M.Tech
Digital Manufacturing

BITS Pilani
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Guest Faculty

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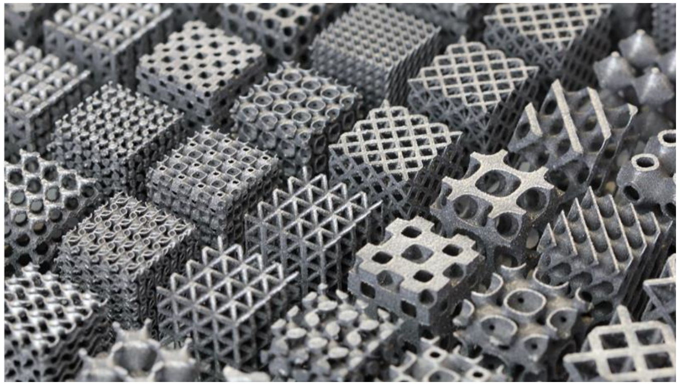
DMZG521- Design for Additive Manufacturing
Session 6 & Lecture 11-12

Lightweighting using AM

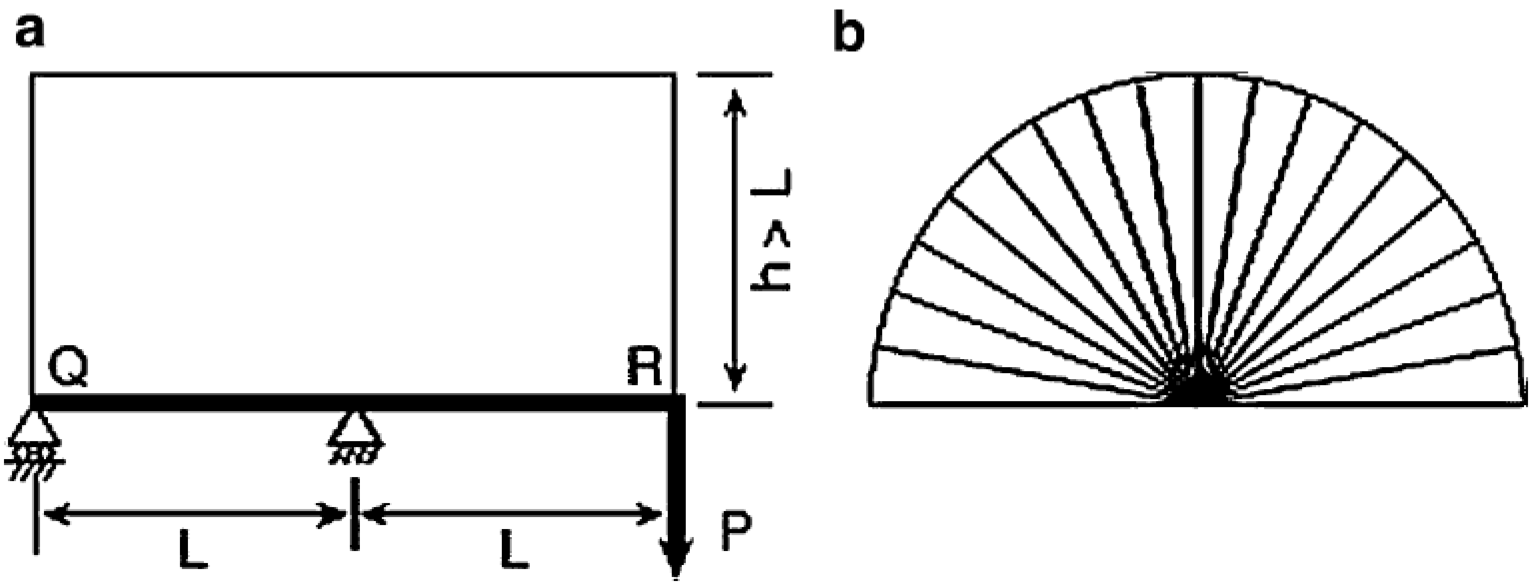
- How to synthesize lightweight structures?
- Capabilities of AM
  - Complex shapes
  - Lattice structures
  - Topology Optimization
  - Generative design



Design Optimization

- Variables: Describe the design alternatives
- Objective: Elected functional combination of variables (to be maximized or minimized)
- Constraints: Combination of Variables expressed as equalities or inequalities that must be satisfied for any acceptable design alternative
- Feasibility: Values for set of variables that satisfies all constraints and minimizes/maximizes Objective.

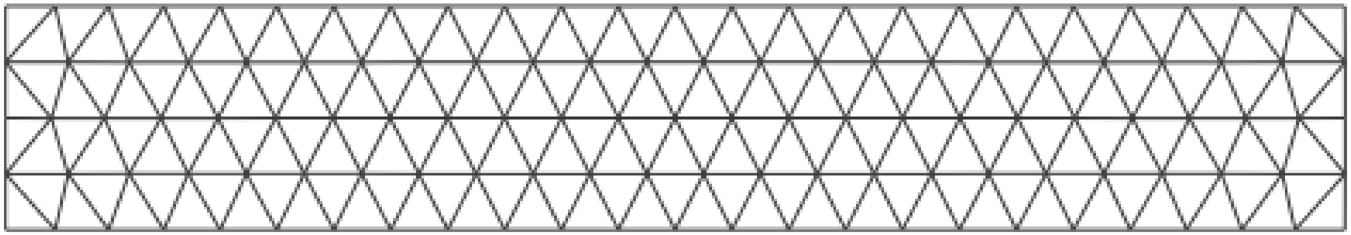
Michell Truss layout



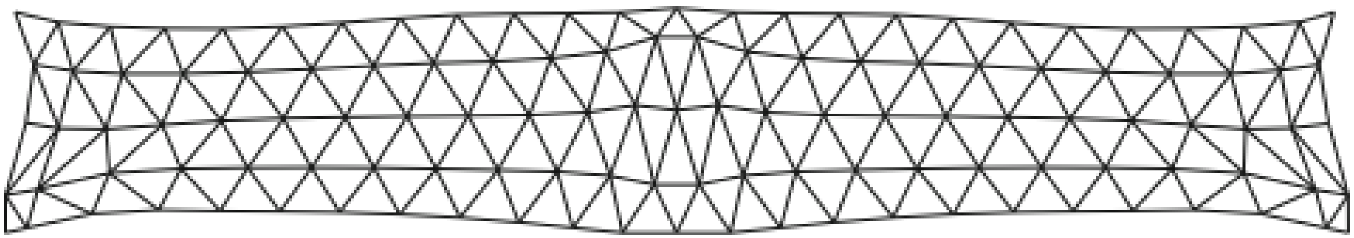
Optimization in AM

- Optimization methods seek to improve the design of an artifact by adjusting values of design variables
  - Size optimization
  - Shape optimization
  - Topology optimization

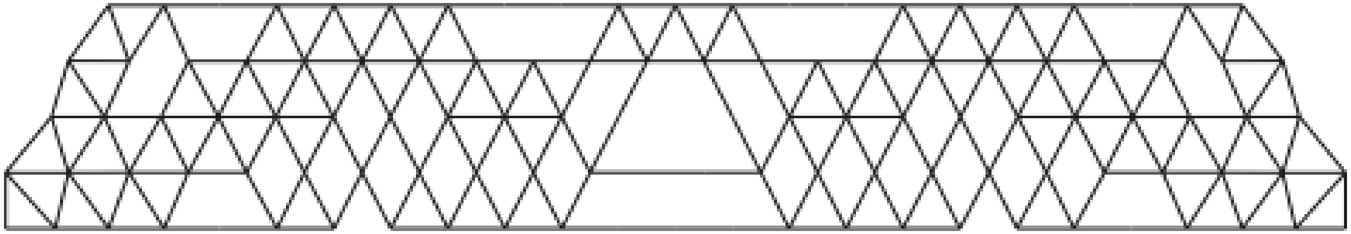
Difference between shape optimization and TO



