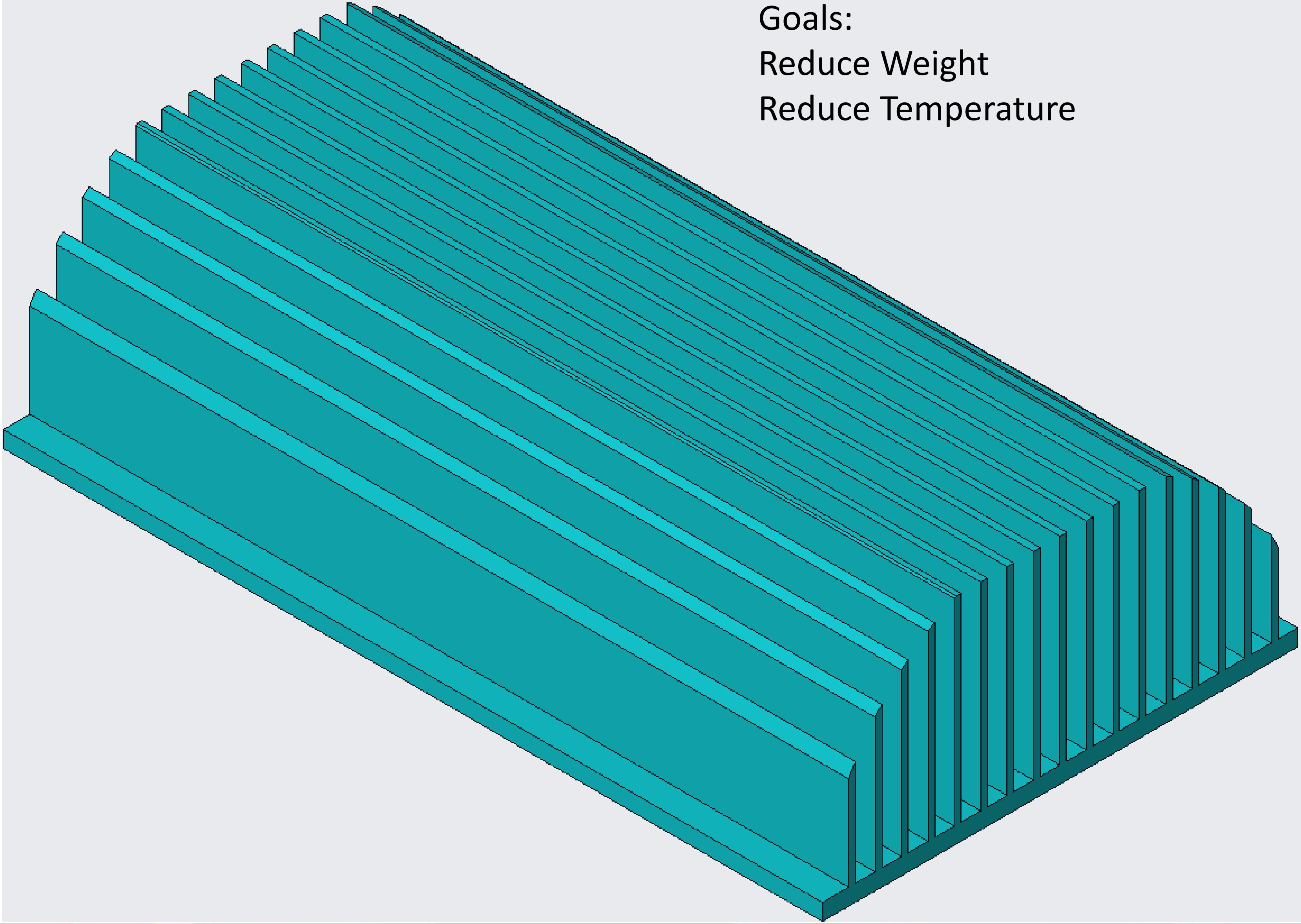
Radial Spokes



Mirror, Cyclic and Periodic Symmetry

Minimum & Maximum Member Size

Example 3 Lightweight the AM Heat Exchanger



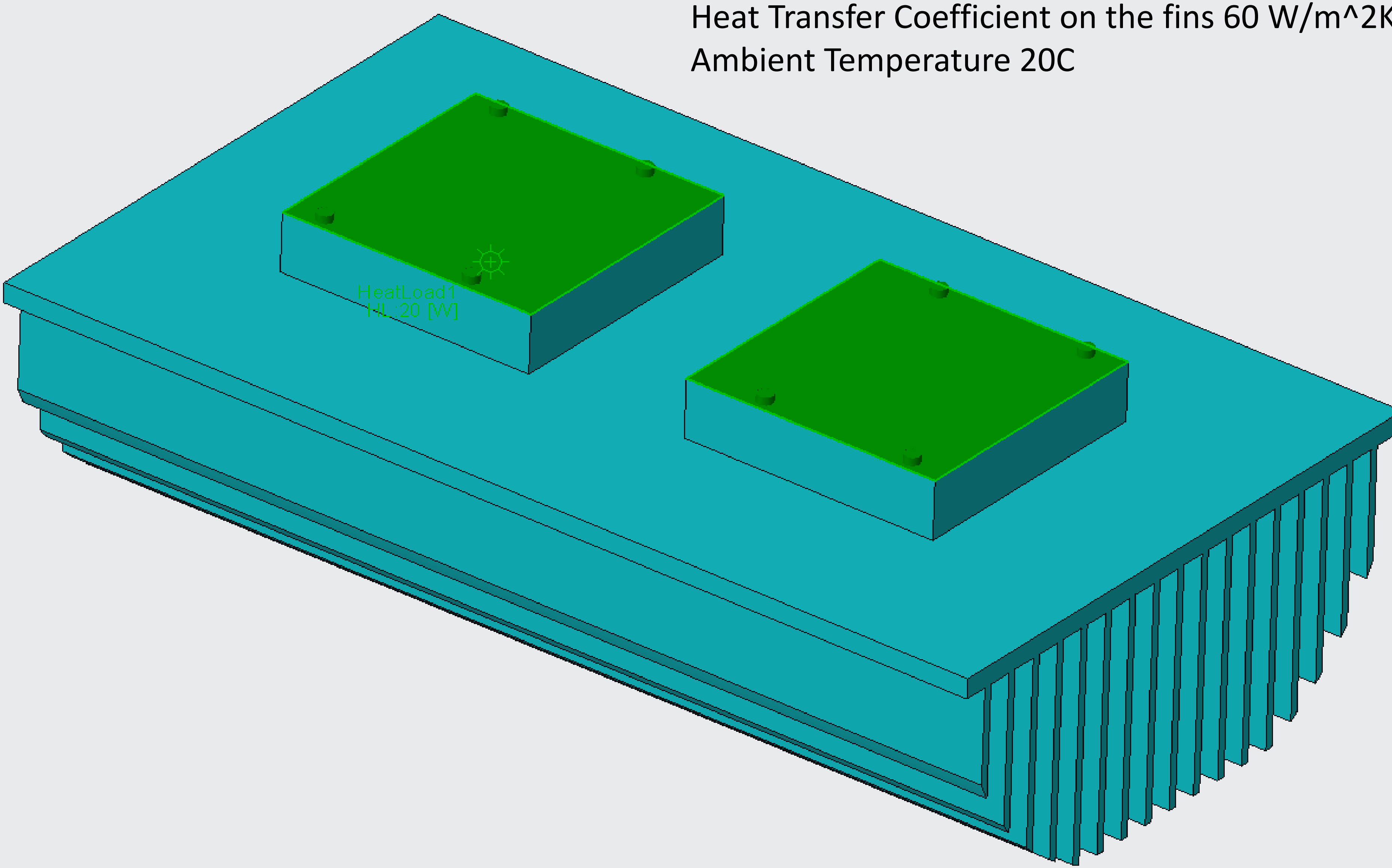
Goals:

