Design Focused For Additive Manufacturing

Alexander Jones

3D Printing Engineer

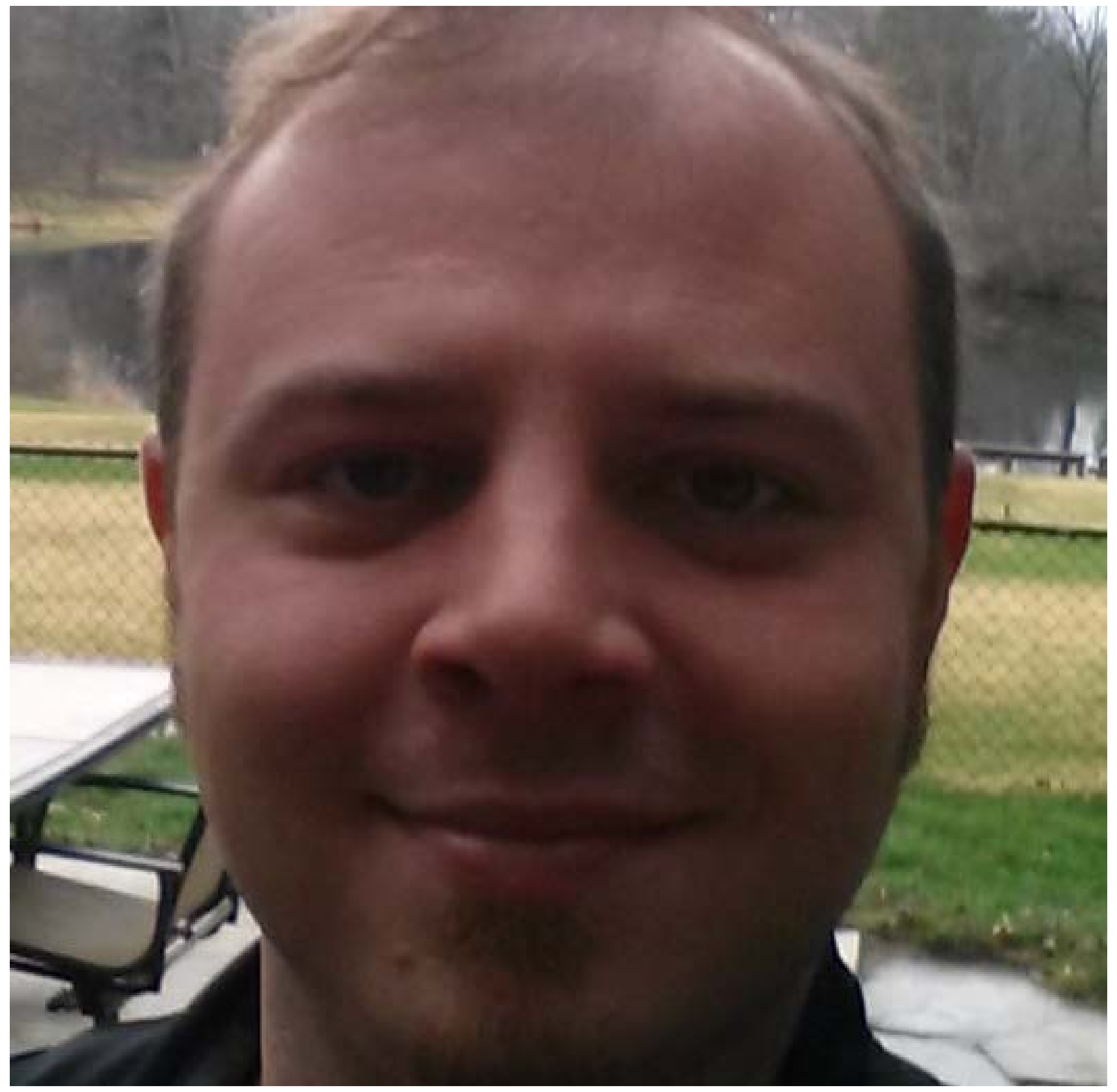
Anthony Muzzillo

Principal Implementation Consultant

About the speaker

Alexander Jones

Alexander Jones is an engineer that supports the Johnson & Johnson 3D Printing Team and leads the 3D printing training and education efforts. He has created and led several in-person and virtual workshops, self-paced trainings, and other educational resources for all in JNJ to understand and utilize 3D printing capabilities. He has also been part of the development process of several 3D printed medical devices and manufacturing tools, jigs, & fixtures.



About the speaker

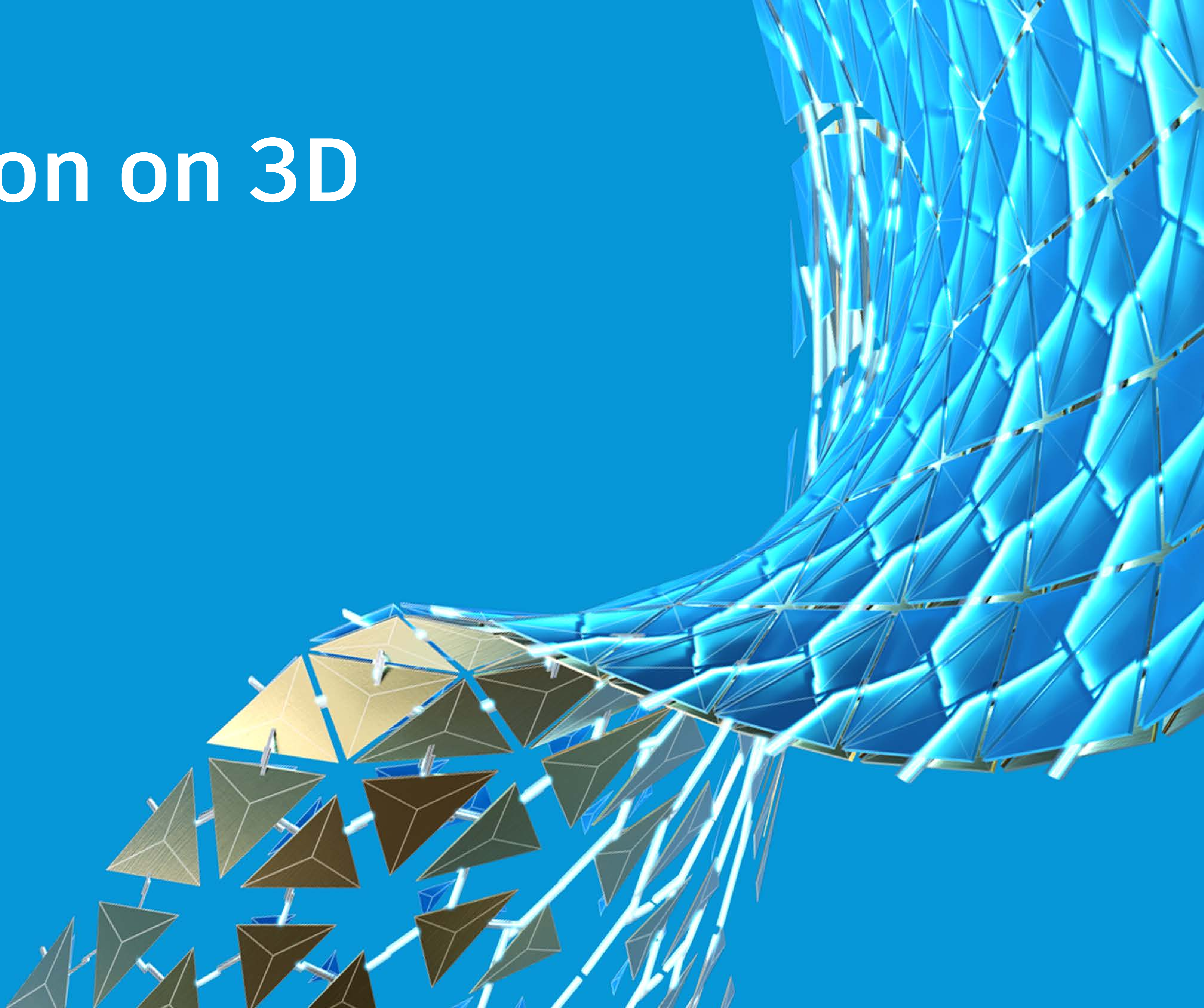
Anthony Muzzillo

Anthony Muzzillo is a Principal tech consultant in the GCD team at Autodesk, Inc. He has been with Autodesk for 6 years after it acquired his former company, Magestic Systems. Muzzillo has working in the manufacturing industry for 14 years in total. His current focus is additive manufacturing primarily polymer and metal 3D printing

Course Agenda

- **Introduction on 3D Printing**
  - What is 3D Printing
  - What are Support Structures
  - How the 3D printing designer is more aligned in the full production process
- **Modifying and Adapting Existing Designs for the Additive Build Process**
  - Design advantages to add to enhance part functionality
- **The Right and Wrong way to Lightweight a Part**
  - Manual material removal
  - Generative design
  - Lattice
  - Infill
  - CASE STUDY
- **Part Orientation and How it can Affect Build Quality and Success**
  - Addition of support structures
  - Compare the time vs cost with changing part orientation
  - CASE STUDY
- **Understanding When the Printing Process will Fail BEFORE trying to Build a Part**
  - Utilizing Netfabb Simulation

Introduction on 3D Printing



What is 3D Printing

- Often referred to as additive manufacturing, is the process of additively building up a part one layer at a time.
- 3D Printing was first patented in 1983 by Chuck Hull
- There are several different types of 3D printing ranging from extrusion technologies to laser- based technologies
- Many materials can be 3D printed including metals, polymers, ceramics, electronics, and even biologics