(a) initial design



(b) result of shape optimization



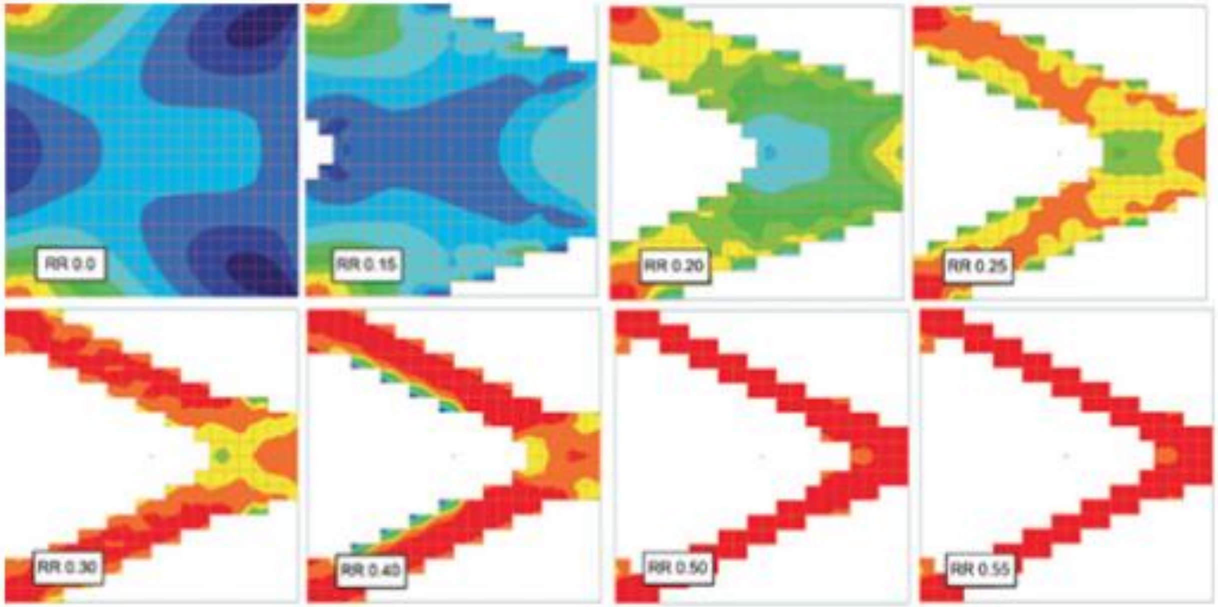
(c) result of topology optimization

Topology Optimization definition

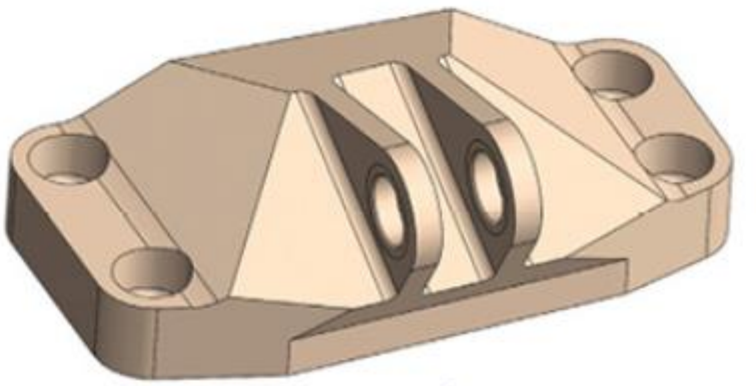
- Topology optimization (TO) is a mathematical method that optimizes material layout within a given design space, for a given set of loads, boundary conditions and constraints with the goal of maximizing the performance of the system.
- TO is different from shape optimization and sizing optimization in the sense that the design can attain any shape within the design space, instead of dealing with predefined configurations

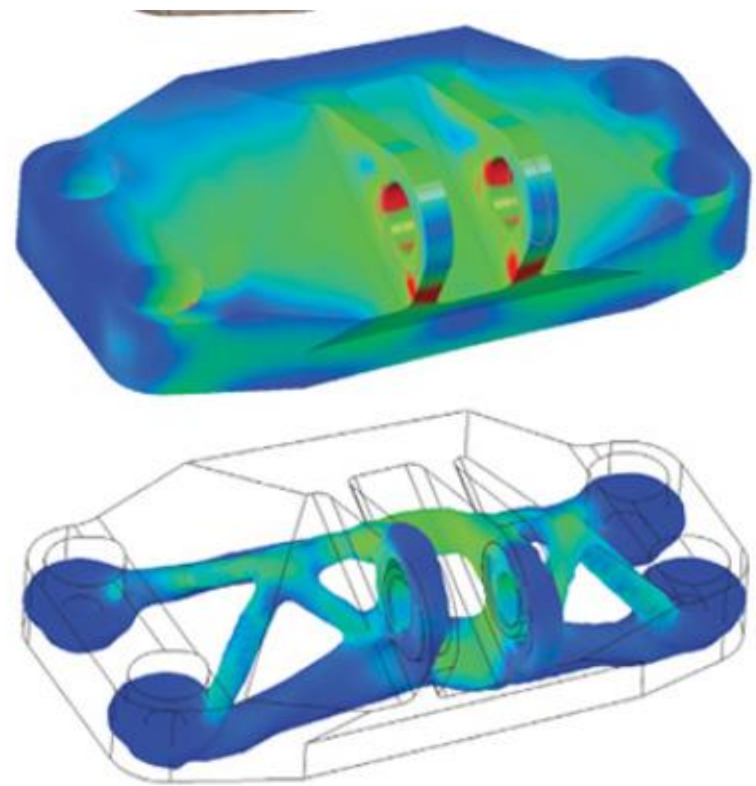
Topology optimization

- Two main approaches have been developed for TO problems
- Truss-based
- Volume-based density methods



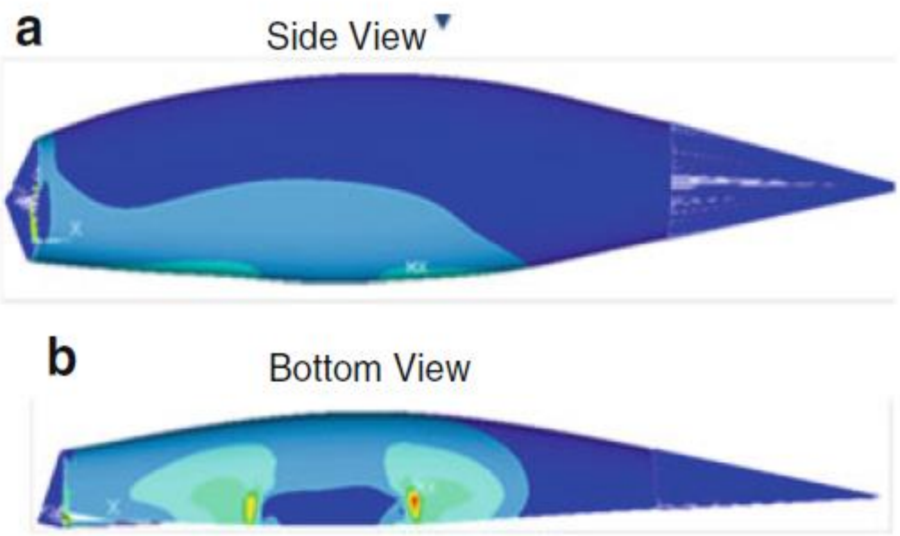
TO Example

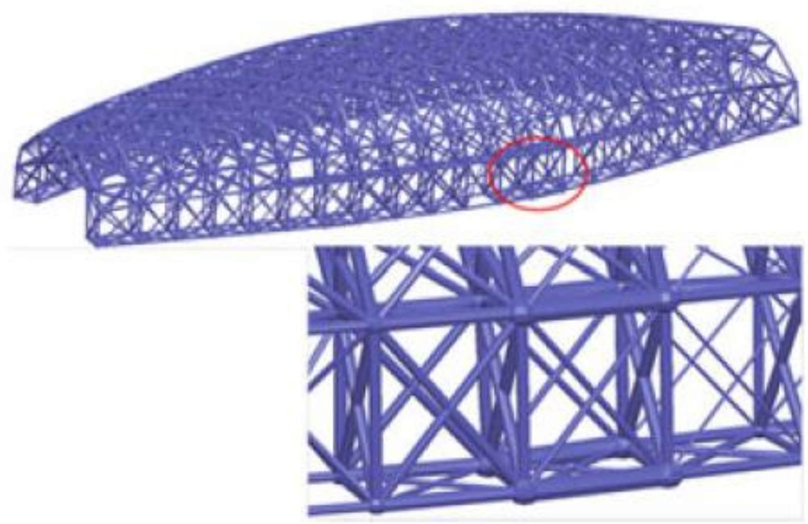




Truss Based Method

- A mesh of struts among a set of nodes is defined
- Identify which struts are most important for the problem
- Determine their size
- remove struts with small sizes