Reduce Weight

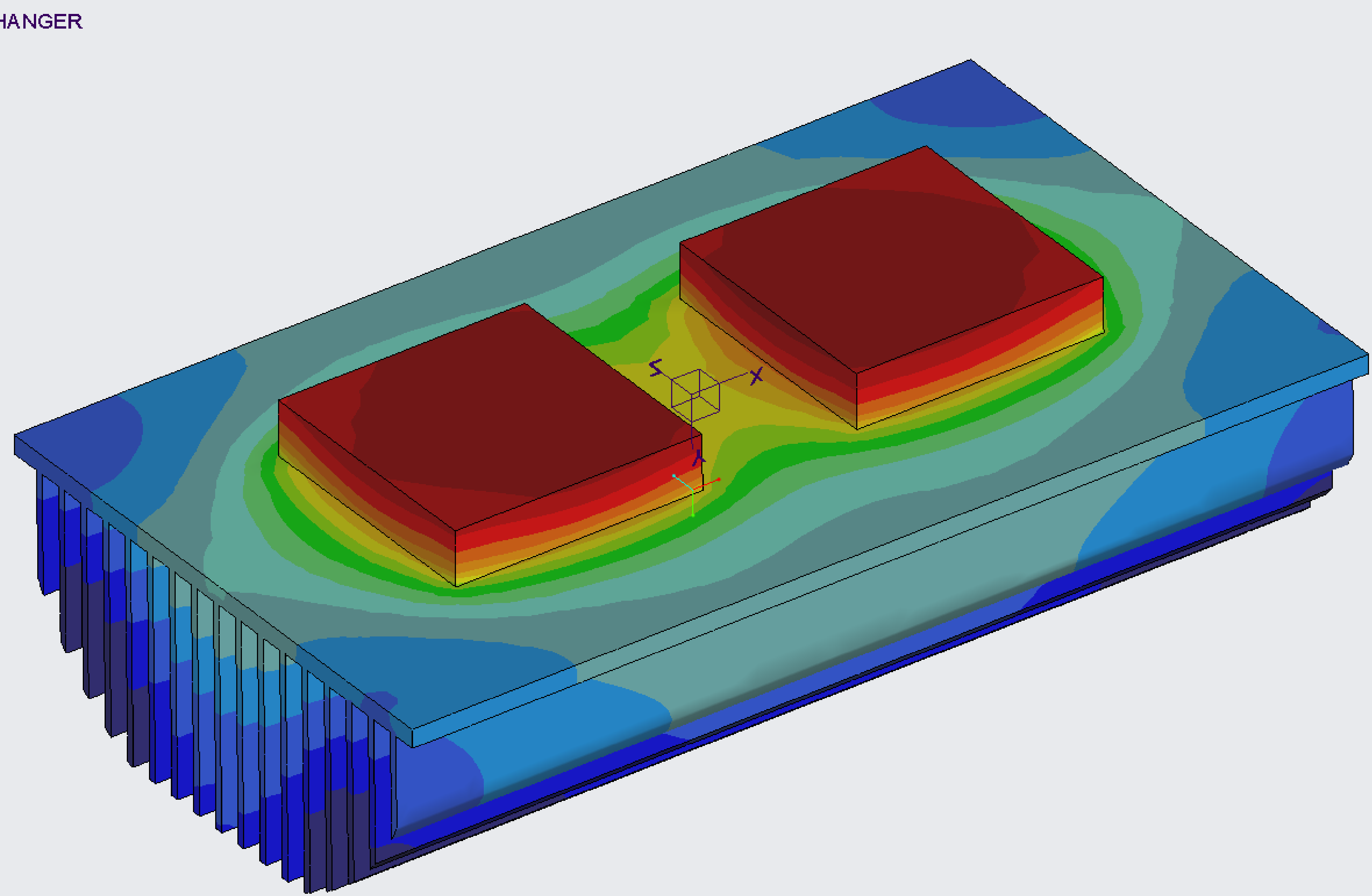
Reduce Temperature

Heat Load and Convection

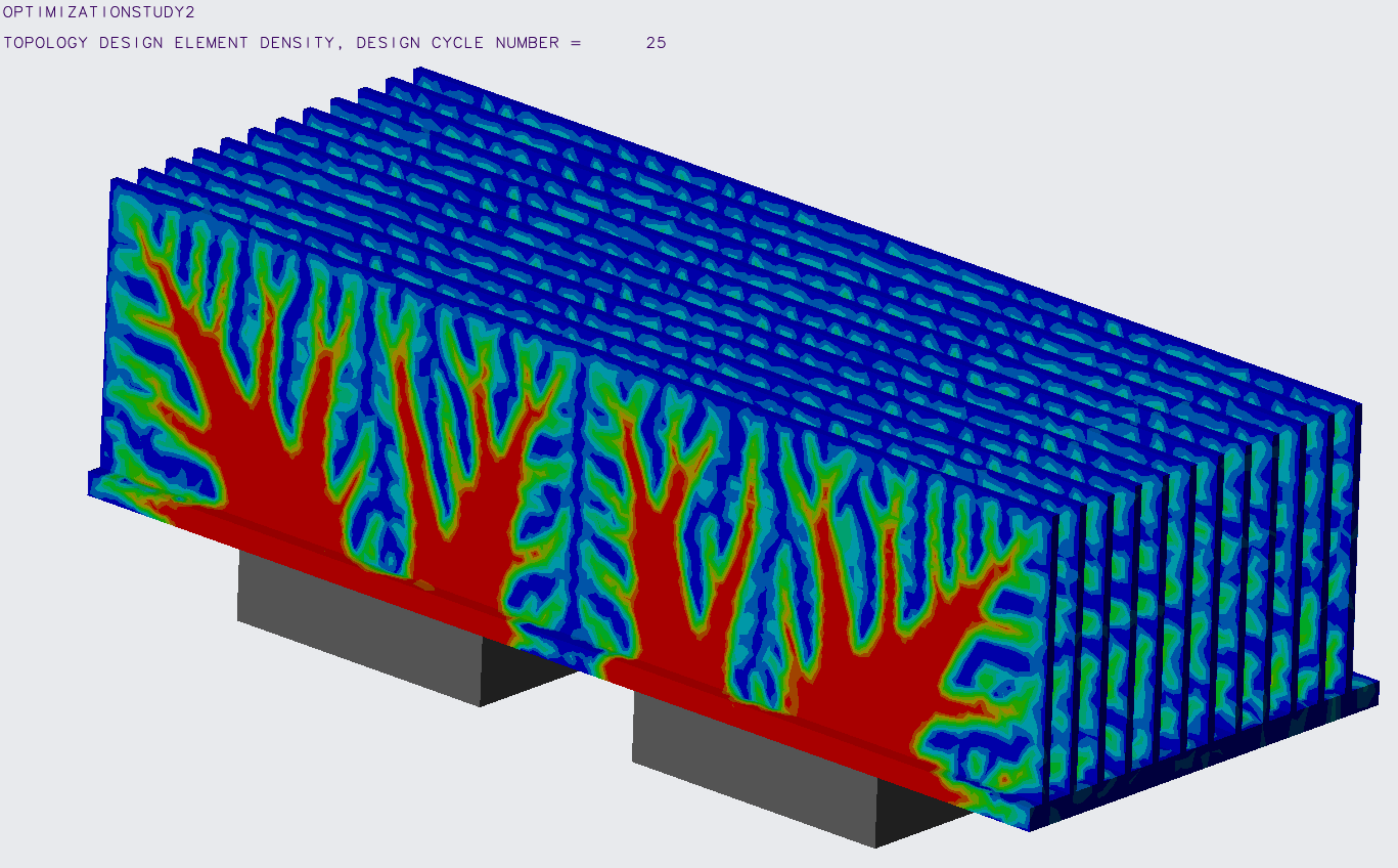
Heat Transfer Coefficient on the fins 60 W/m^2K
Ambient Temperature 20C