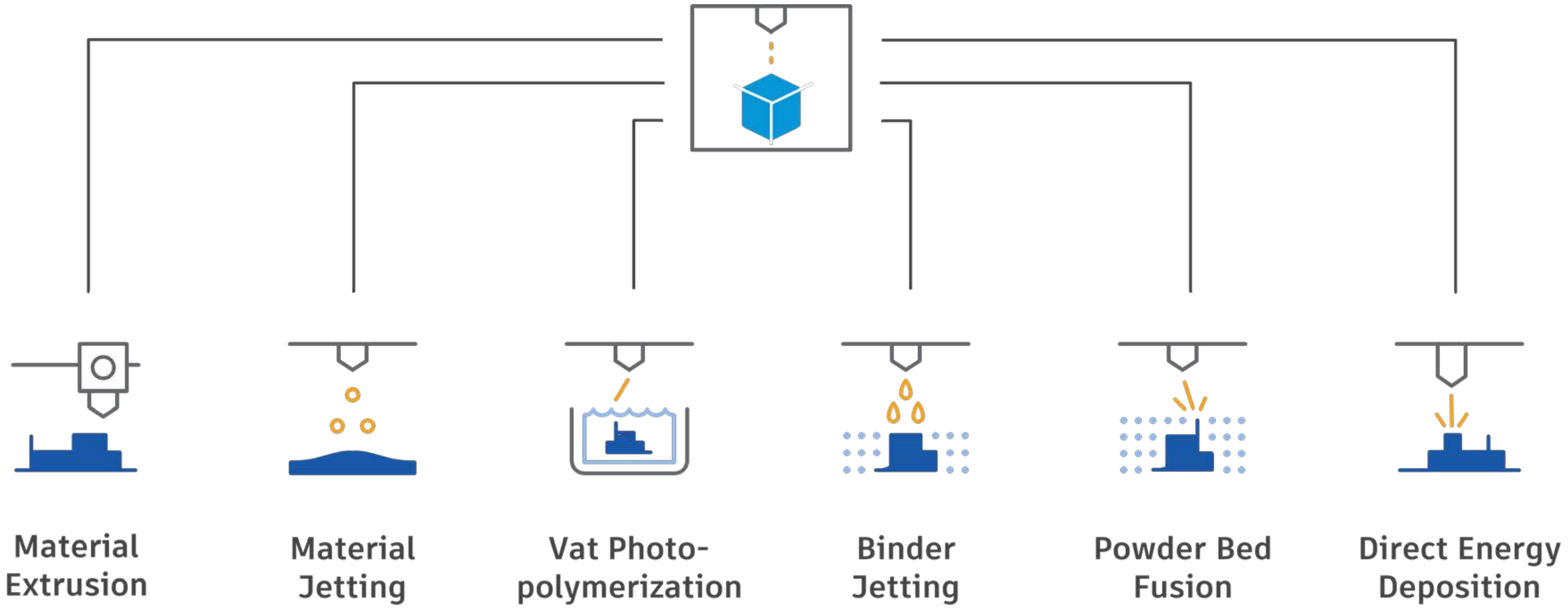


Image Source: 3D Hubs

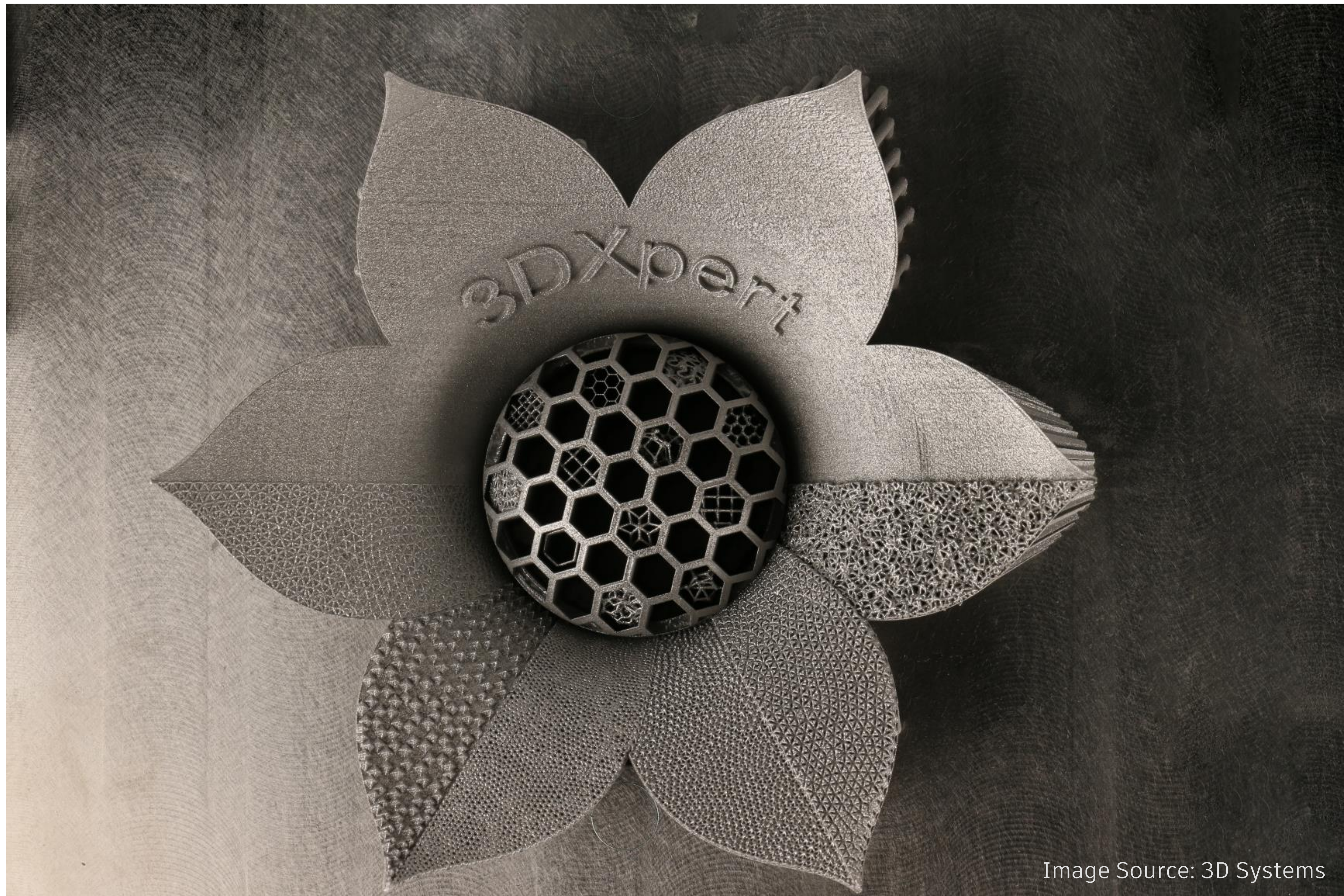


Image Source: 3D Systems

What Are Support Structures

Support Structures are a scaffold-like structure added to parts to ensure successful printing against the forces of gravity and thermal properties.

- Overhang features of less than 45 degrees require supports to successfully build
- Require post processing to remove after printing
- The geometry varies in each technology
  - Some technologies do not require them at all

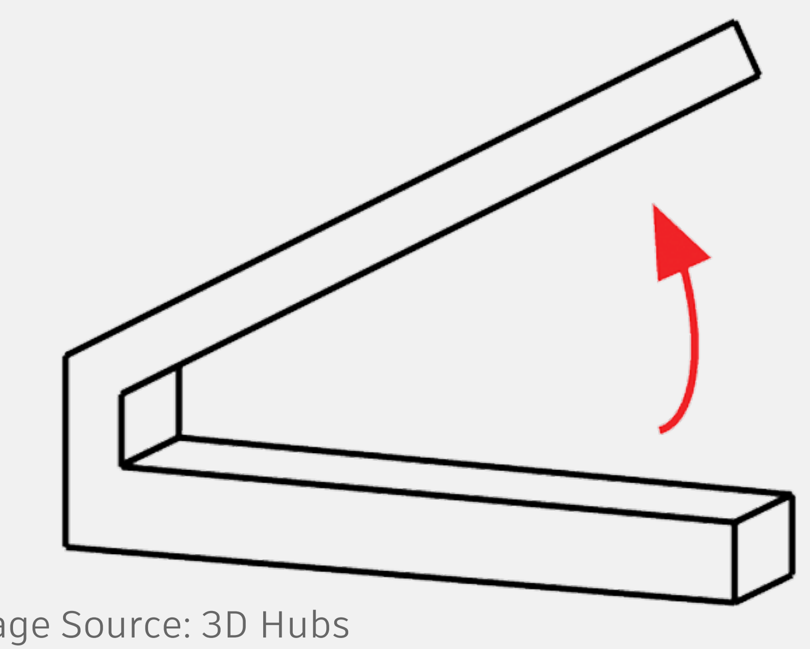


Image Source: 3D Hubs

Rule of Thumb

< 45 degrees requires support structures

Image Source: 3D Hubs

Image Source: 3D Hubs

Image Source: 3D Hubs

The 3D Printing Process & the Designer

Design

- **3D CAD (e.g. Fusion 360) is used to create the design with the intention of 3D Printing as the manufacturing method**
    - Features are designed to print successfully for 3D printing process

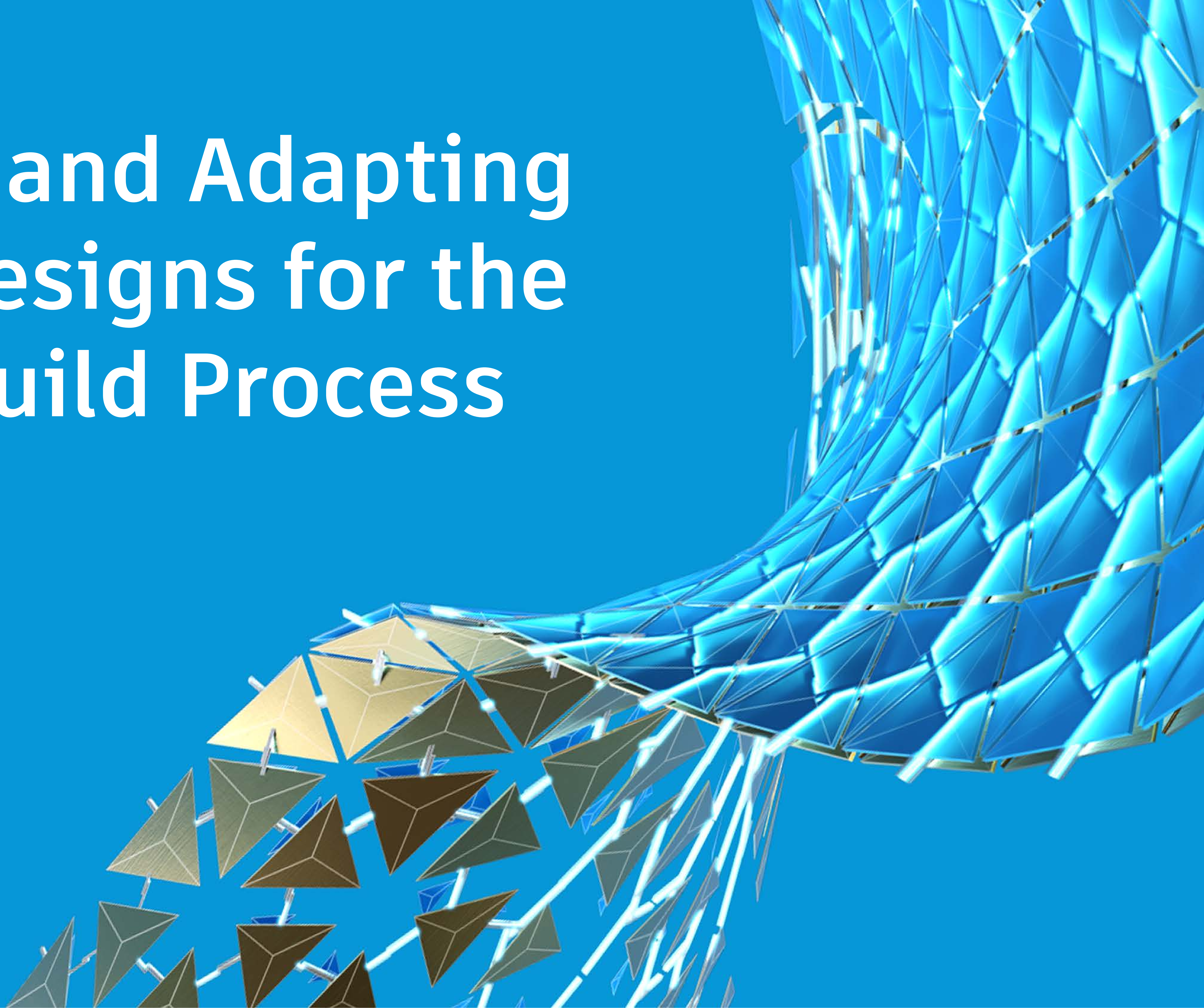
Build Prep

- **Part Orientation & Supports**
    - Features are given min 45-degree angles to lessen required supports
    - Critical features do not have supports on them