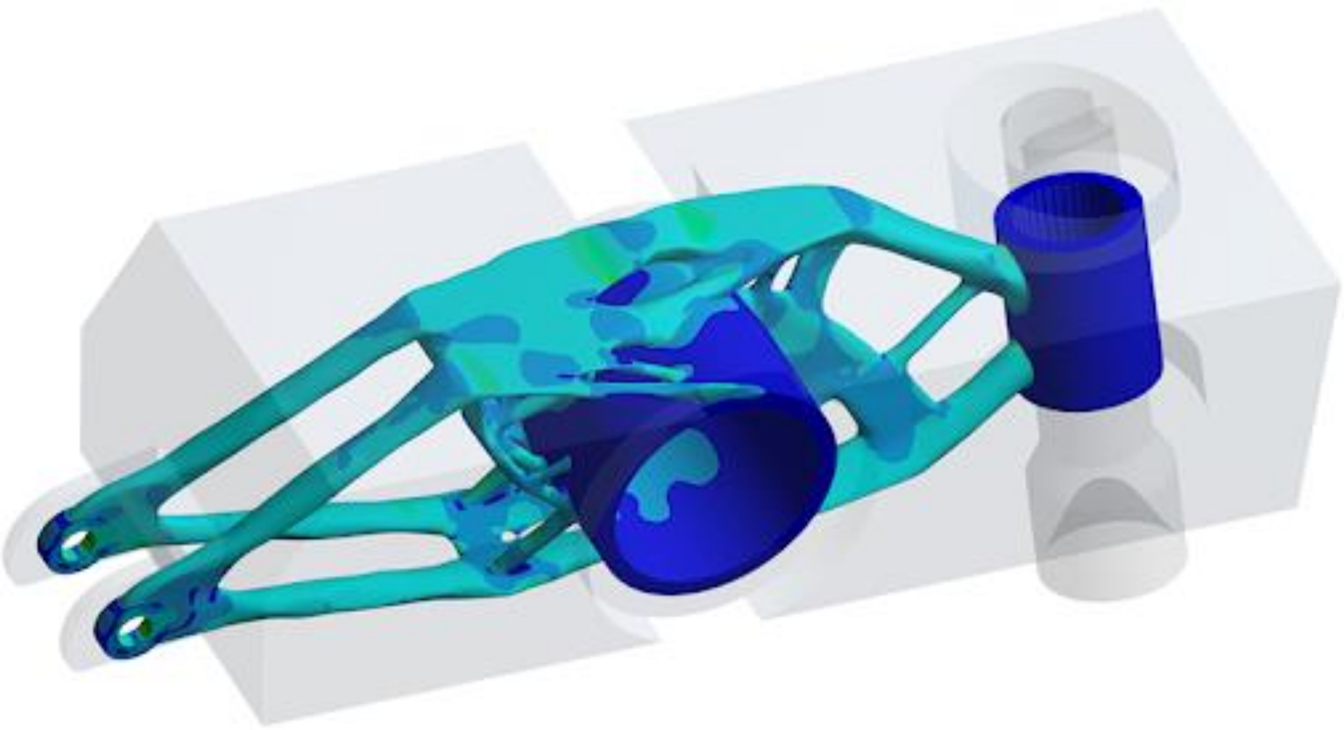


Density based methods

- Determining the appropriate material density in a set of voxels that comprise a spatial domain
- Each voxel has a density value which is used as its design variable

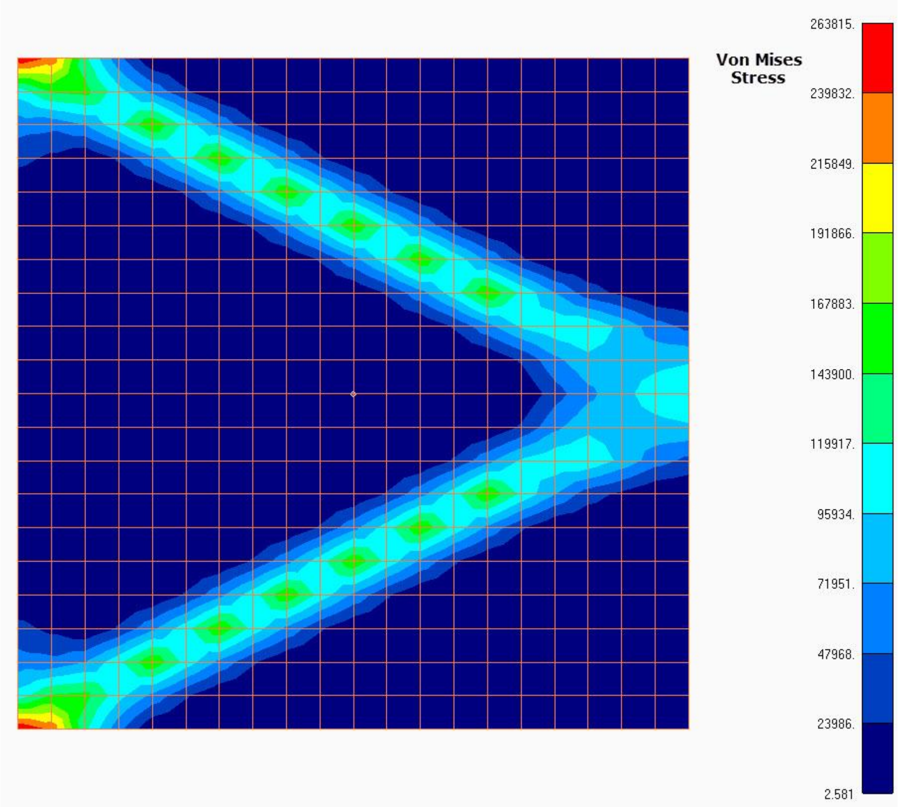
Density Methods

- Evolutionary Methods
- Penalty methods



Evolutionary Methods

- Any element with a stress level below a certain limit is eliminated from the model
- Fully stressed design (FSD)

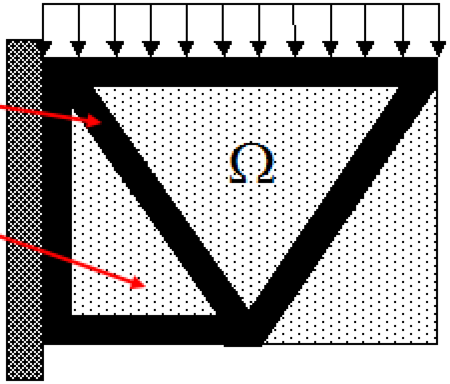


Penalty Methods

- SIMP method (Solid Isotropic Material Penalization)
- Proposed and developed by *Bendsoe and Kikuchi (1988)* and *Rozvany and Zhou (1992)*

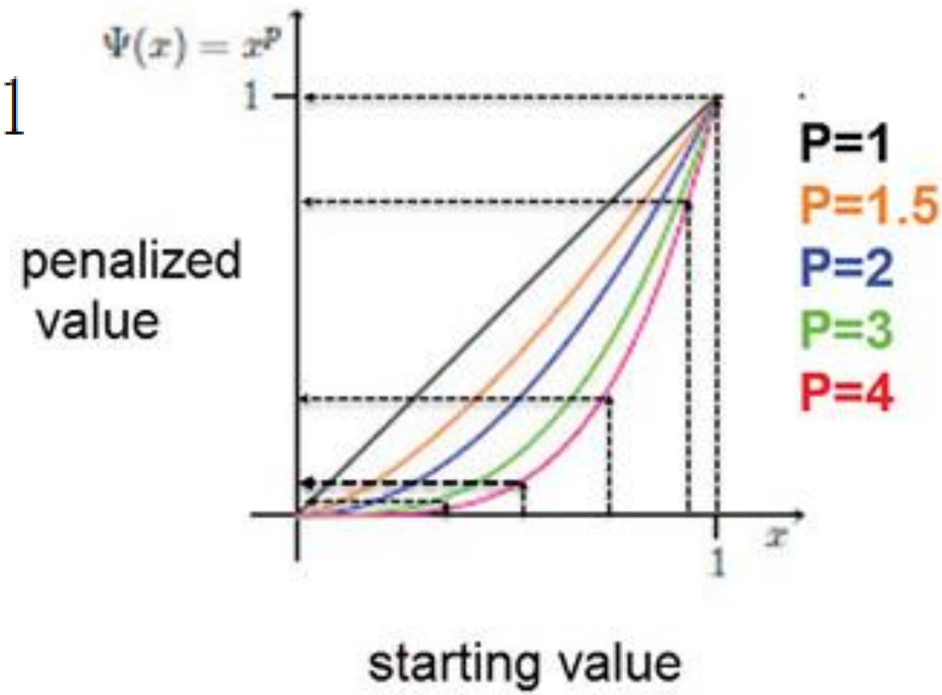
$\rho_{(e)}$ = 1 where material is required (black)

$\rho_{(e)}$ = 0 where material is removed (white)