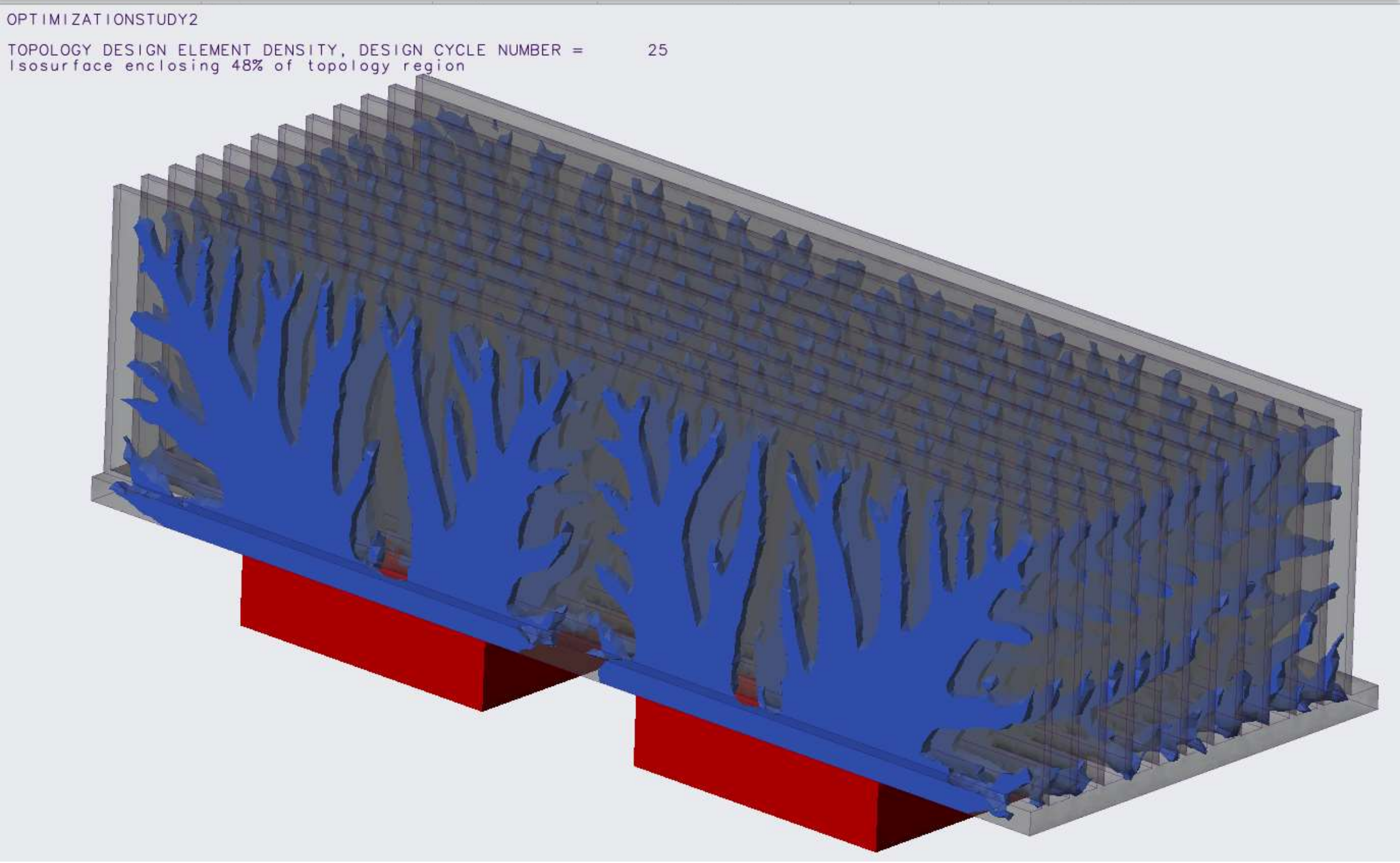
Temperature Distribution



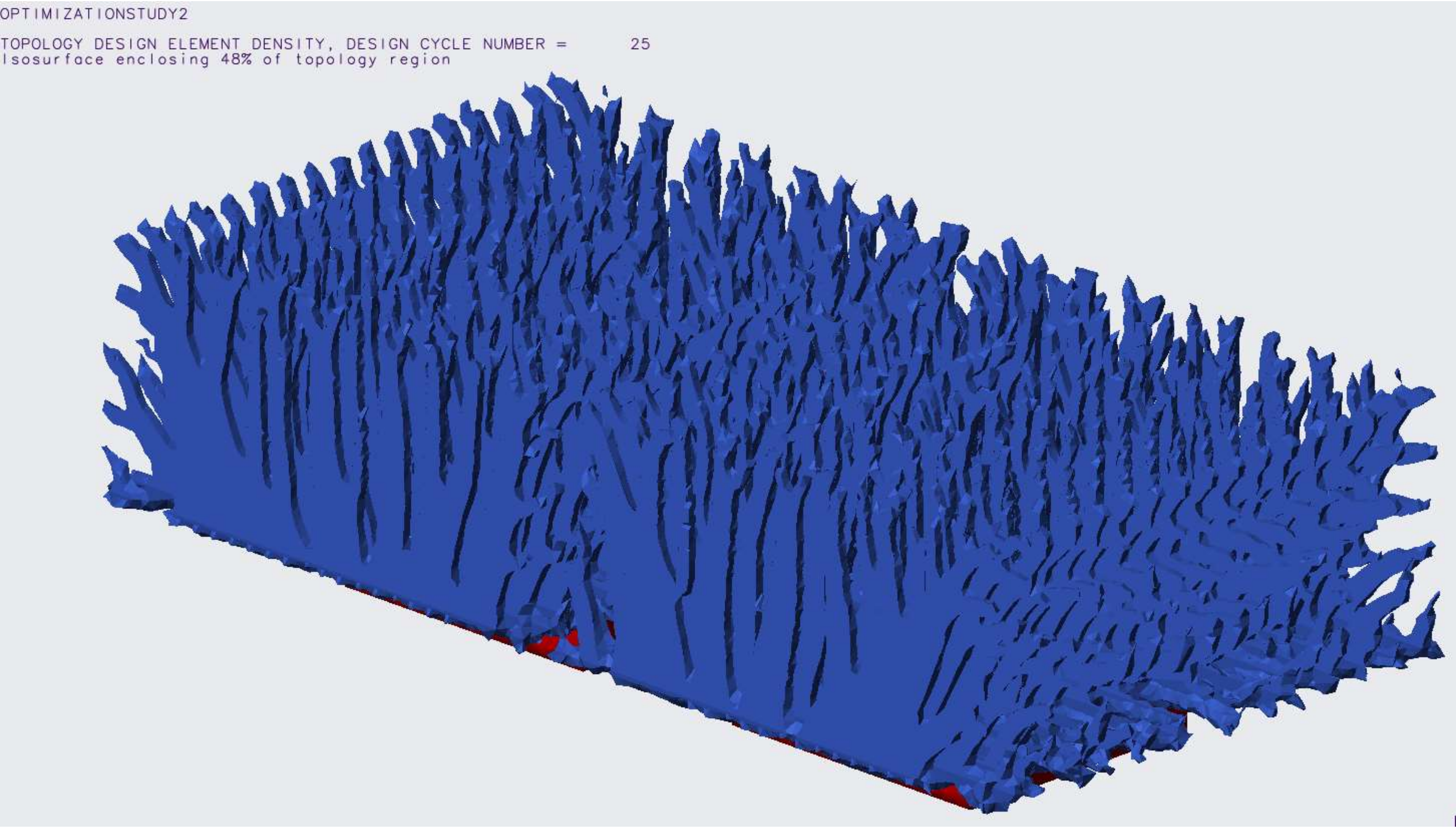
Topology Density Field



Design Region and Topology Optimization Results



Topology Optimization Results



Second Enabler of GD: Frame Lattice Generation Cell Homogenization into Topology Optimization

2

Cell Geometry Definition

Cell Size, Configuration, Shape, etc.