Post Processing

- **Additional operations used to meet requirements 3D Printing alone cannot**
    - Stock material provided for machining operations or heavy surface finishing
    - Datums are provided for machining

Modifying and Adapting Existing Designs for the Additive Build Process



Design Advantages help Enhance Part Functionality

The layer-by-layer process in 3D Printing technologies enables unique, previously impossible designs

Image Source: 3D Systems

As-Printed Moving Assemblies

- **Due to the way additive manufacturing produces parts layer – by – layer, it is possible to create moving assemblies in the assembled form.**
  - Often can be function directly after printing
- **This capability removes assembly requirements**
- **If designed appropriately, can prevent disassembly**
  - This can be useful to prevent user error or losing parts
  - Example: Captured screws preventing them from becoming loose and loosing them

Part Consolidation

- **Traditionally complex parts are static assemblies that involve several parts that are then assembled with welding, pinning, bolts, or other methods**
  - Addition step increase the manufacturing time and cost
  - More parts increases potential for tolerance stack and alignment issues
  - Large part assemblies cause difficult change over processes
- **Additive Manufacturing designs can combine the assemblies into one single complex part**

Image Source: 3D Systems

- Part count reduction 20:1
- Production time reduced by 75%
- A better lighter part
- Assembly errors eradicated

Internal Channels, Holes, and Features

- **Traditionally internal channels and holes are typically drilled out**
  - o Channels are straight with circular cross section
- **Additively created designs can create the channels without additional process steps**
  - o Channels can bend corners and change cross sectional shape
  - o Software can be used to optimize channels based on the application needs
  - o Is useful in parts where cooling is needed

Image Source: Forefront AM

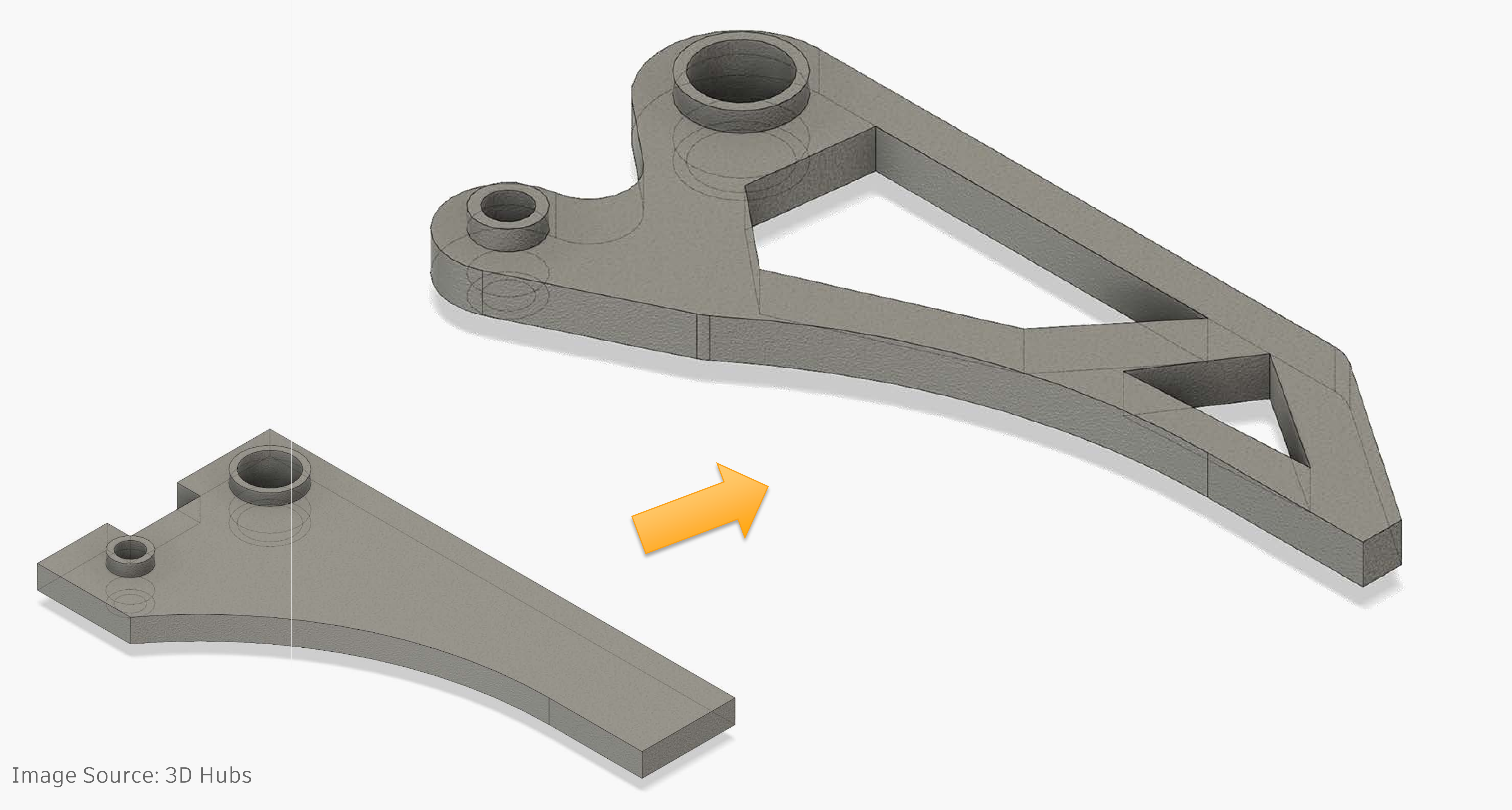
Conformal cooling channels can be added into molds and other parts to increase and optimize cooling.

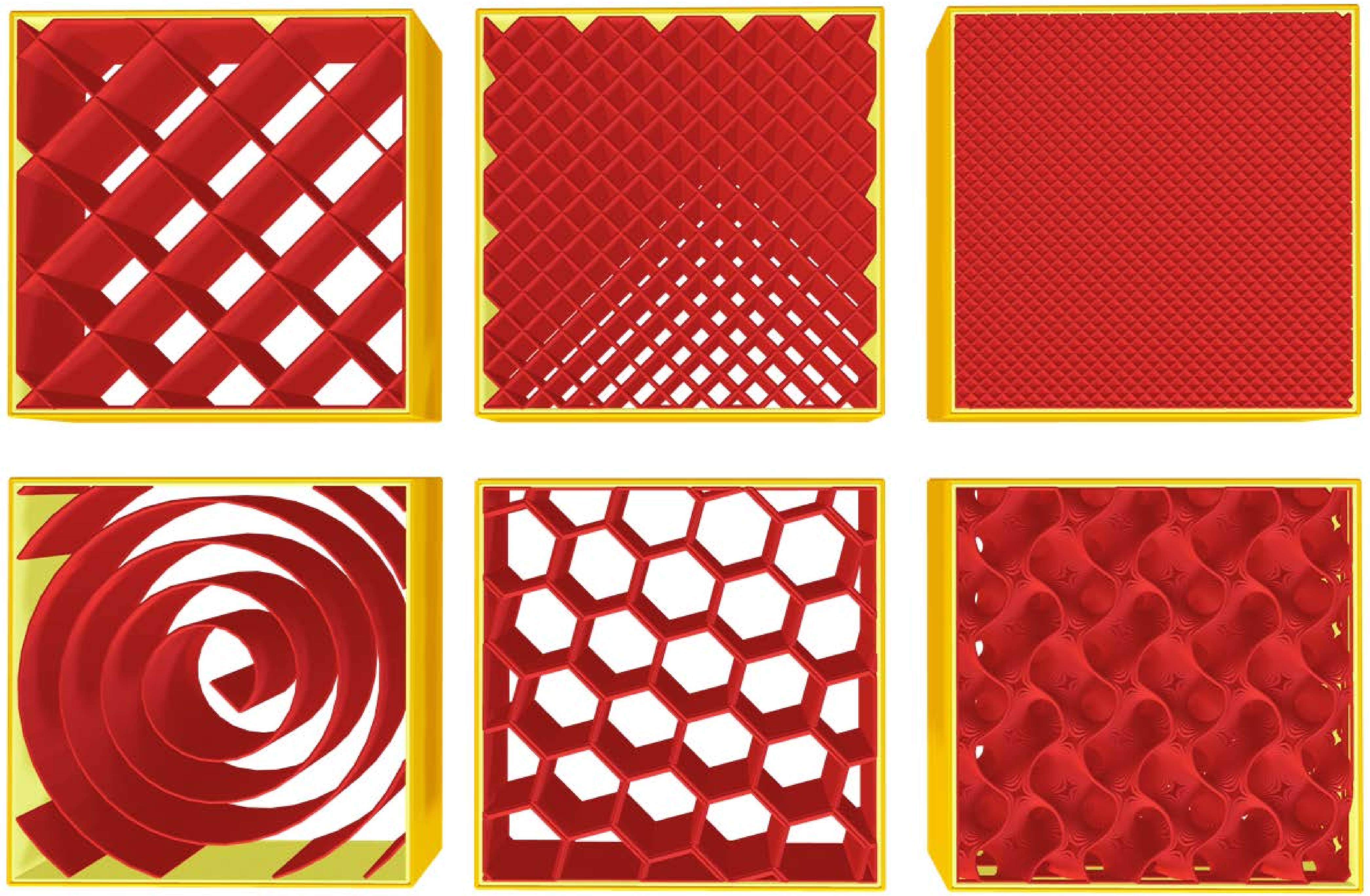
Light Weighting

- **Machining starts with a block of material and the costs increase with every operation to remove material**
- **Additive starts with nothing and the costs increase with every operation to add material**
  - Removing unnecessary material helps lower the cost (and time) of 3D printed parts
- **Excess weight in parts often lowers functionality**
  - (e.g. Automation)
- **Excess weight creates ergonomic issues**
- **Reducing material is more sustainable**

Image Source: Materialise

The Right and Wrong way to Lightweight a Part





Manual Material Removal

Designs can be designed with cutouts placed into them. If loads are present on the part than additional analysis and/or testing would be required.