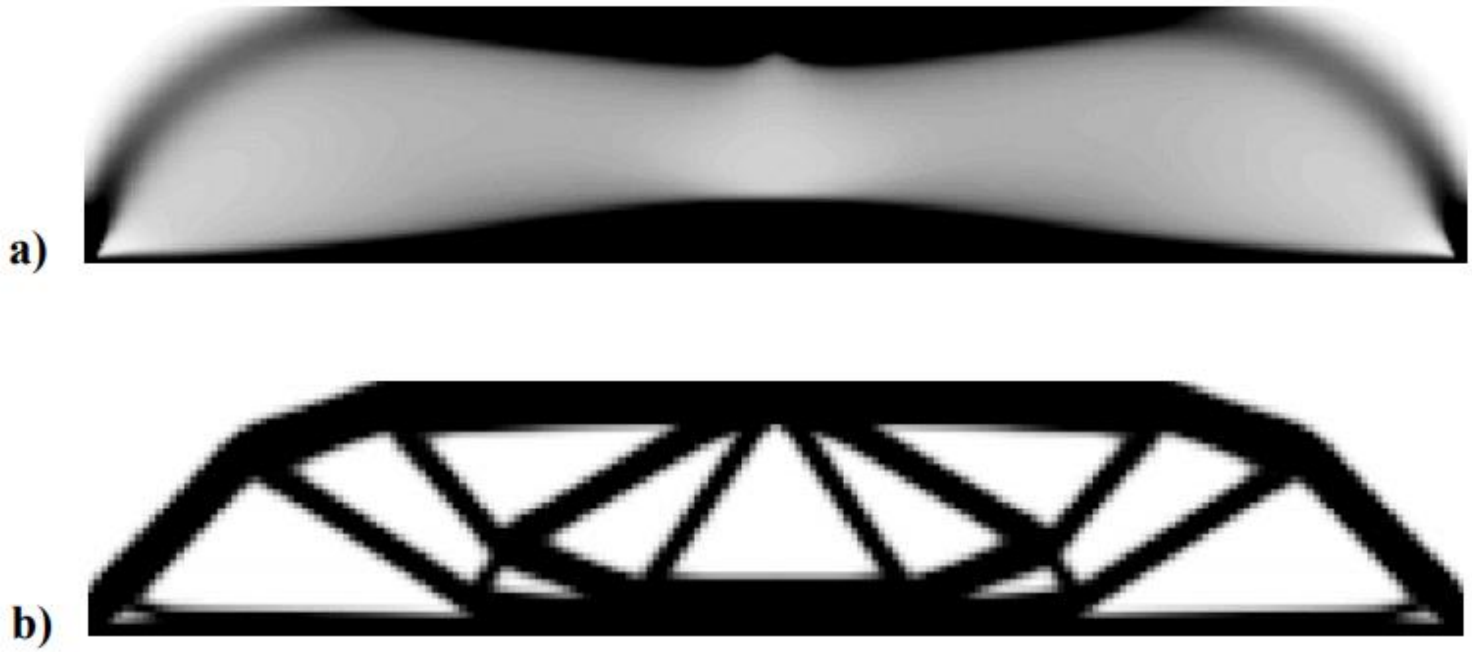


SIMP method

$$E = \rho^p E^0, \quad \rho \in [\rho_{min}, 1], \quad p > 1$$



With and without penalization



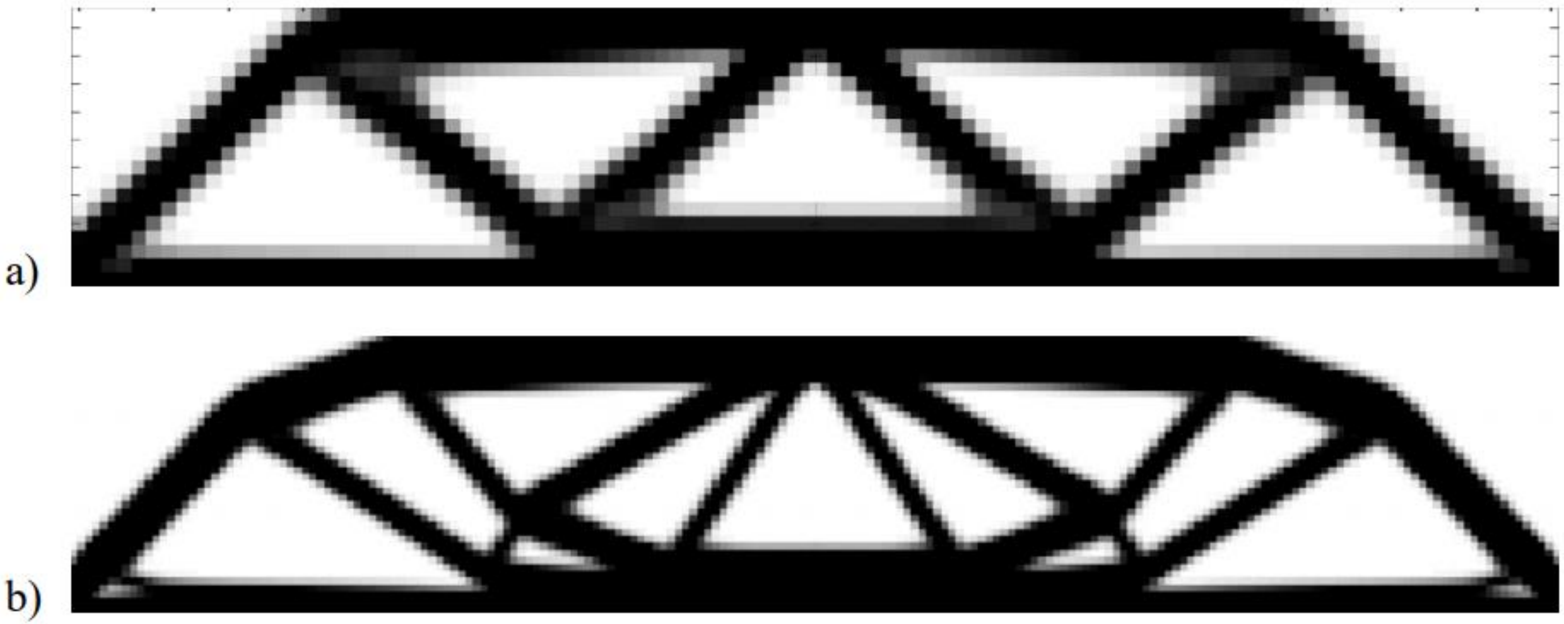
a) without penalization **b)** with penalization

Issues with the SIMP

Checkerboard Issue

Mesh Dependencies

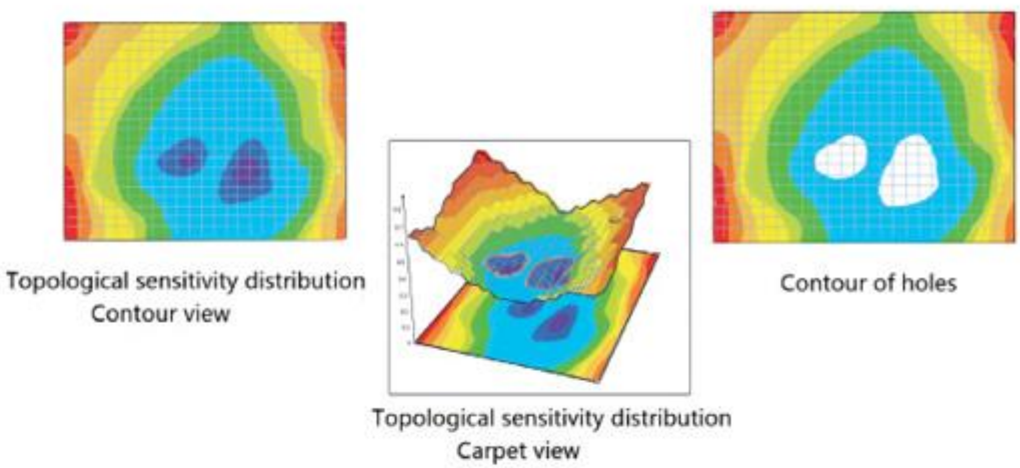
Mesh dependencies



a) 50x20 elements and **b)** 100x40 elements

Level set method

- The concept of LSMs was developed by Osher and Sethian around [1988](1988)