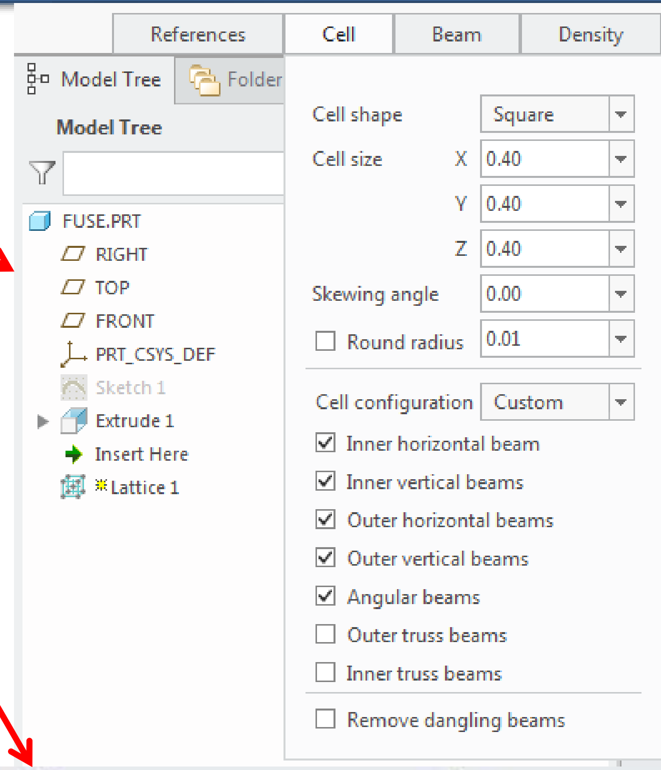
Homogenization

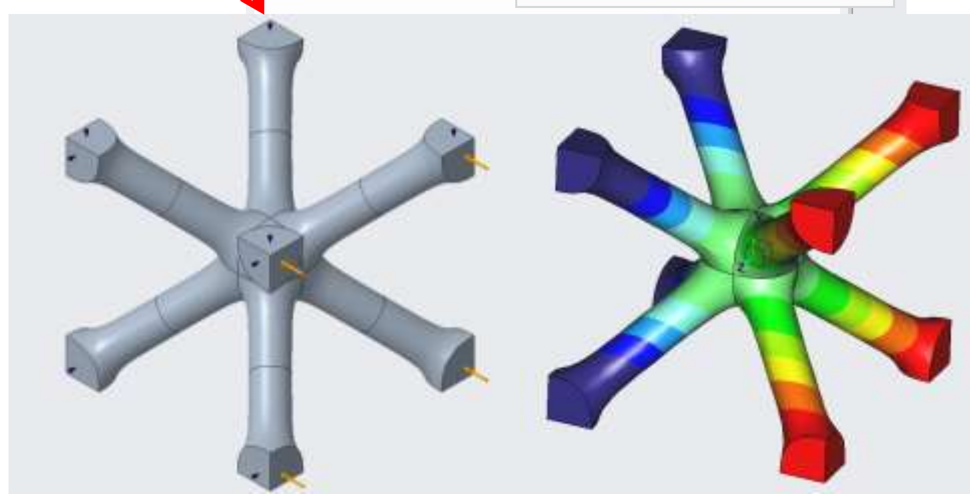
Material Properties Computation

Cell Size (periodic)
Density ρ (mass fraction)
Modulus of Elasticity (Ex, Ey, Ez)
Poisson's ratio (ν_x, ν_y, ν_z)
Thermal Conductivity (Kx, Ky, Kz)
Coefficient of Thermal Expansion α
Porous Media properties for CFD