- Honeycomb pattern cutouts are often used

Infill

Infill is the density or how solid a part is built. In Extrusion based technologies (e.g. FDM) the infill can be set as a percentage of how solid the part is.

- The default for many FDM printers is around 20% to save time and material.


Image Source: 3D Hubs


Image Source: 3D Hubs

Generative Design

Organic designs are created based on the loads and boundary conditions on the part. Allows for parts to be created with material on in areas required

- Instead of being used to validate a design, as done traditionally, Finite Element Analysis (FEA) is used to help create the design.

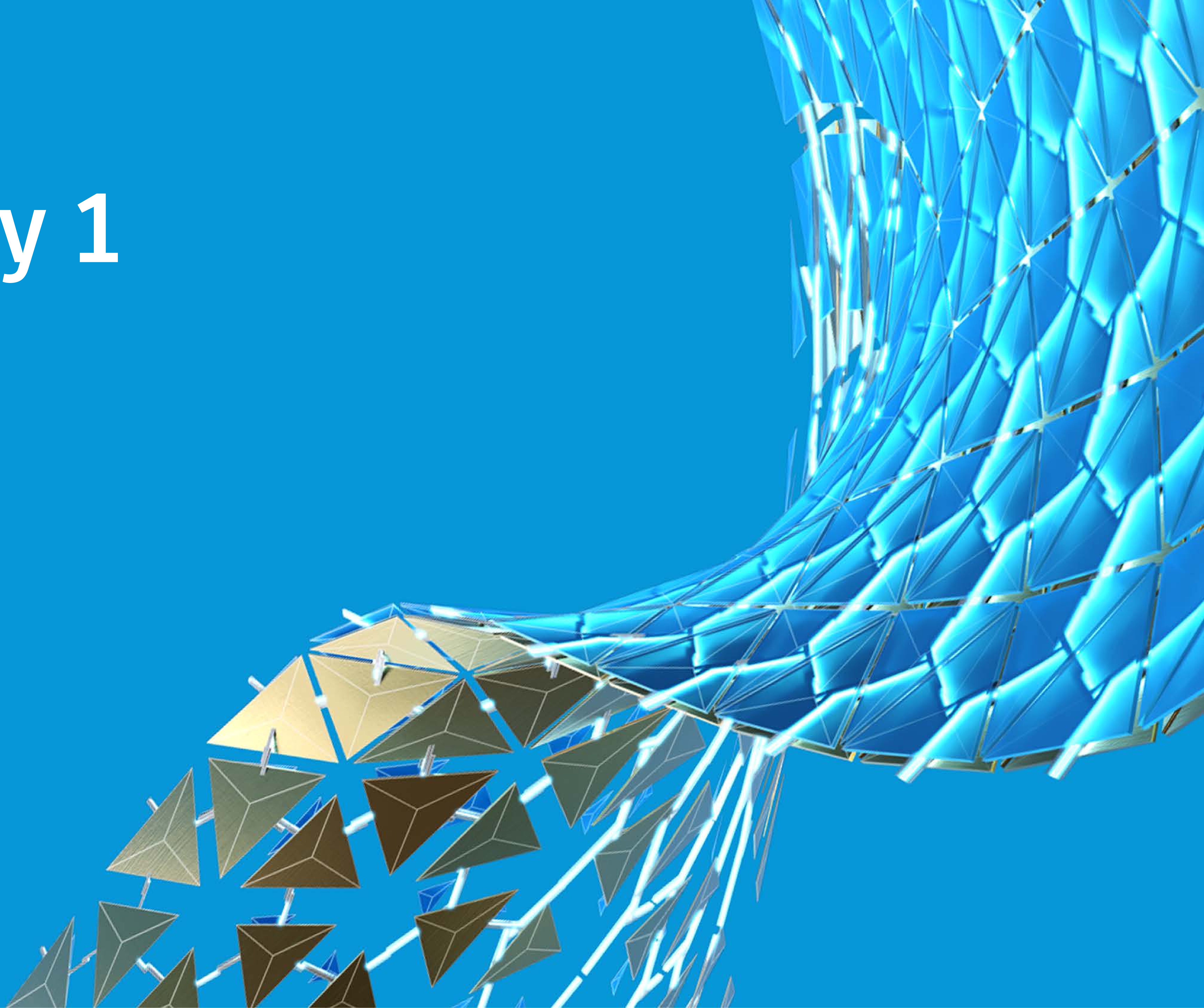
Lattice

Along with being lightweight and using less material, lattice structures can be used for heat-dissipation properties, shock-absorption, and more.

- Like Generative design, software is utilized to customize and generate the lattice to fit the application and the loads the part sees.

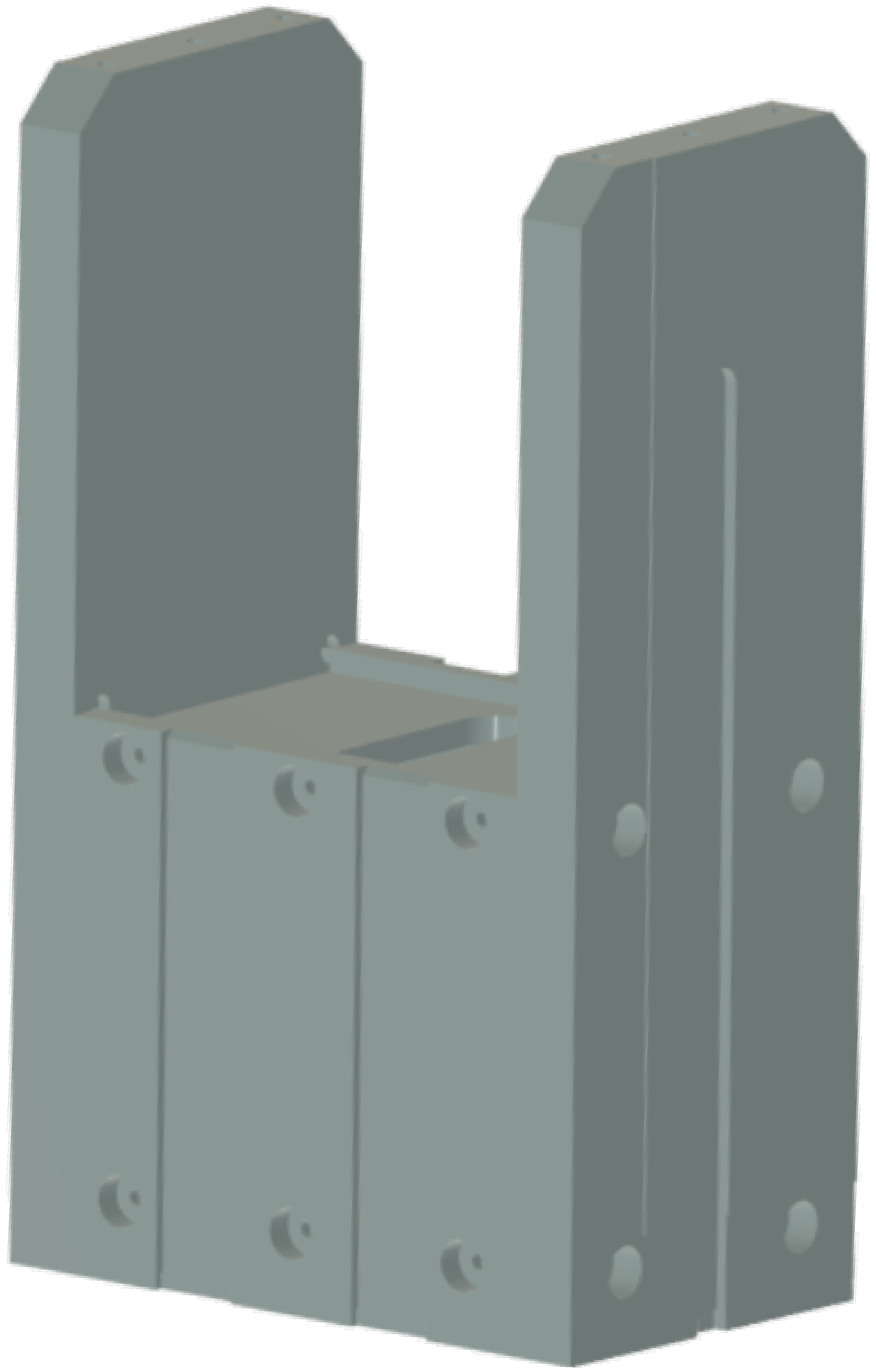
Case Study 1

Light-weighting



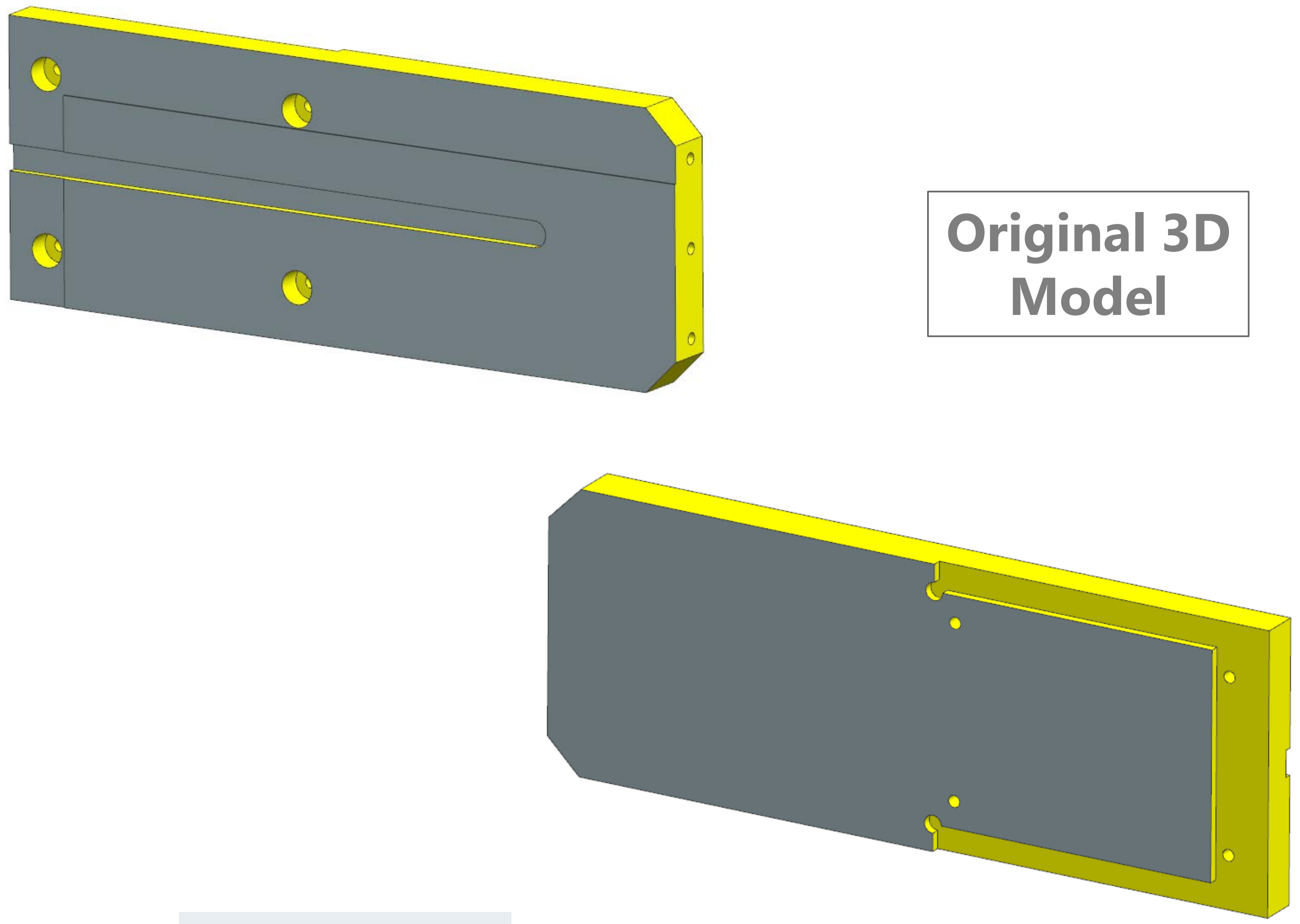
Enclosure Assembly: Light Weighting Case Study