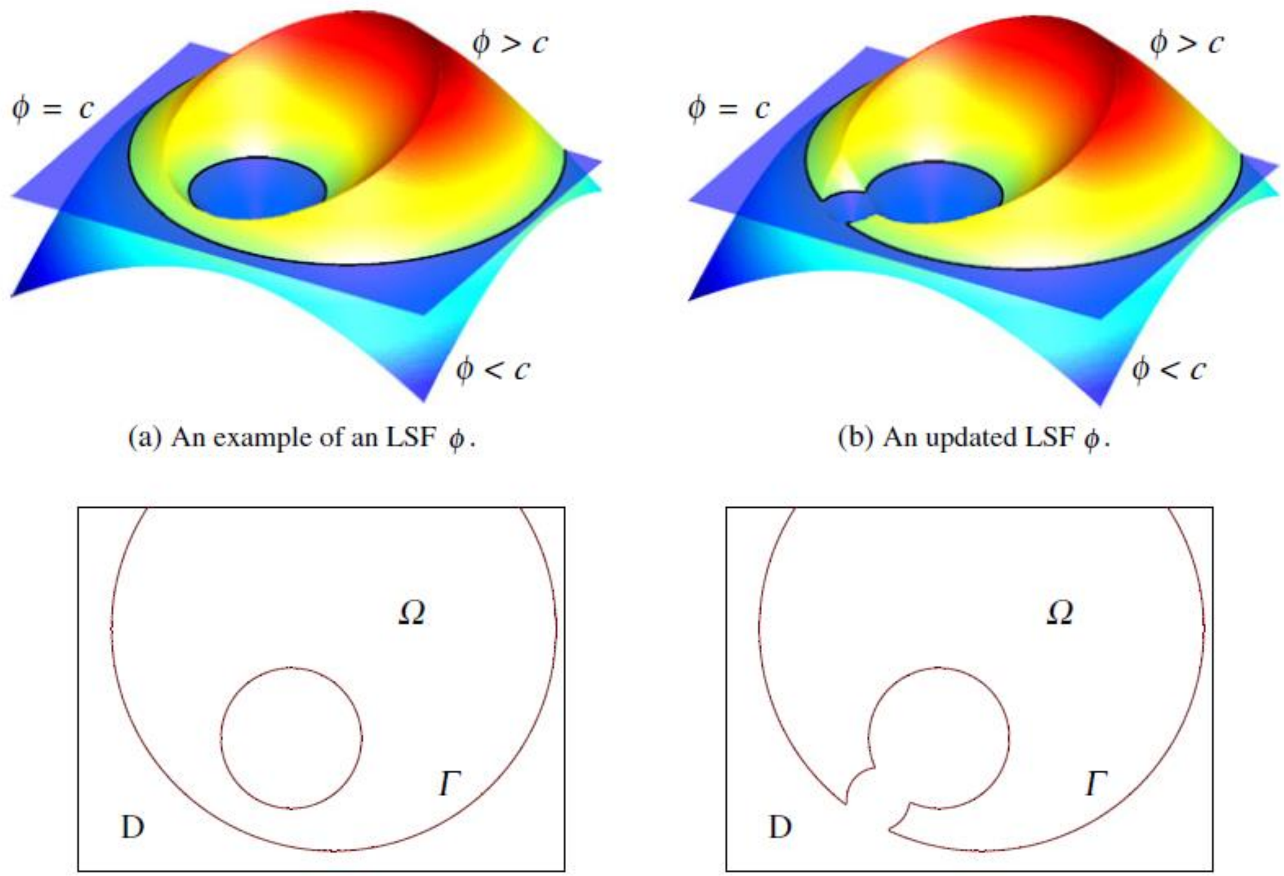


Topological sensitivity distribution
Contour view

Topological sensitivity distribution
Carpet view

Contour of holes

Level set method



(a) An example of an LSF ϕ. (b) An updated LSF ϕ.