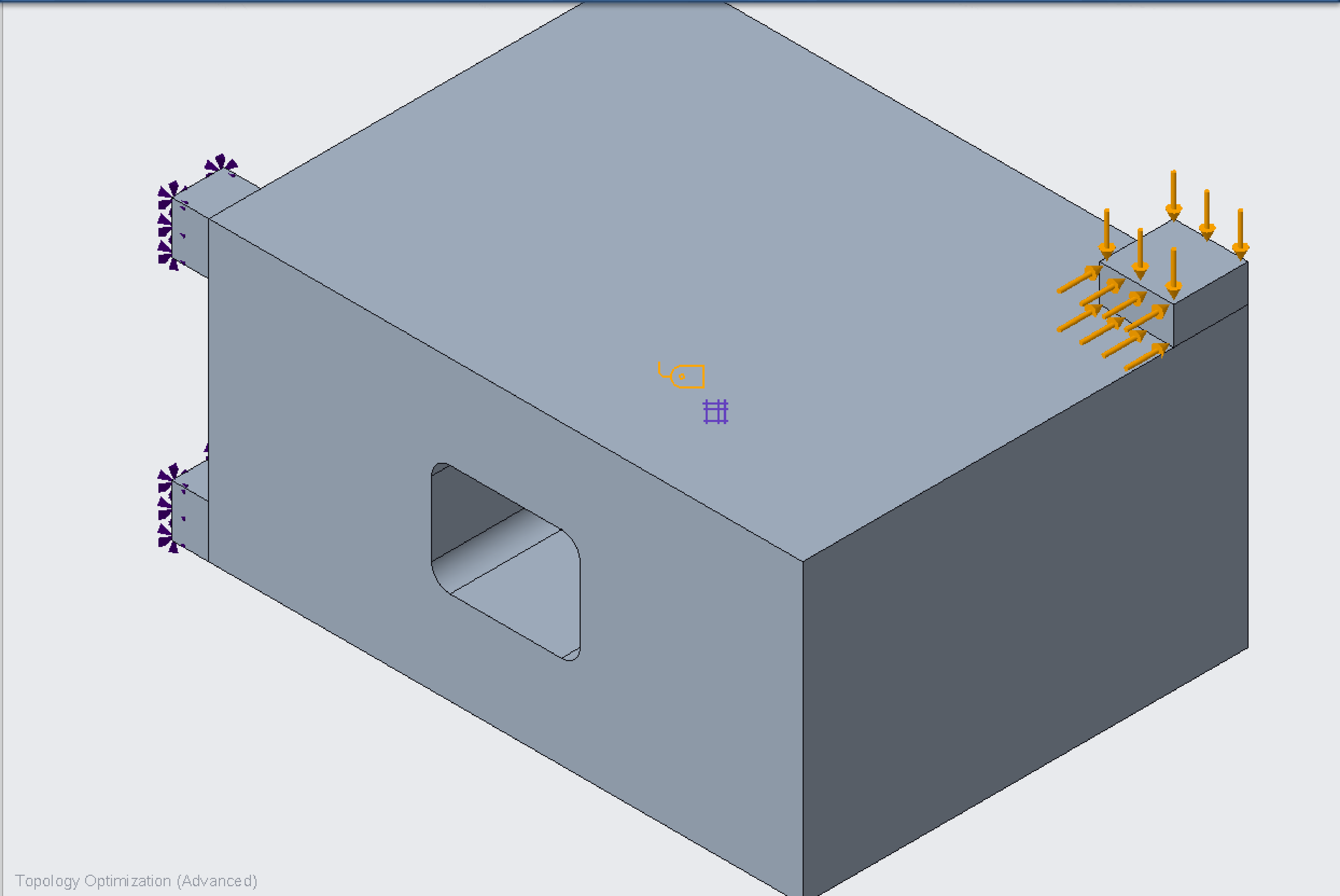
Design Space & Topology Optimization

Optimal Geometry with this cell

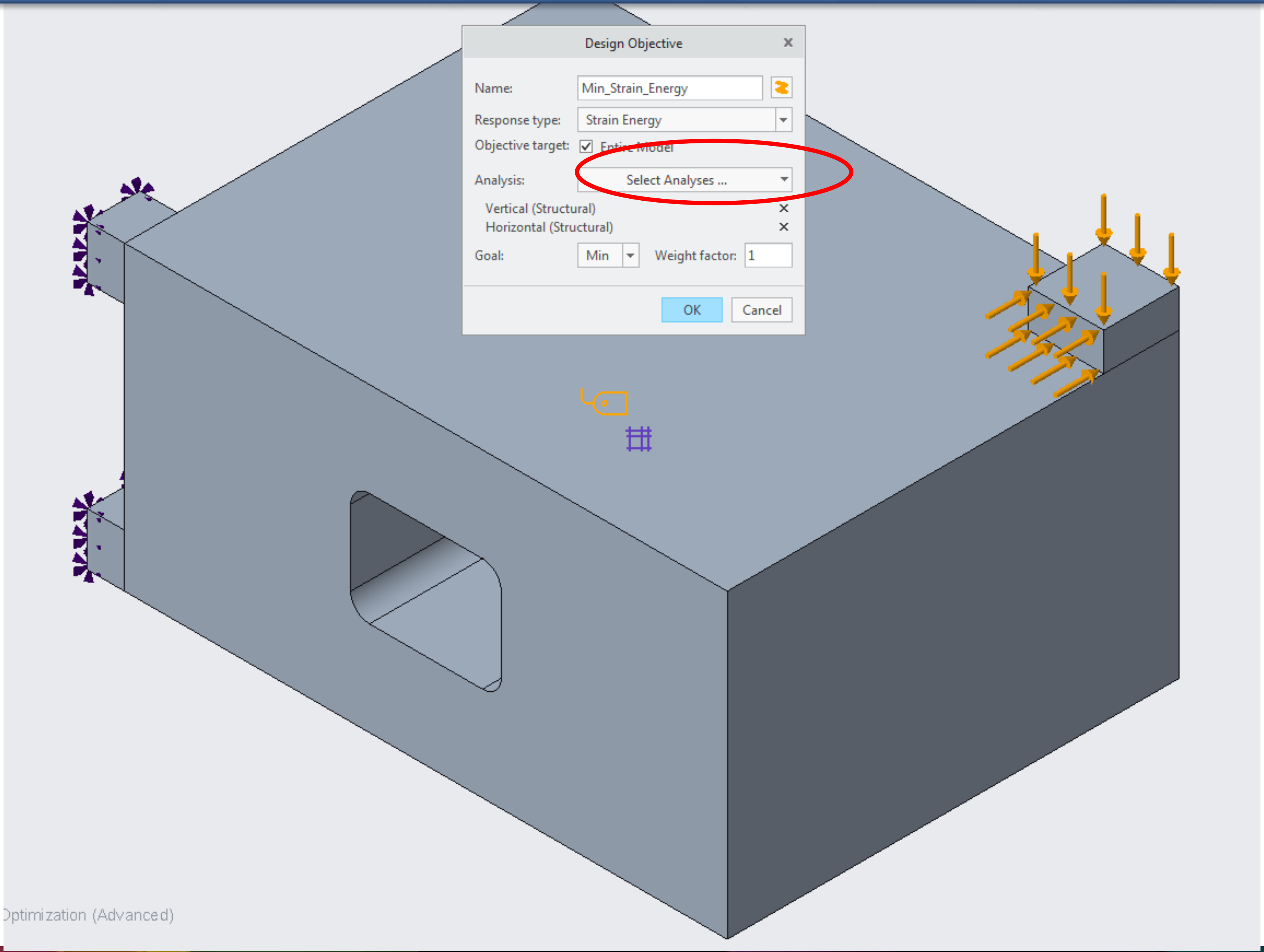




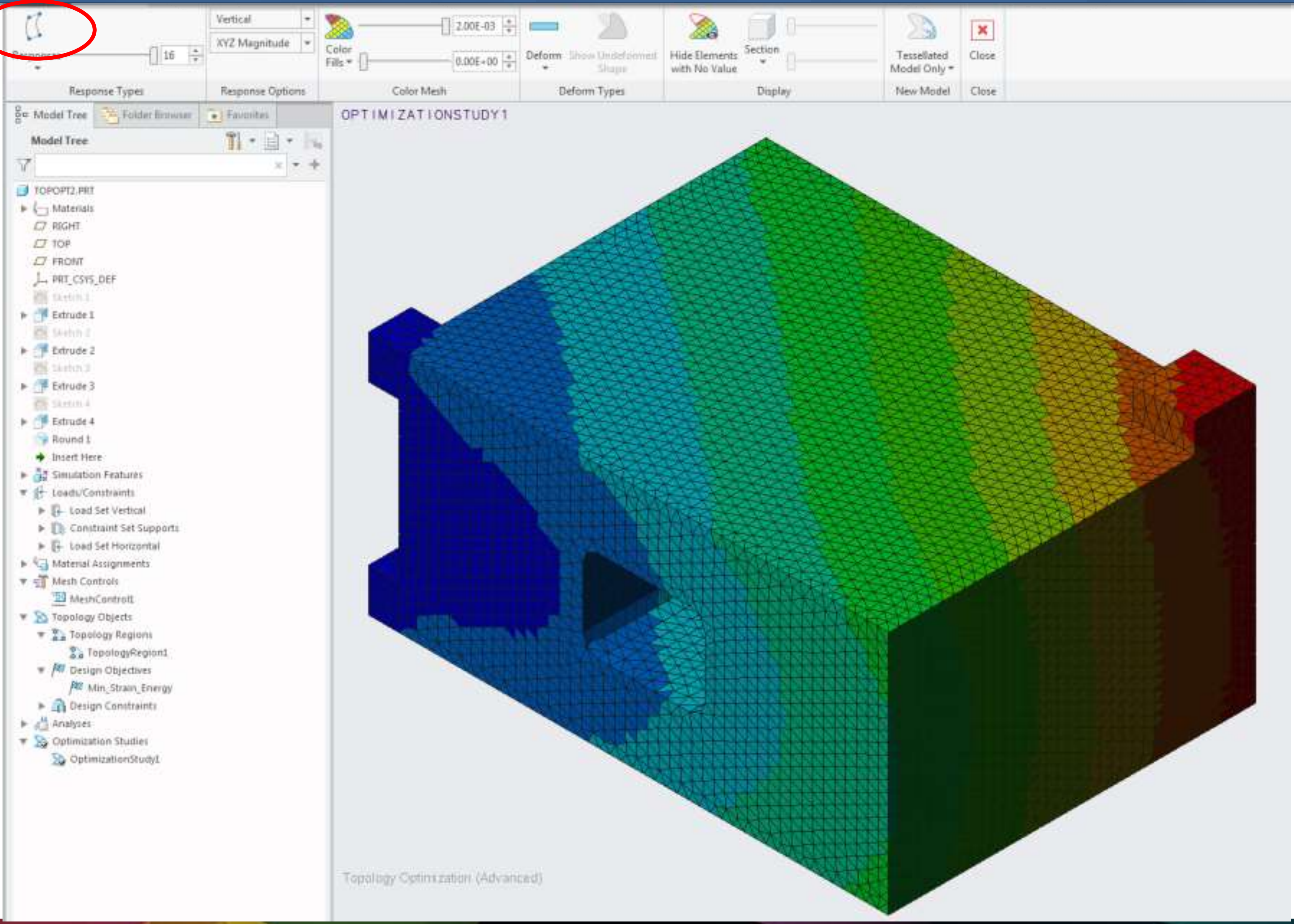
Design a light weight part that transfers the loads to the supports
Use available design space shown for both Load cases