- **There are various levels of Light Weighting with Design for Additive Manufacturing**
  1. Hollow existing part
  2. Lattice existing part and validate new design will perform in real world
  3. Start design from scratch and optimize component for printing process and material
- **In this example, the main goal was to reduce weight due to ergonomics of lifting the heavy part during changeovers on the manufacturing floor**
  - All the parts could potentially be consolidated to a single piece, but due to lack of potential value, it was settled to simply address individual parts in the assembly

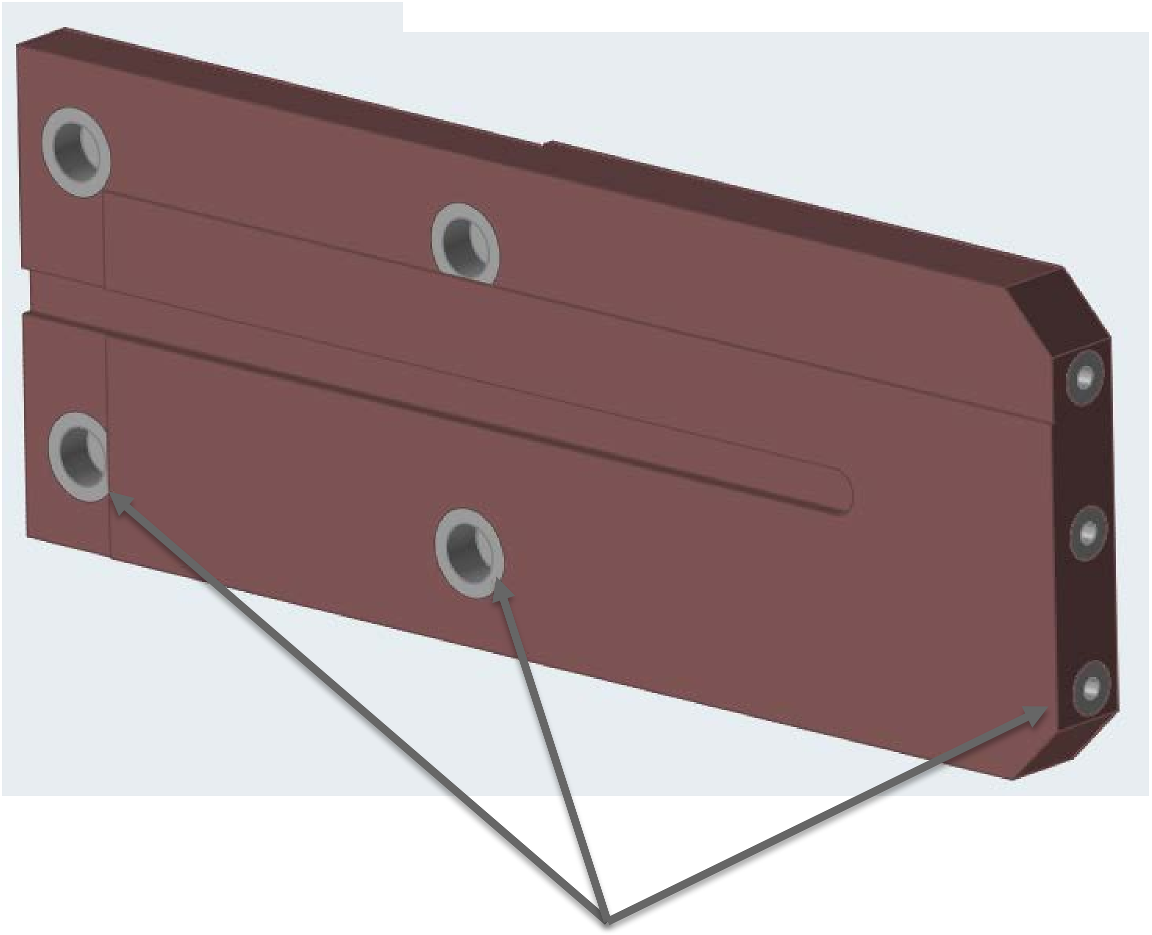


Enclosure Assembly: Side plate

Original Material: Delrin
AM Material: SLS – PA2200



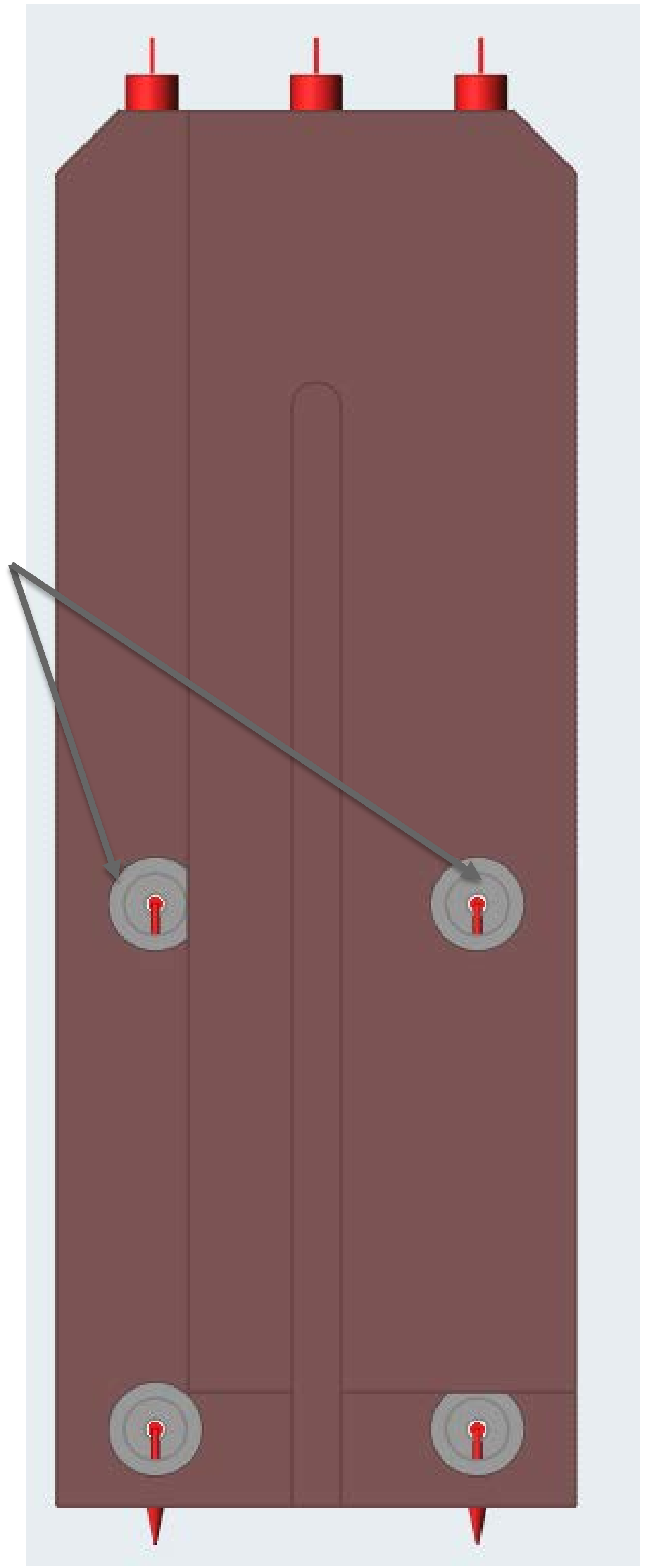
Original 3D Model



Features to be retained after Optimization (Grey Areas)

Functional Areas

Features to be retained after Optimization (Grey Areas)