(c) The material domain Ω corresponding (d) The updated material domain Ω

TO softwares

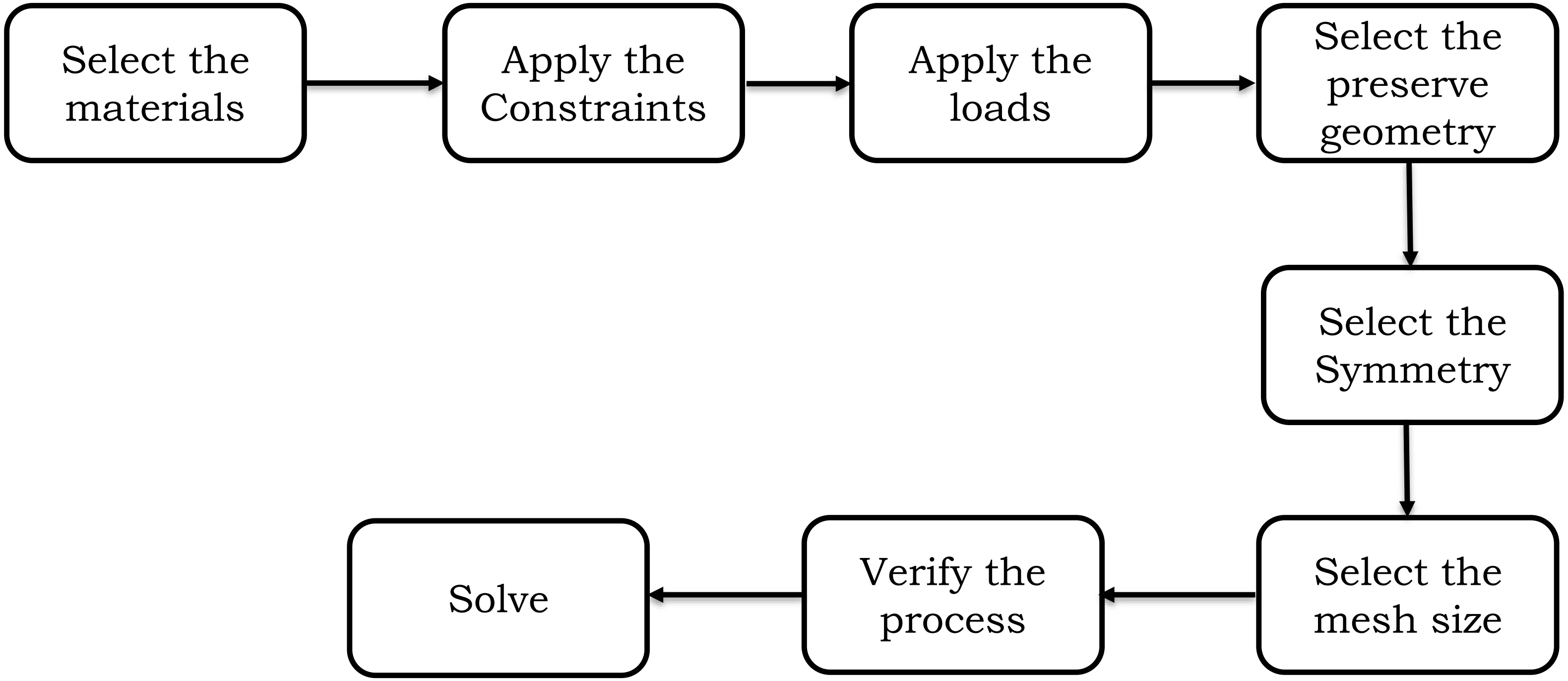
Autodesk Fusion360

ANSYS Workbench

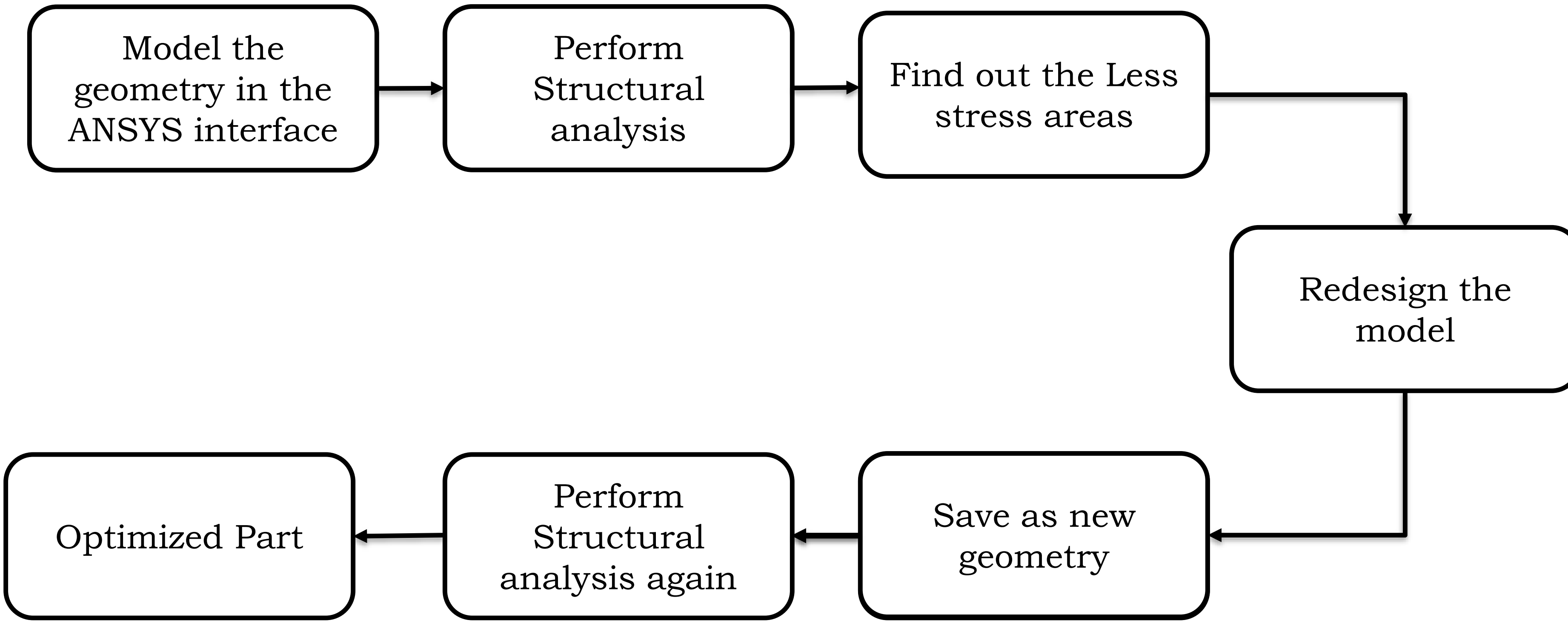
TOSCA

Optistruct altair

TO Process

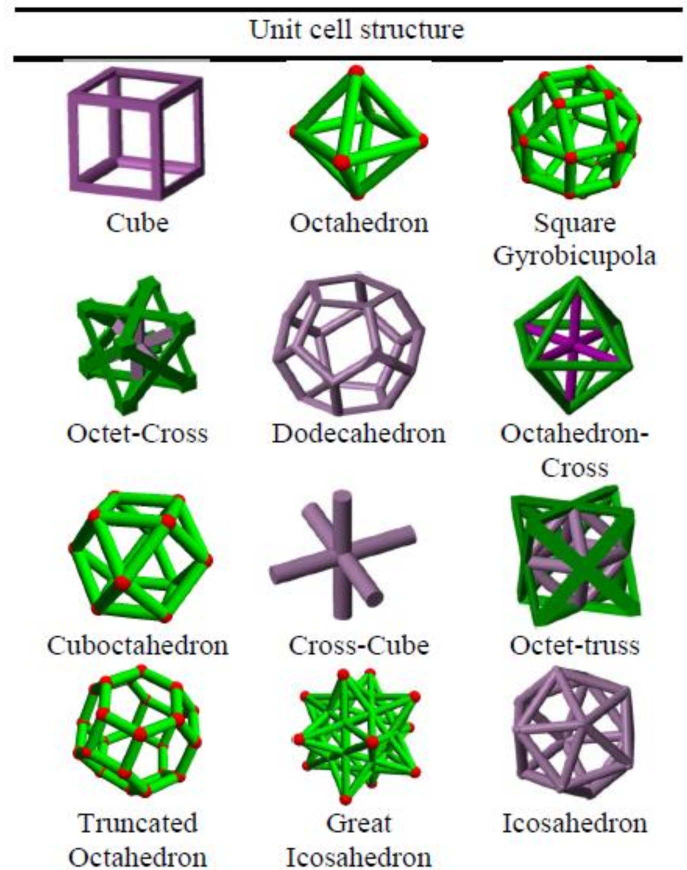

Select the materials
Apply the Constraints
Apply the loads
Select the preserve geometry
Select the Symmetry
Select the mesh size
Verify the process
Solve

TO in ANSYS


Model the geometry in the ANSYS interface
Perform Structural analysis
Find out the Less stress areas
Redesign the model
Save as new geometry
Perform Structural analysis again
Optimized Part

Lattice structures

- Lattice structures are defined as continuously repeating unit cells that interconnect in three dimensions.
- The amount of material, energy and time utilised is reduced
- The improvement in strength to weight ratio.



Different application of lattice structures

- Lightweight structure due to its high specific stiffness and strength
- Heat exchanger because of its large surface area
- An energy absorber due to its ability to undergo great deformation at a relatively low stress level
- Acoustic insulator due to its large number of internal pores

SOFTWARE CAN HELP GENERATE LATTICE STRUCTURES

- Materialise magics
- Autodesk Netfabb
- nTopology
- Rhino Grasshopper
- 3Dxpert by solidworks

Generative design

- Autodesk generative design is a **design exploration** technology.
- generate multiple CAD ready solutions based on real-world manufacturing constraints and product performance requirements

Generative design

- Design parameters are entered into software, and algorithms explore all possible combinations of a solution, often resulting in hundreds of options.
- Mimics the nature's evolutionary approach to create designs.

Difference between TO and Generative design

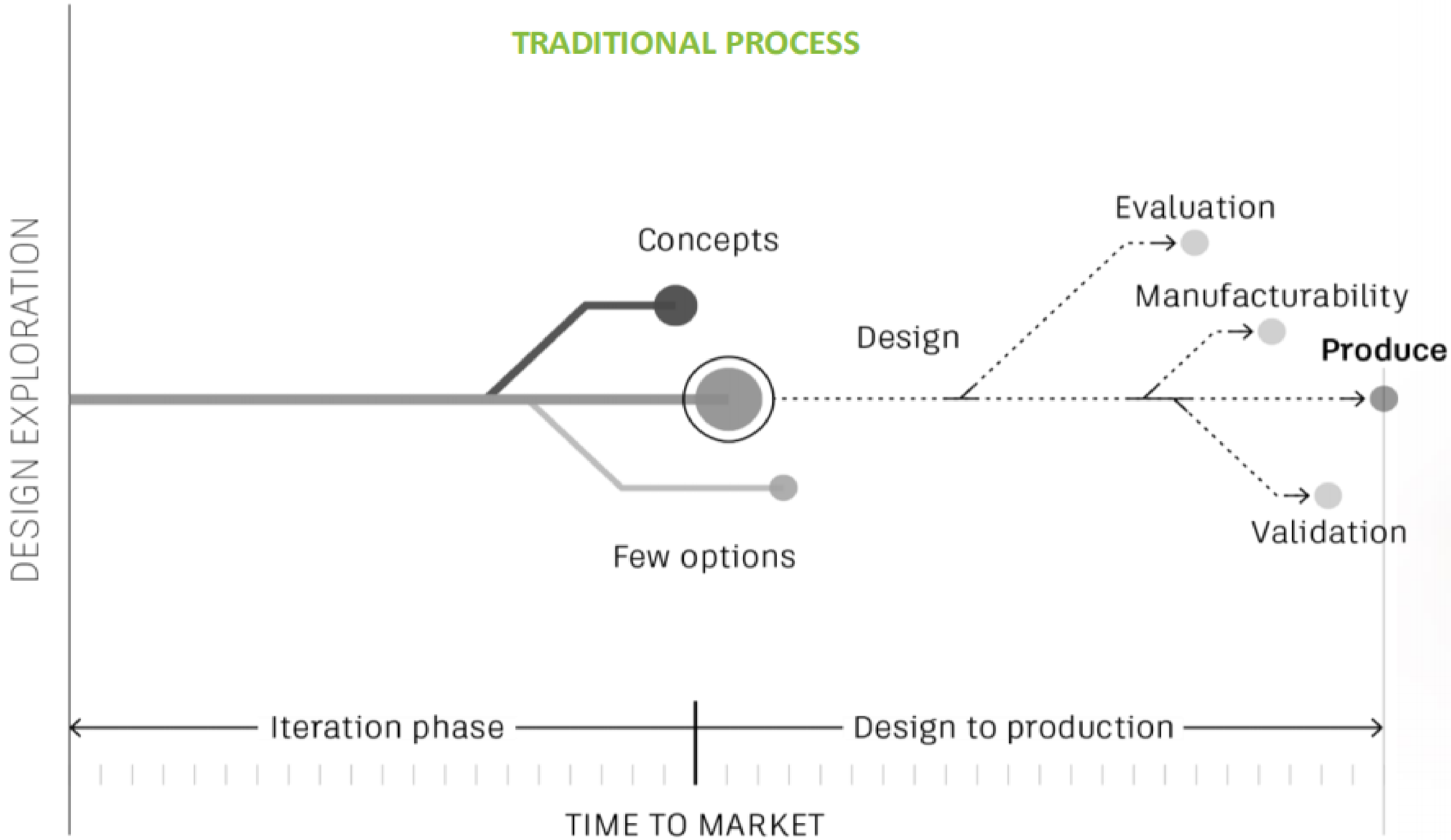
Topology Optimization

- Requires “expert” user to invest time in fully confining the problem
- Typically a light-weighting goal
- Only represents one solution, totally dependent on accuracy of confinement
- Typically is not manufacturing-aware