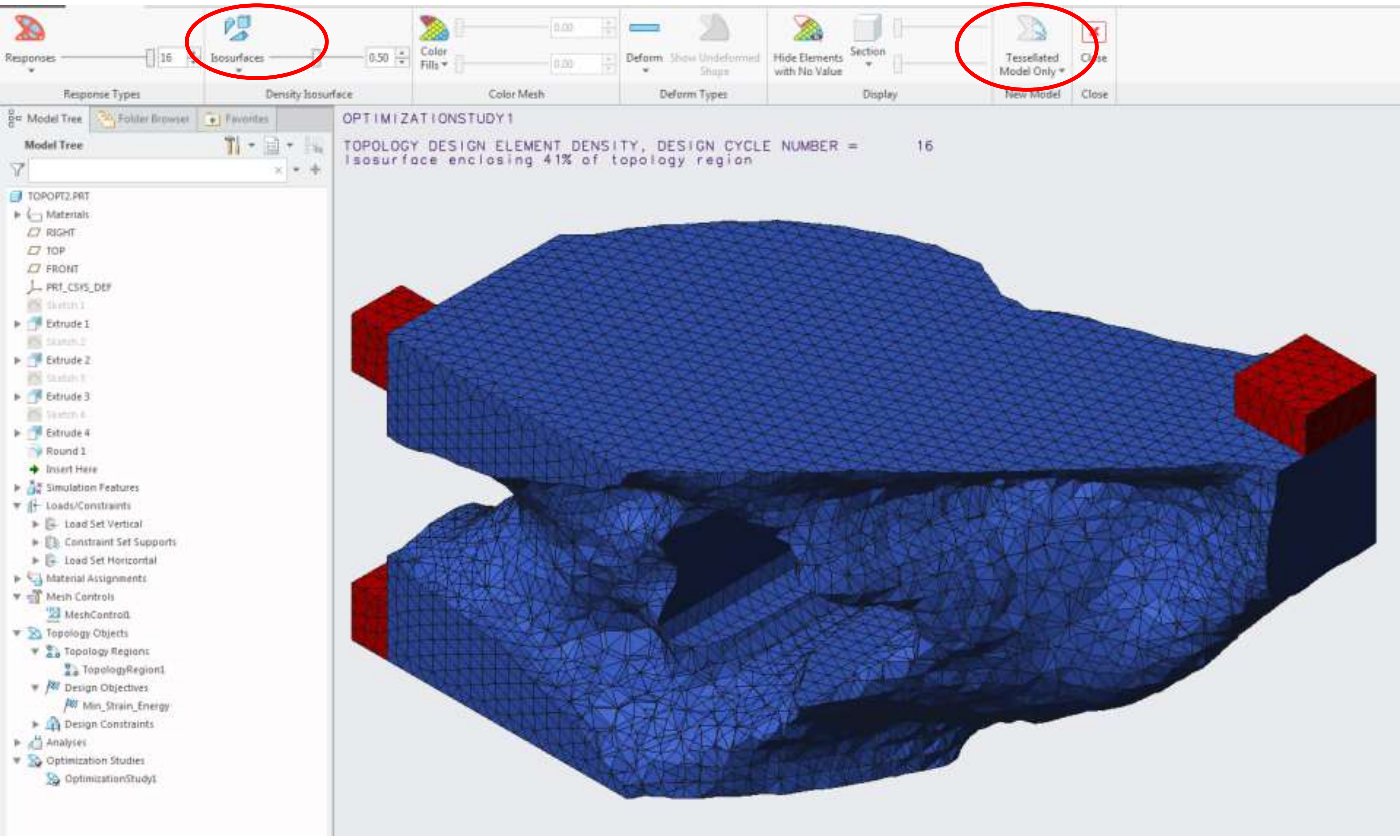
CREO Topology Optimization Set up for Multiple Load cases



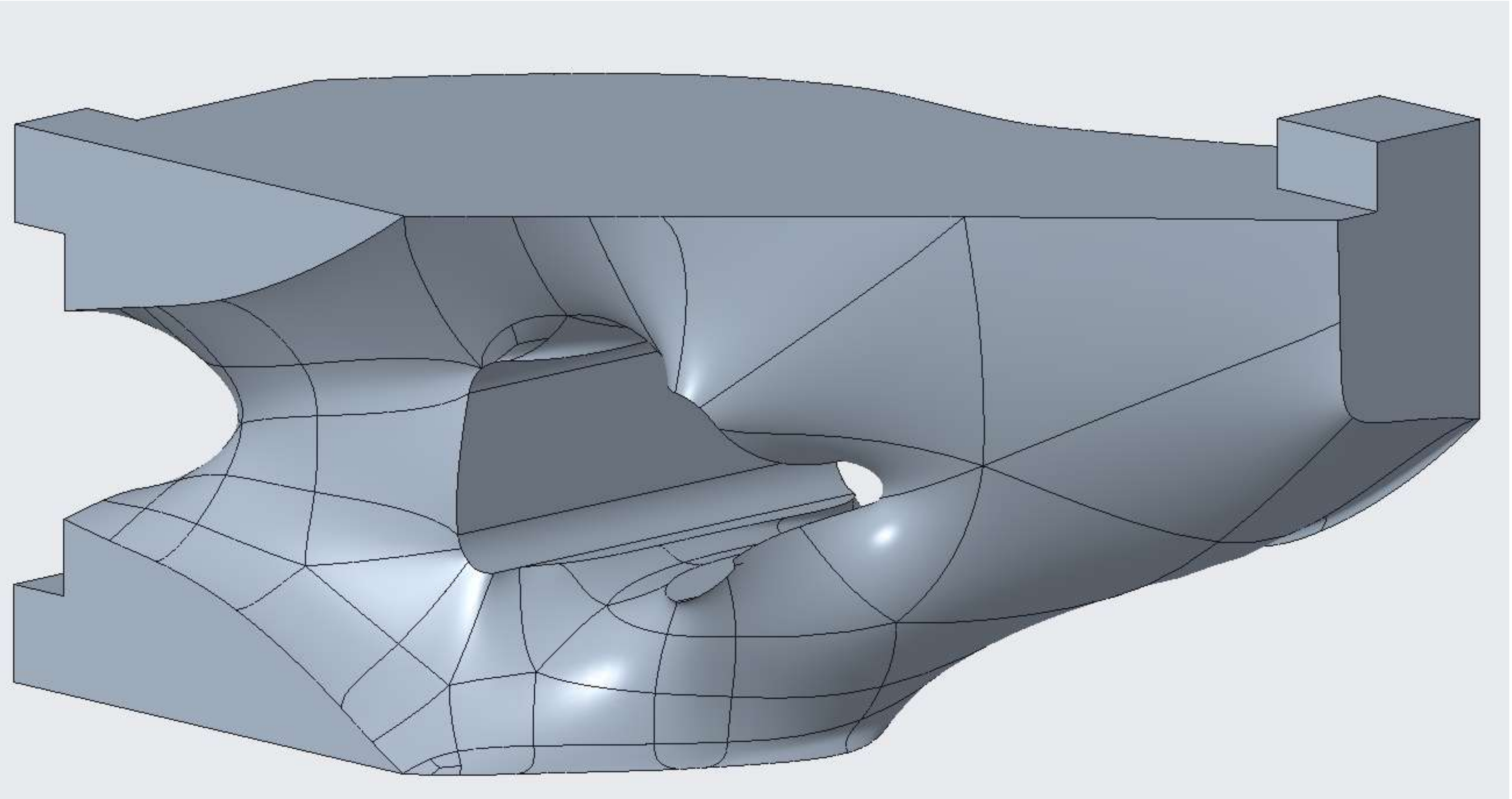
Displacement Distribution on the Entire Design Domain