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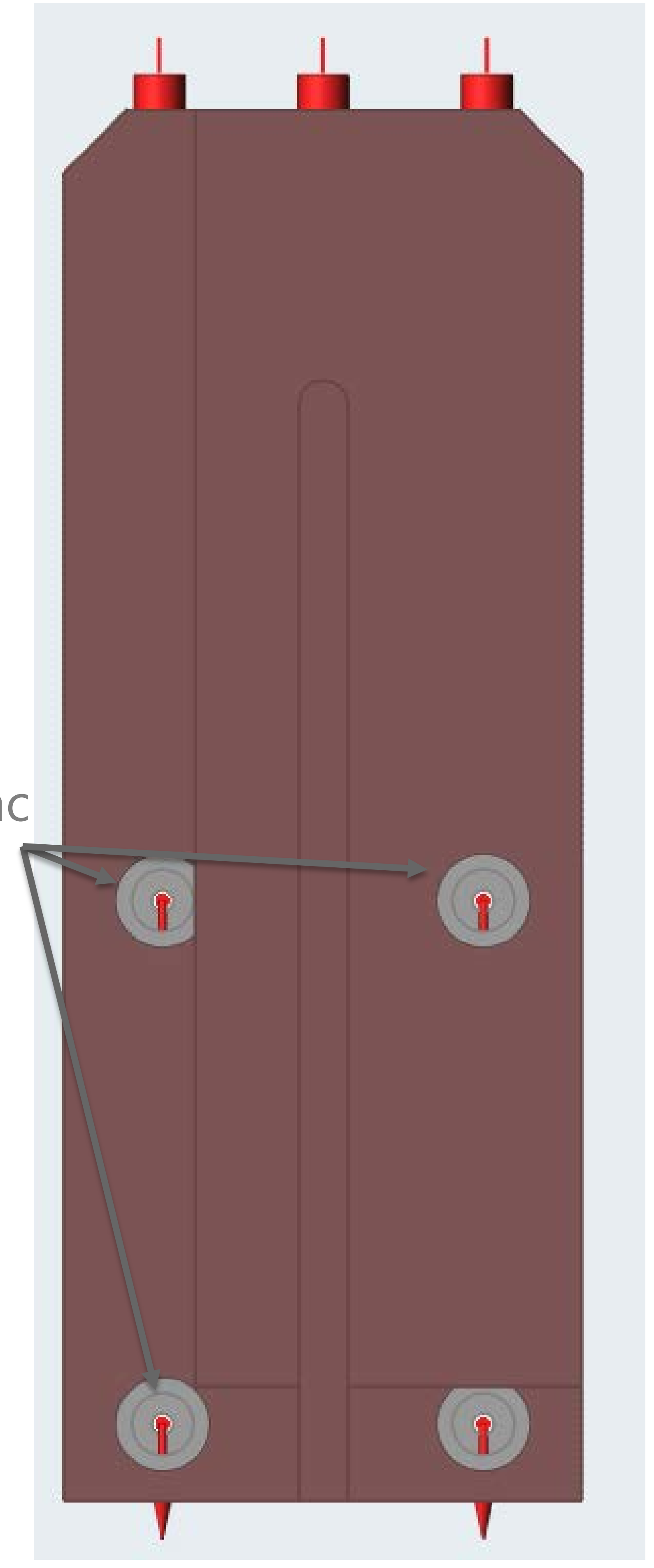
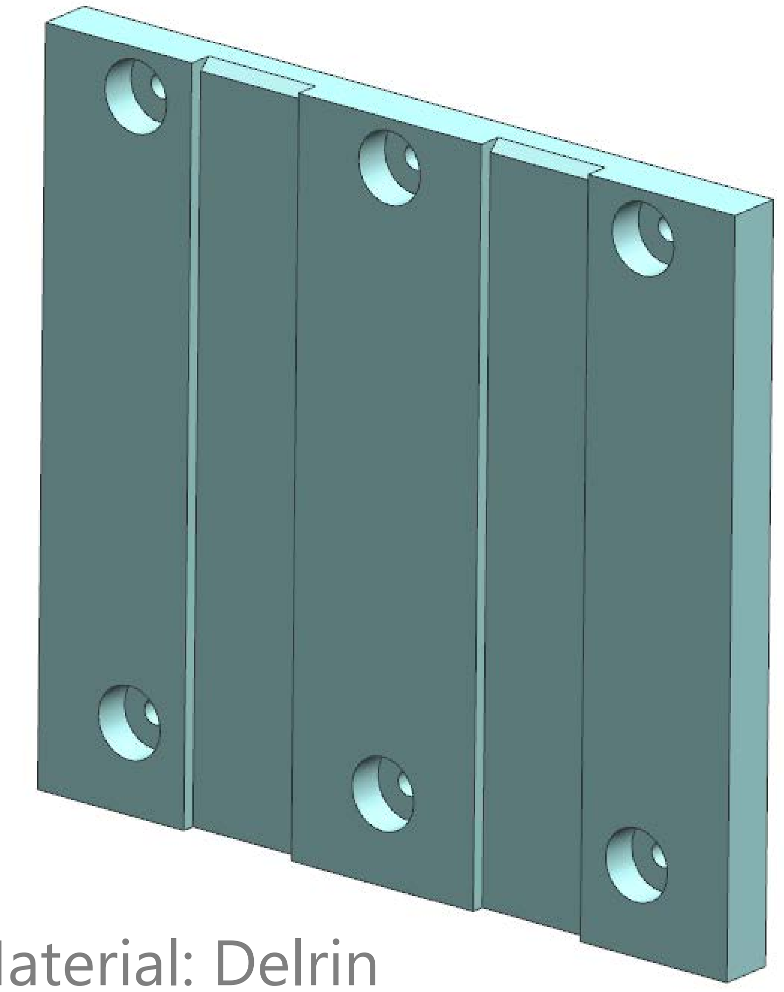


Component has been overloaded to account for dynamic loadings and uncertainty effects

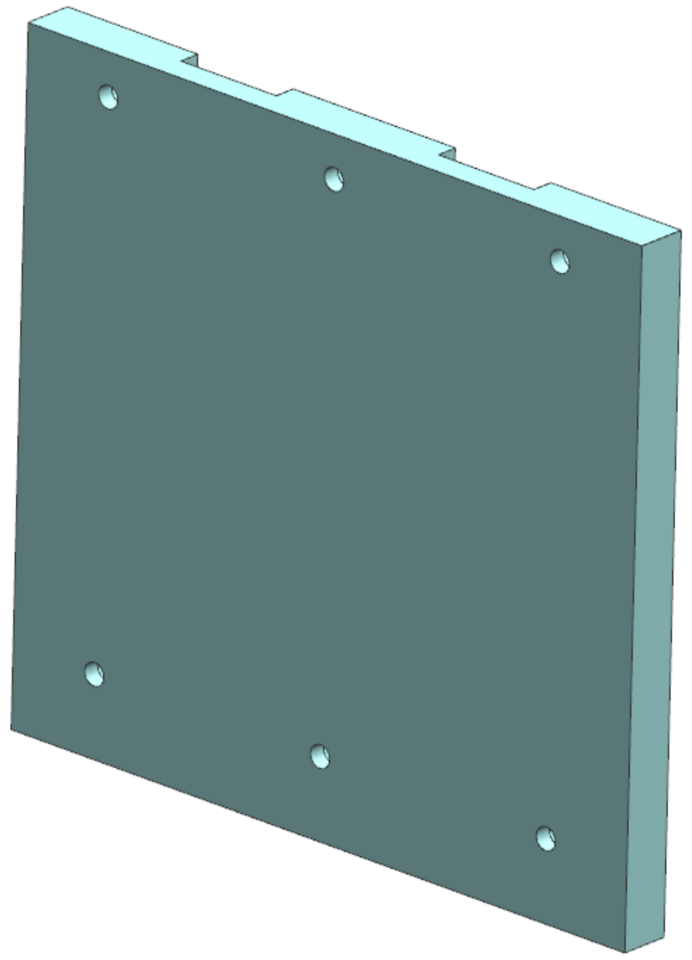
Loading Condition

Enclosure Assembly: Top plate

Original Material: Delrin
AM Material: SLS – PA2200



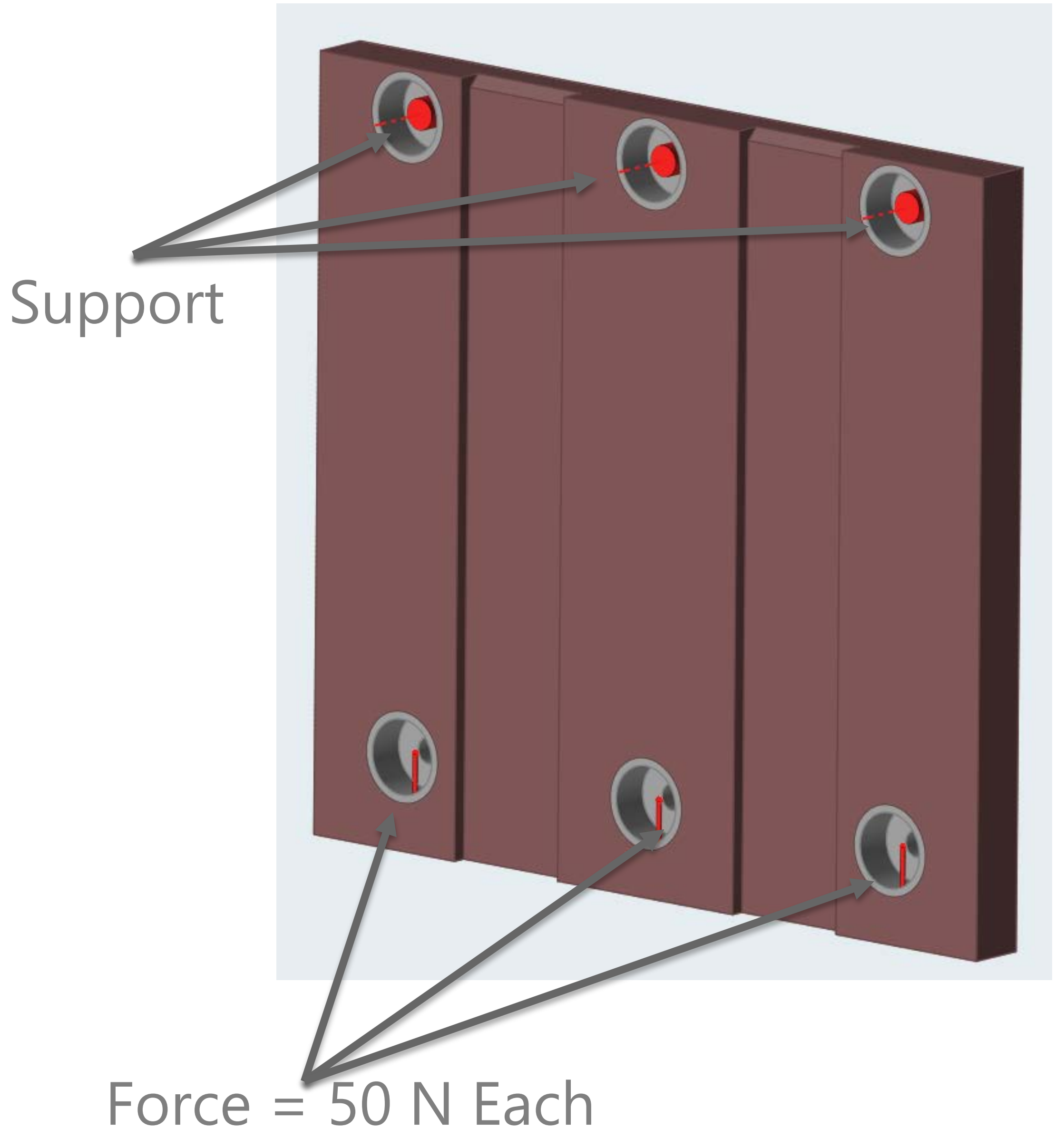
Material: Delrin



Original 3D Model

Features to be retained after Optimization (Grey Areas)