Generative design

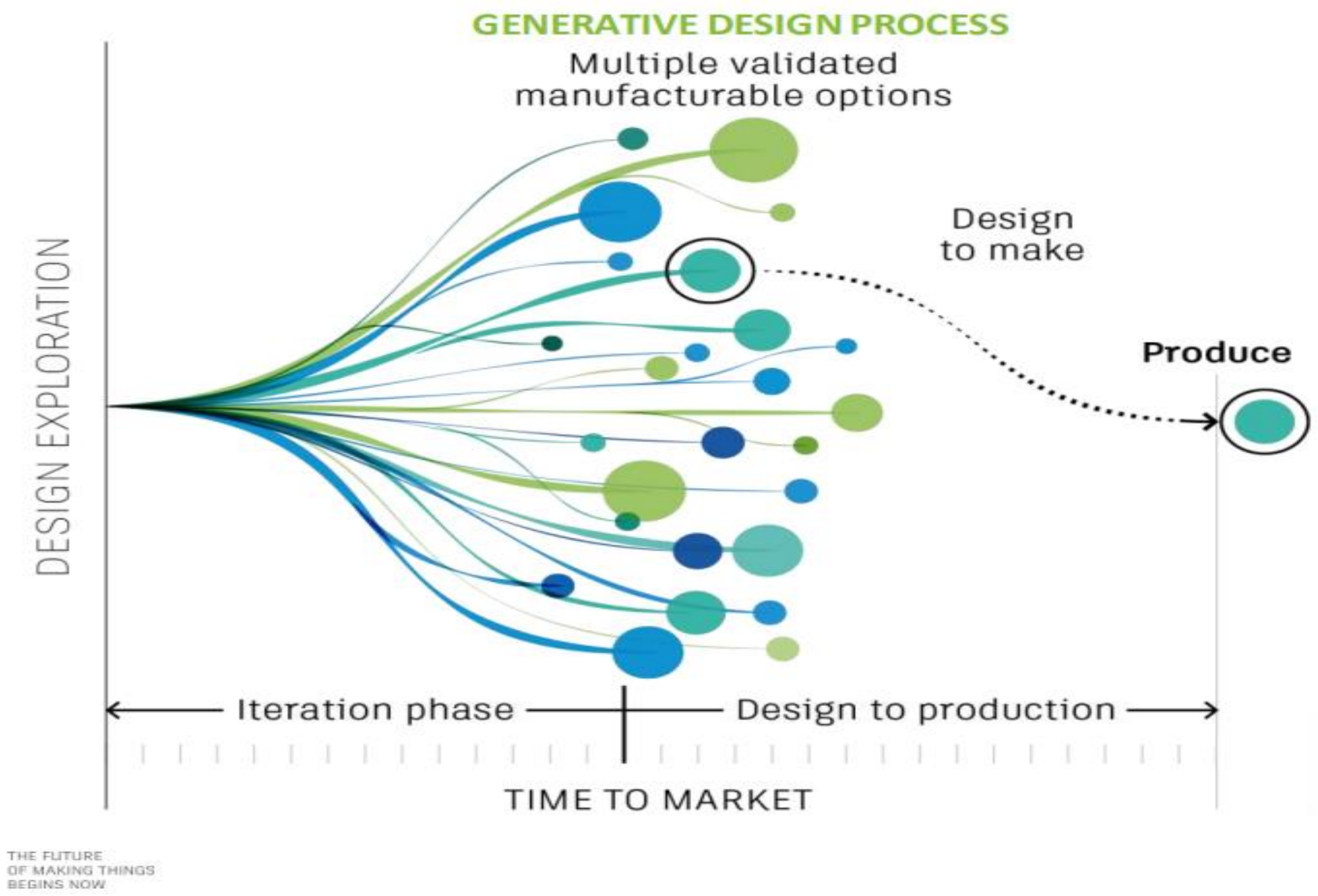
- Explorative methodology that has a goal driven approach
- All viable outcomes are presented to the user
- User can do tradeoffs for performance (go beyond light weighting)
- Manufacturability is taken into account during ideation

Traditional Design



THE FUTURE
OF MAKING THINGS
BEGINS NOW

Generative Design



Classification of Generative design

Closed Design Space

- Generate multiple design based on an existing model

Ex: GE Engine bracket

Open Design Space

- Generate multiple design models without an initial model

Ex: Wall mount stand

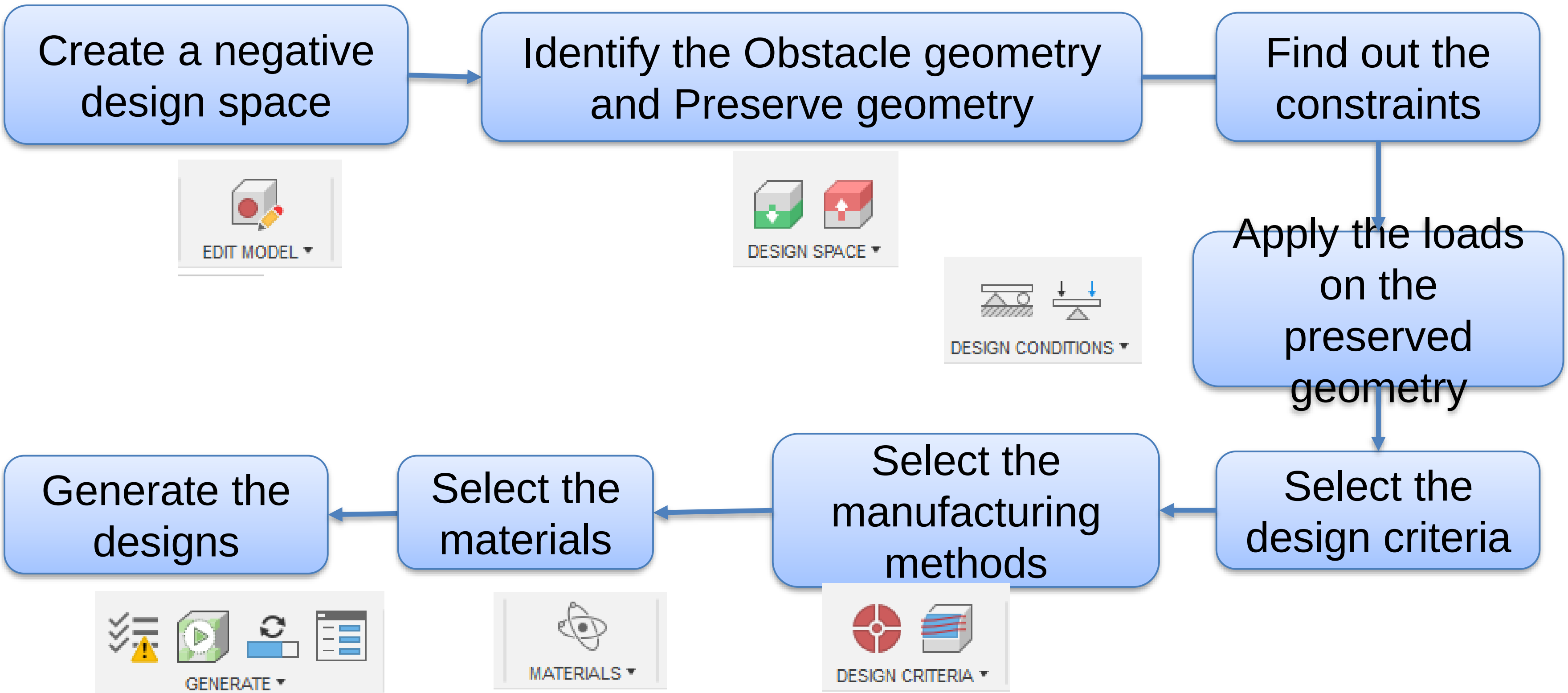
Autodesk Fusion 360

- Create an Autodesk account using the below link
  https://accounts.autodesk.com/
- Download the student version of Fusion360

Prerequisite

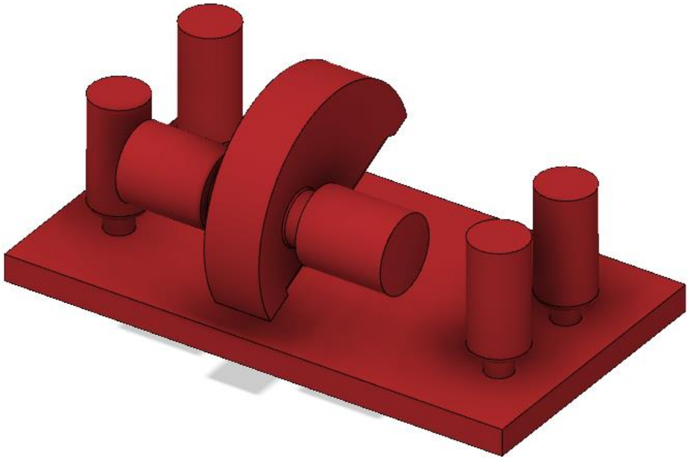
- Functional requirements
- Materials available
- Available manufacturing recourses
- Objective for generative design