Iso-surface Enclosing 41% of Topology Region

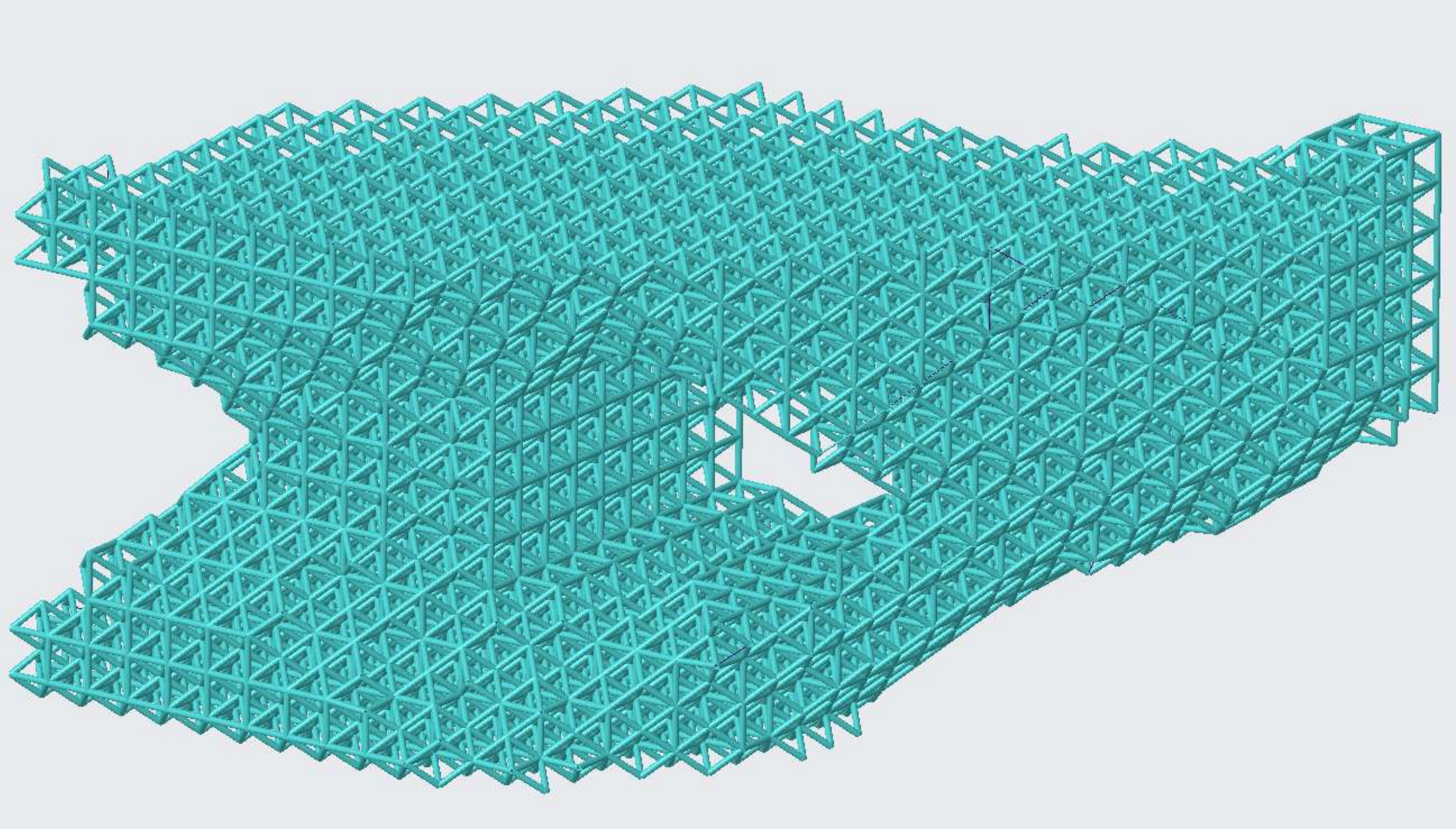


Automatic Geometry Reconstruction with Free Style Feature

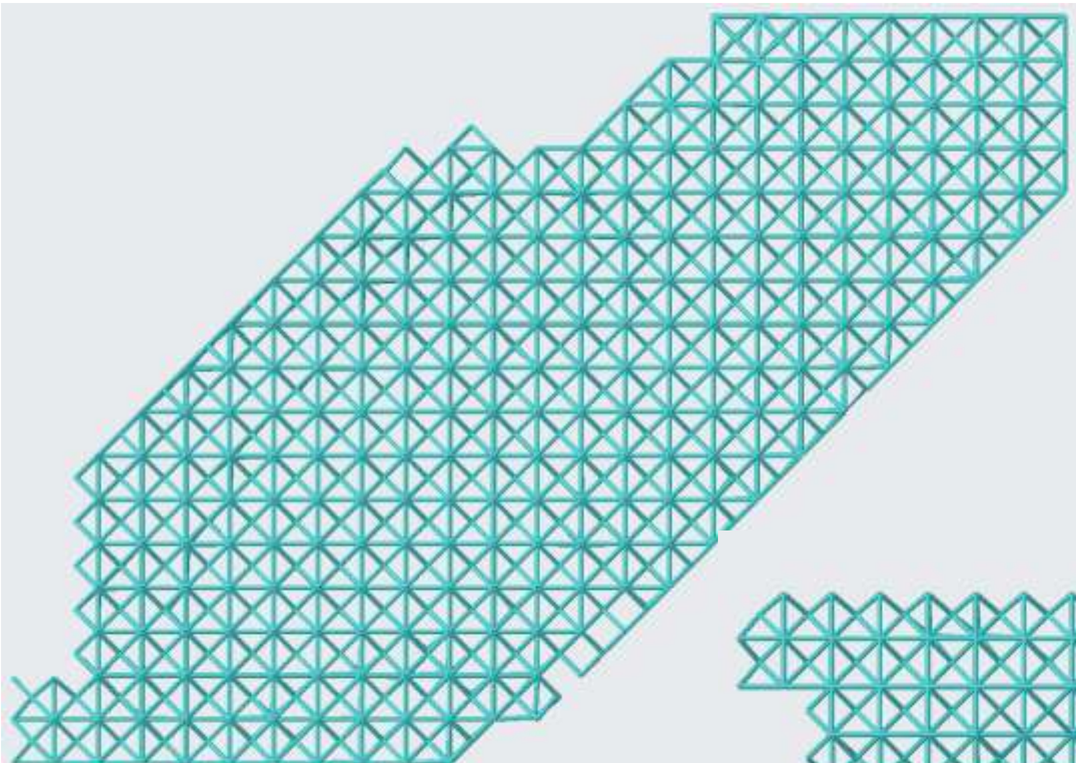


Automatic Lattice Feature Generation with AM Extension

Lightweight structural panels, energy absorption devices, thermal insulation, porous implants