Functional Areas

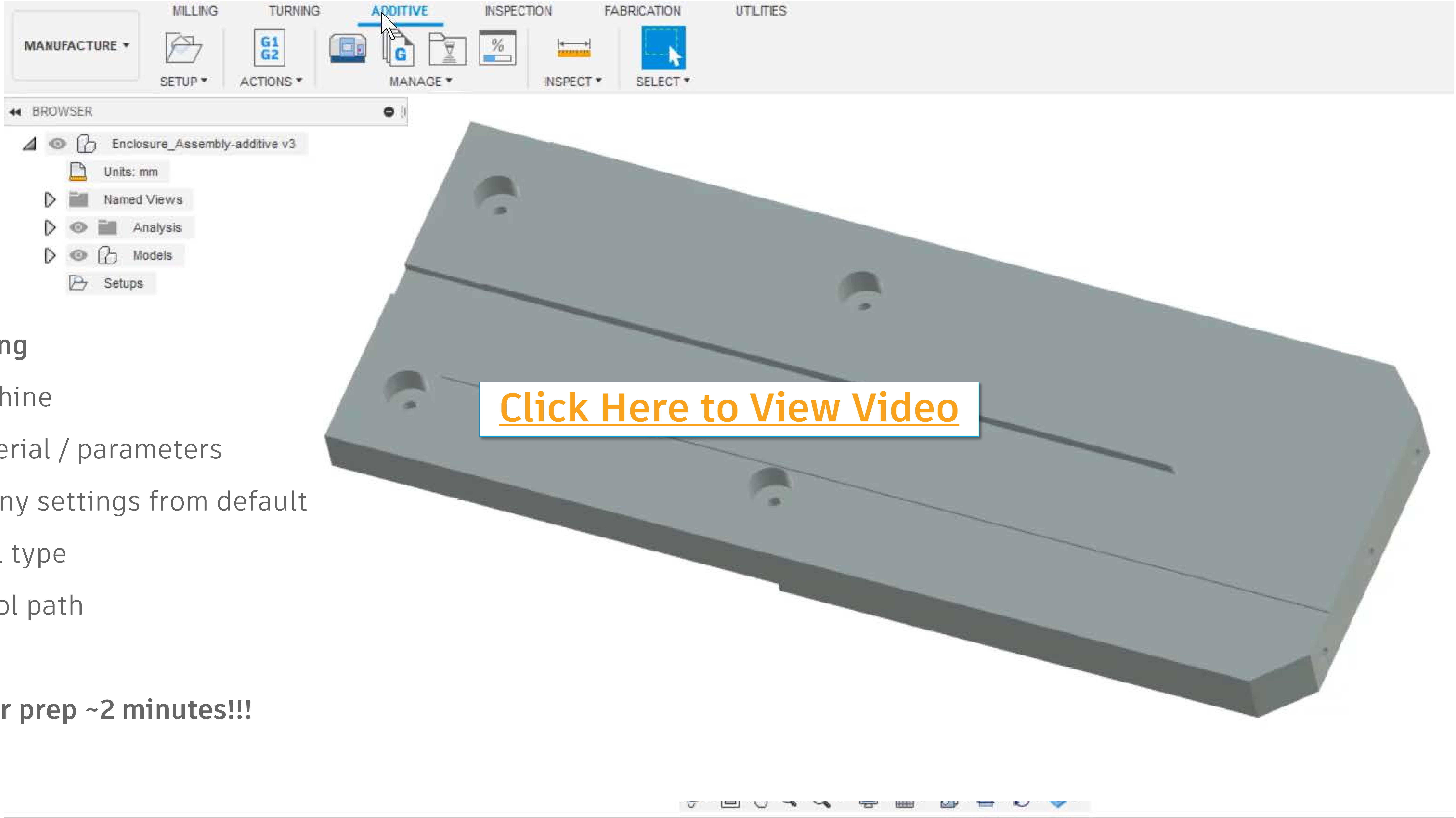


Loading Condition

Component has been overloaded to account for dynamic loadings and uncertainty effects

Enclosure Assembly: Level 1 DfAM

Top and Bottom Plate: Baseline Analysis



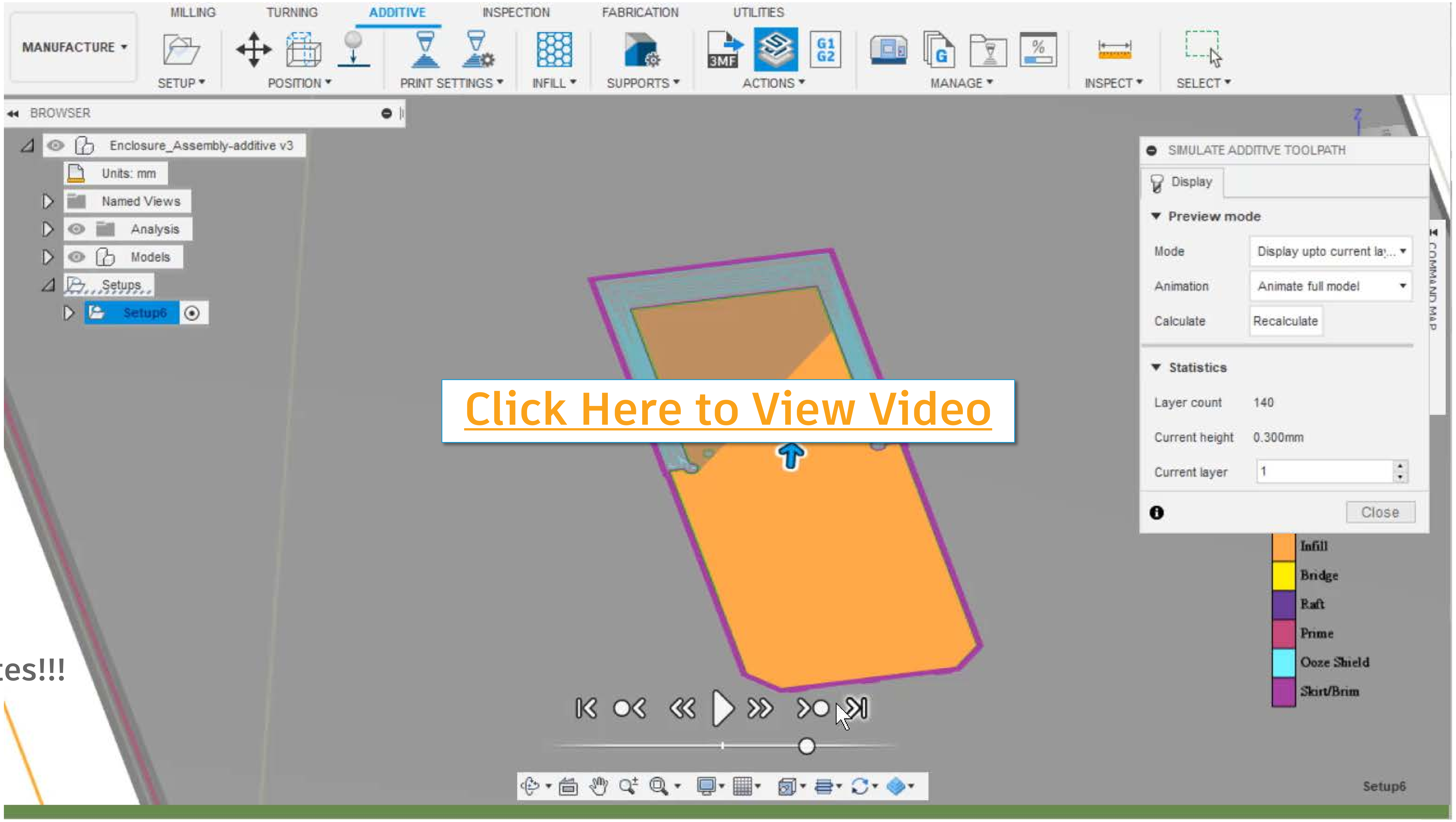
[Click Here to View Video]

- **Prep for printing**
  - o Choose machine
  - o Choose material / parameters
  - o Customize any settings from default
  - o Choose infill type
  - o Generate tool path

- **TOTAL TIME for prep ~2 minutes!!!**

Enclosure Assembly: Level 1 DfAM

Top and Bottom Plate: Baseline Analysis



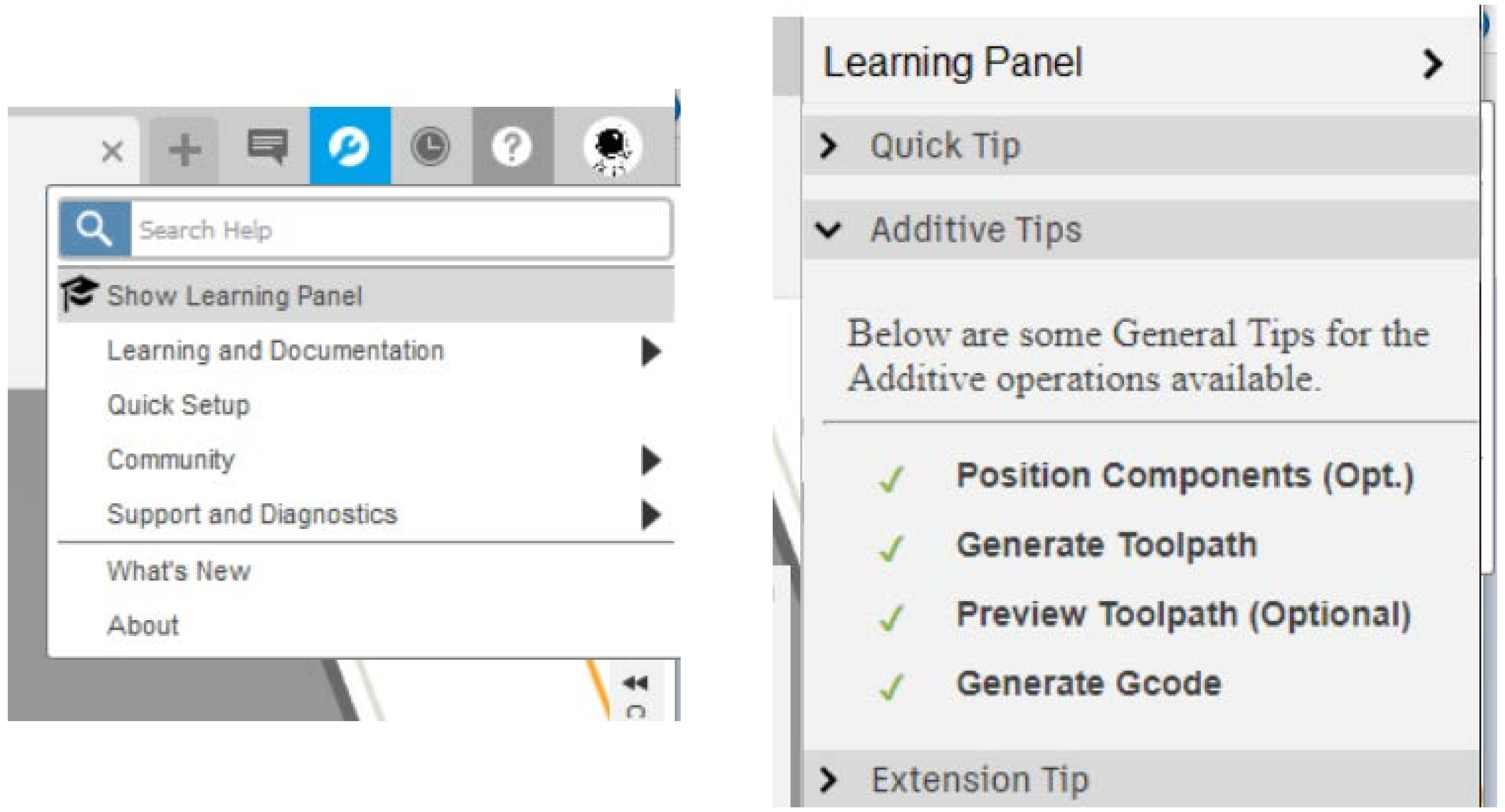
- **Simulate Tool path**
  - Color coded geometry
  - Shows infill pattern
- **TOTAL TIME for prep ~2 minutes!!!**