Generative Design Steps



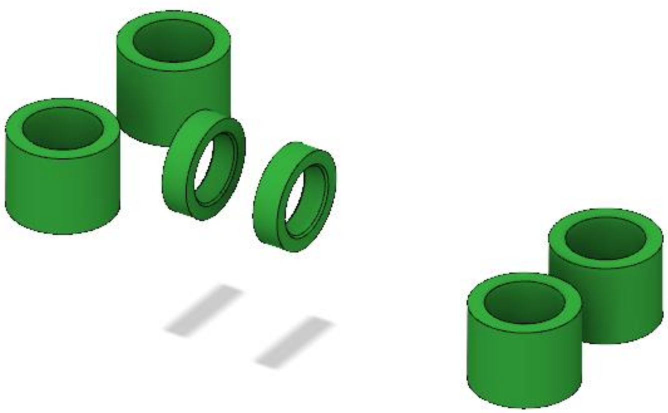
Obstacle geometry

- The negative space where no we need not to create any generative design ideas
- Represented in Red Color
- The other geometries get interaction with the actual model

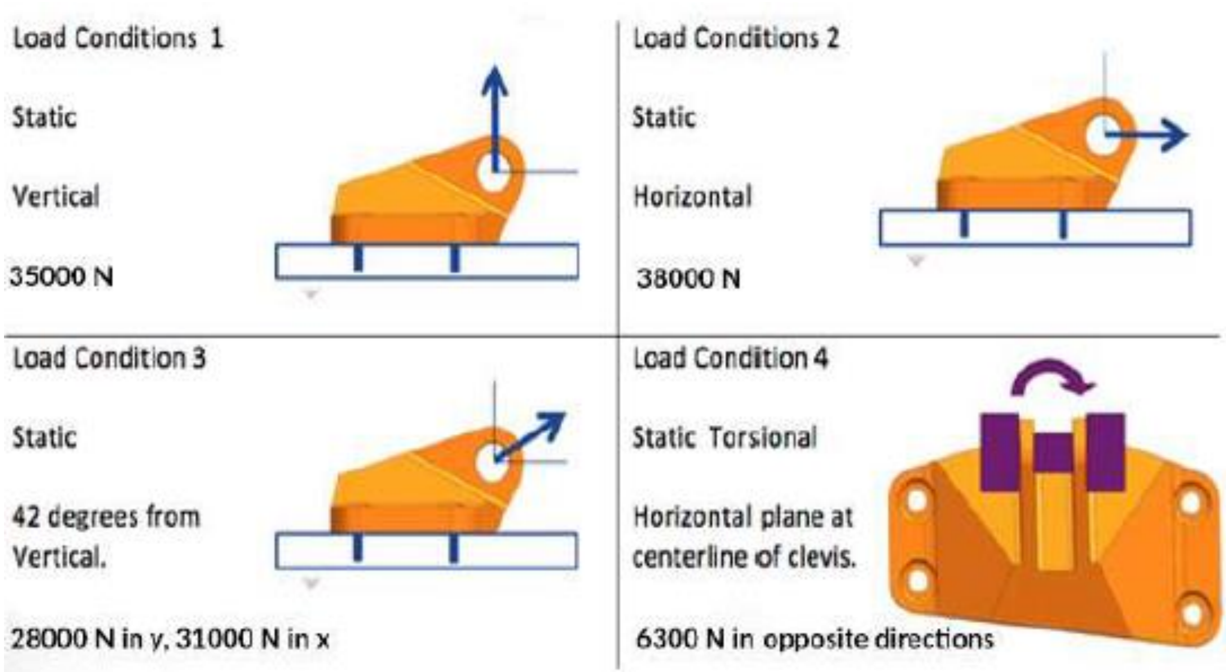


Preserve Geometry

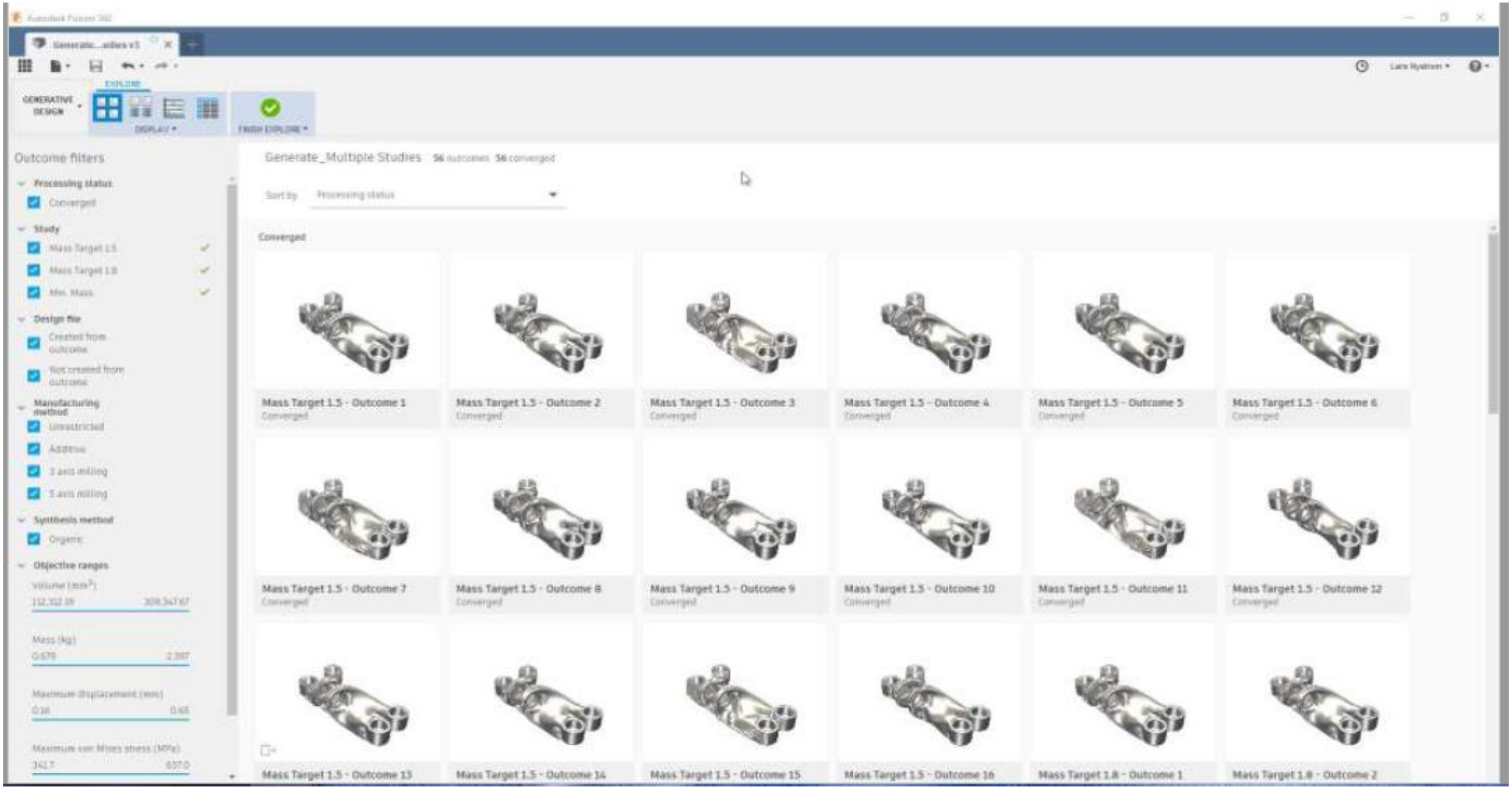
- Part of the required geometry which will not under go any design changes
- Represented in green colour
- Will remain as it is even after generating multiple designs



Case study


Load Conditions 1
Static
Vertical
35000 N
Load Conditions 2
Static
Horizontal
38000 N
Load Condition 3
Static
42 degrees from
Vertical.
28000 N in y, 31000 N in x
Load Condition 4
Static Torsional
Horizontal plane at
centerline of clevis.
6300 N in opposite directions

Results


Generate_Multiple Studies
Outcome filters
Processing status
Converged
Study
Design file
Manufacturing method
Synthesis method
Objective ranges
Mass Target 1.5 - Outcome 1
Mass Target 1.5 - Outcome 2
Mass Target 1.5 - Outcome 3
Mass Target 1.5 - Outcome 4
Mass Target 1.5 - Outcome 5
Mass Target 1.5 - Outcome 6
Mass Target 1.5 - Outcome 7
Mass Target 1.5 - Outcome 8
Mass Target 1.5 - Outcome 9
Mass Target 1.5 - Outcome 10
Mass Target 1.5 - Outcome 11
Mass Target 1.5 - Outcome 12
Mass Target 1.5 - Outcome 13
Mass Target 1.5 - Outcome 14
Mass Target 1.5 - Outcome 15
Mass Target 1.5 - Outcome 16
Mass Target 1.8 - Outcome 1
Mass Target 1.8 - Outcome 2

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End of session 6