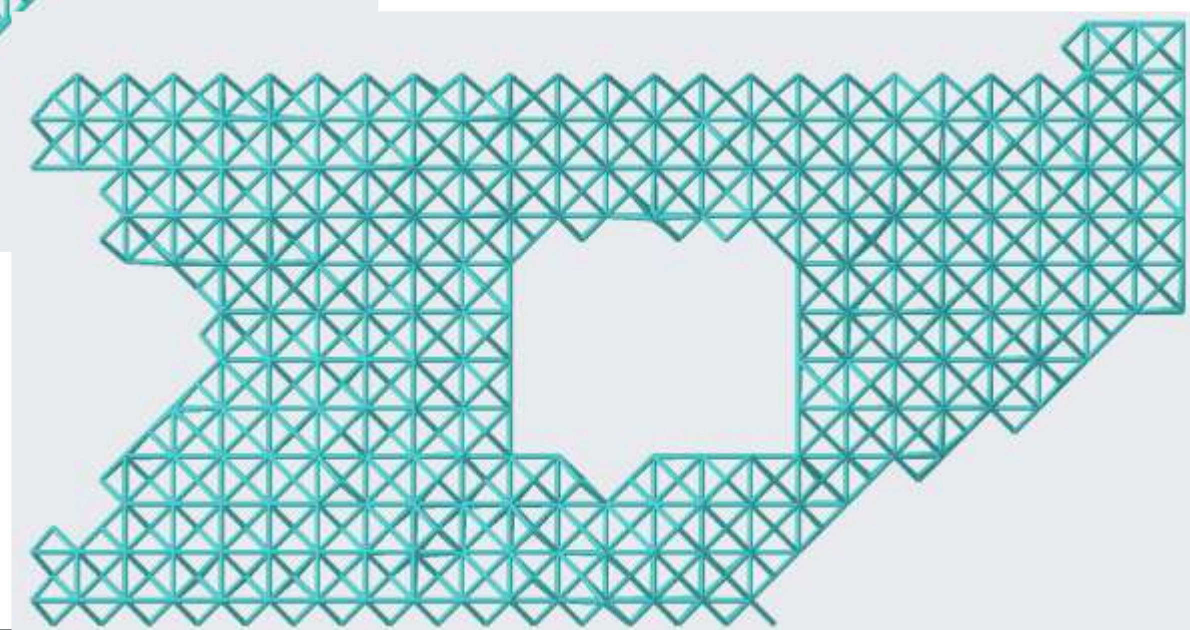


Top and Side views of the internal lattice structure

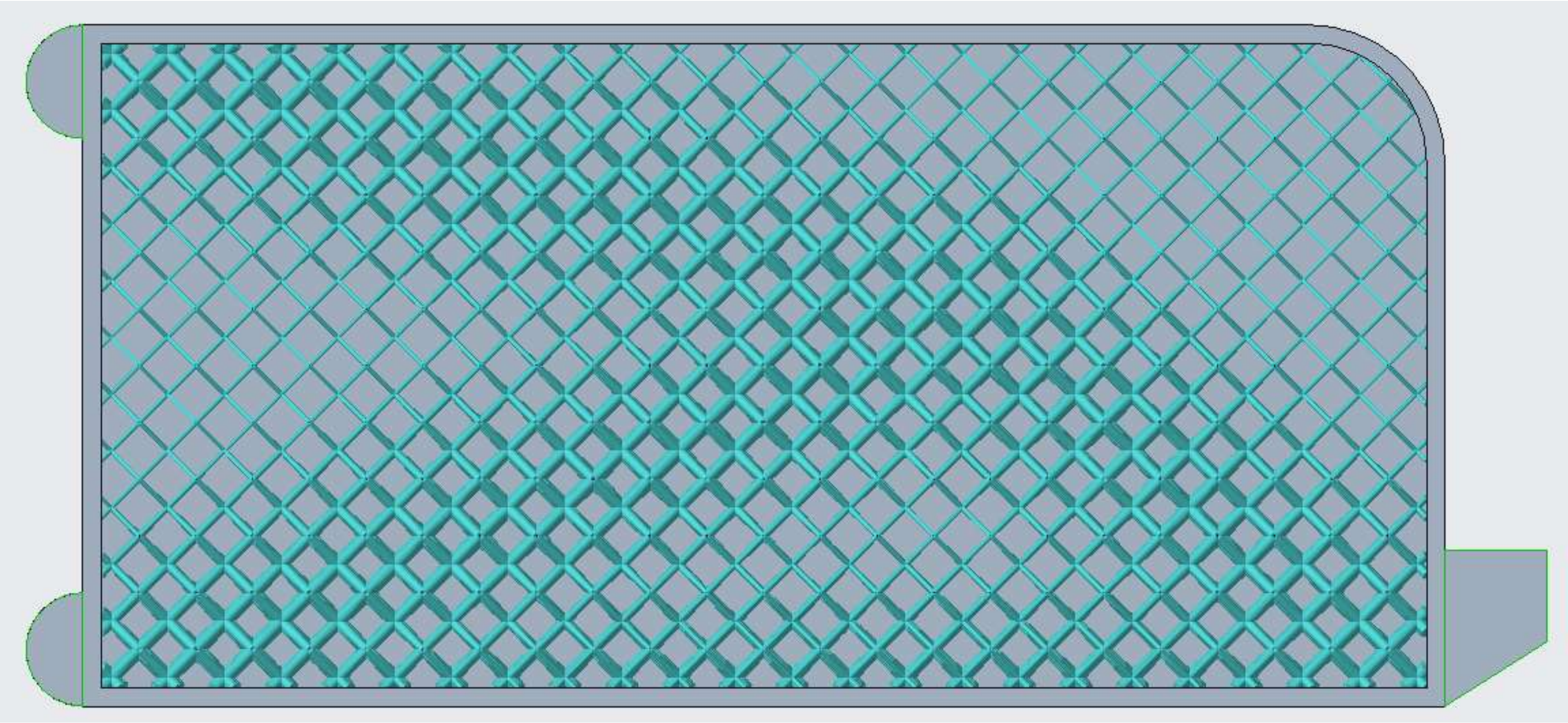


Lattice structure can be modeled with

- Solids if small number < 2,000
- Beams if less that 20,000
- Homogenized material if more than 20,000 elements



Lattice element size based on the Topology Optimization



Modeling Lattices - Complexity versus size

Simplified Geometry Simulation - Homogenization

Full Geometry Simulation

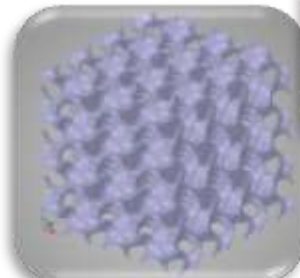
Complexity

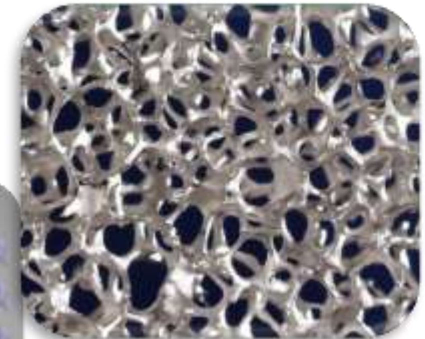
Metallic Foams

Surface lattices
minimal Surfaces

Stochastic
i.e. Voronoi

Beams &
Shells





Homogeniz
ation with
uncertainty

Simplified
Rep Ex, Ey, Ez

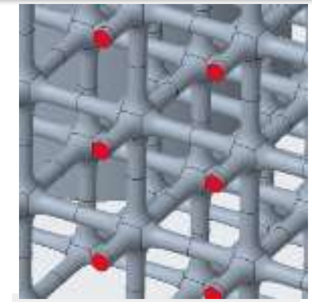
Full Geometry Rep

1000	10,000	1,000,00	100,000,000

Number of Cells

Short Course by AES on:
Design Optimization Process for 3D Printed Designs

- Is your organization ready to unleash the full potential of Additive Manufacturing?
- A two day course on *Design Optimization Process for 3D Printed Designs*
- Learn how to:
  - Create in CREO parametric 2 ½ D and 3D Lattice Features
  - Learn how to size and generate Lattice Structures
  - Optimize Lattice Structures using Behavioral Modeling
  - Use topology optimization to find the best distribution of material for stiffness or compliance with *homogenization techniques*
  - How to reconstruct the CAD geometry from the optimization results (*Nurbification*)
  - Design for additive manufacturing and practice the validation and verification steps required for Aerospace & Defense applications
  - Use topology optimization for light weight heat exchangers
  - Synthesize *Metamaterials* using Topology Optimization & Lattices



For more information contact Andreas at andreas@aes.nu