Level 1 DfAM: Learning Resources

Use the following resources to learn more about Fusion 360

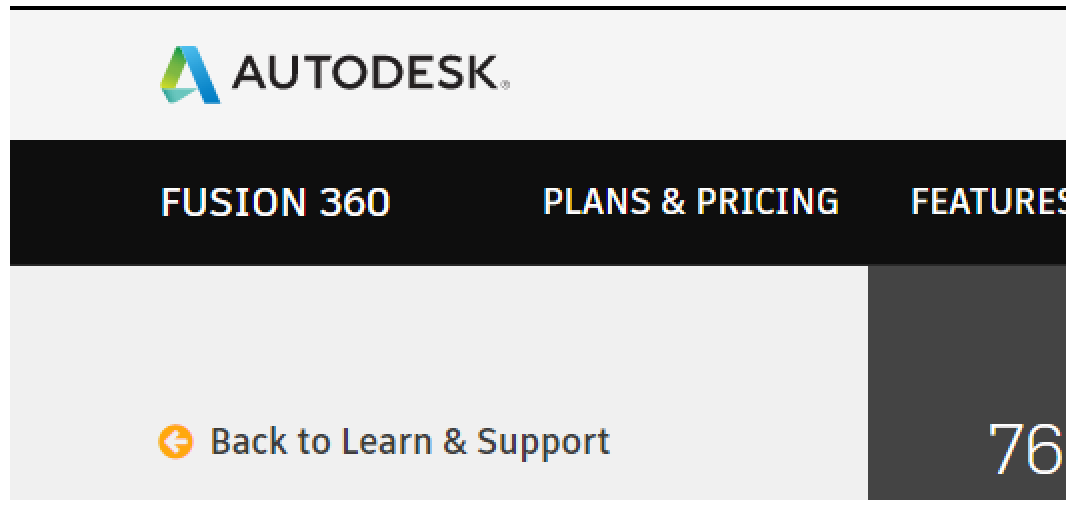
- Learning Panel within Fusion 360

Turn on Learning panel

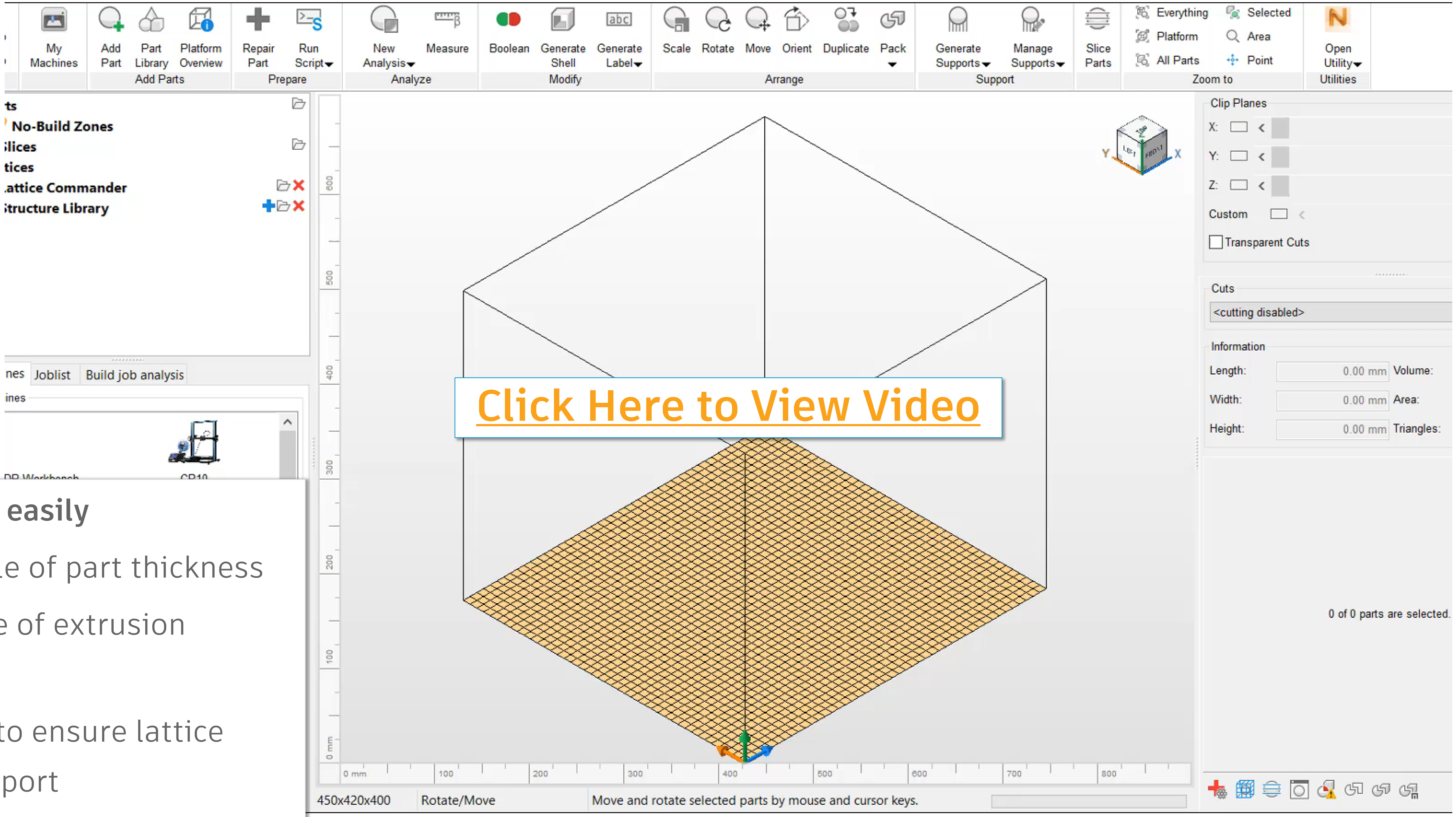


- Via Autodesk Design Academy
  - https://academy.autodesk.com/course/129267/introduction-cad-learn-fusion-360-90-minutes

- Via Autodesk Learn & Support
  - https://www.autodesk.com/products/fusion-360/learn-support



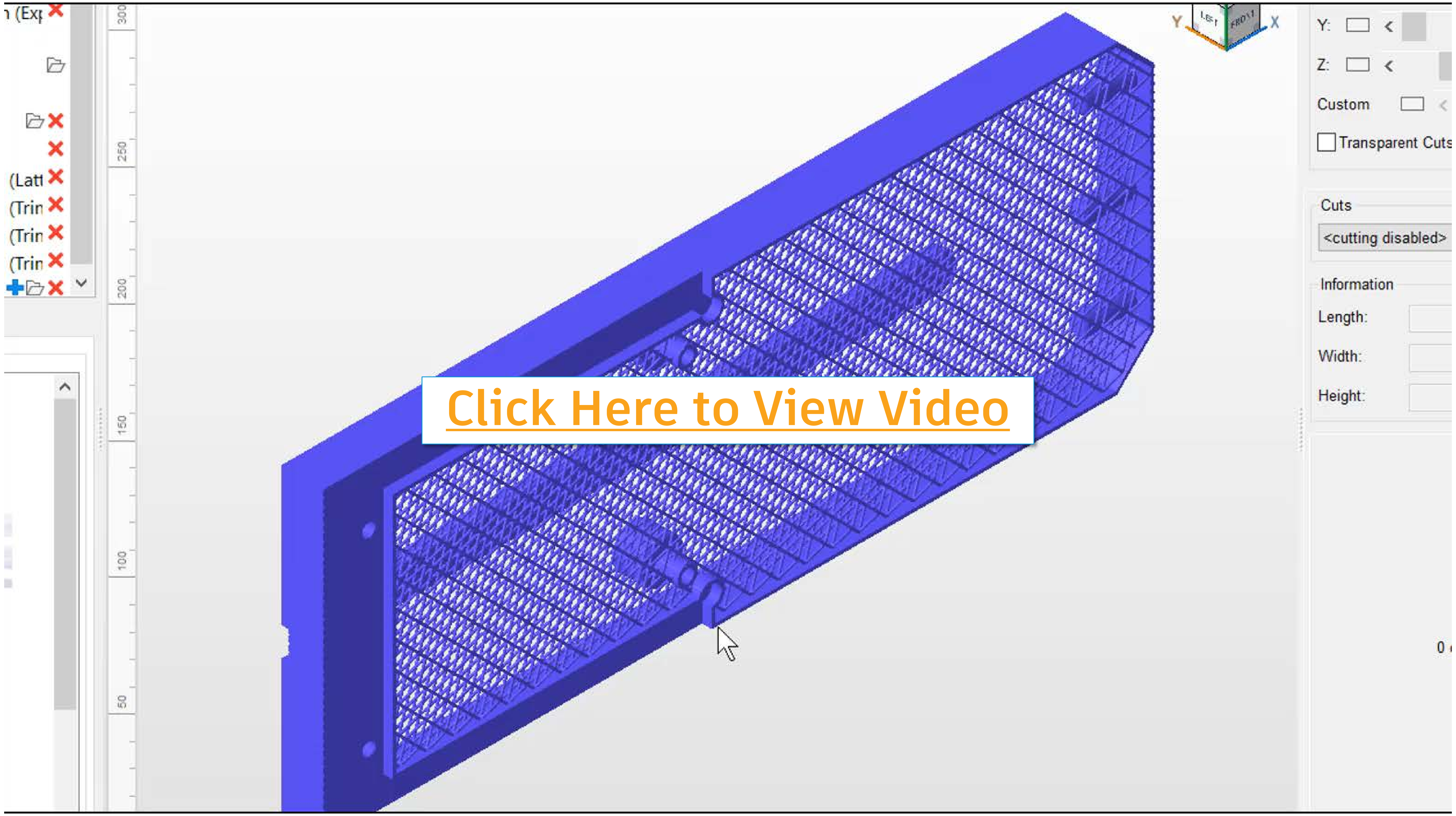
Enclosure Assembly: Level 2 DfAM



- **Create simple lattice easily**
  - Unit size is multiple of part thickness
  - Bar size is multiple of extrusion thickness
  - Pattern is chosen to ensure lattice does not need support

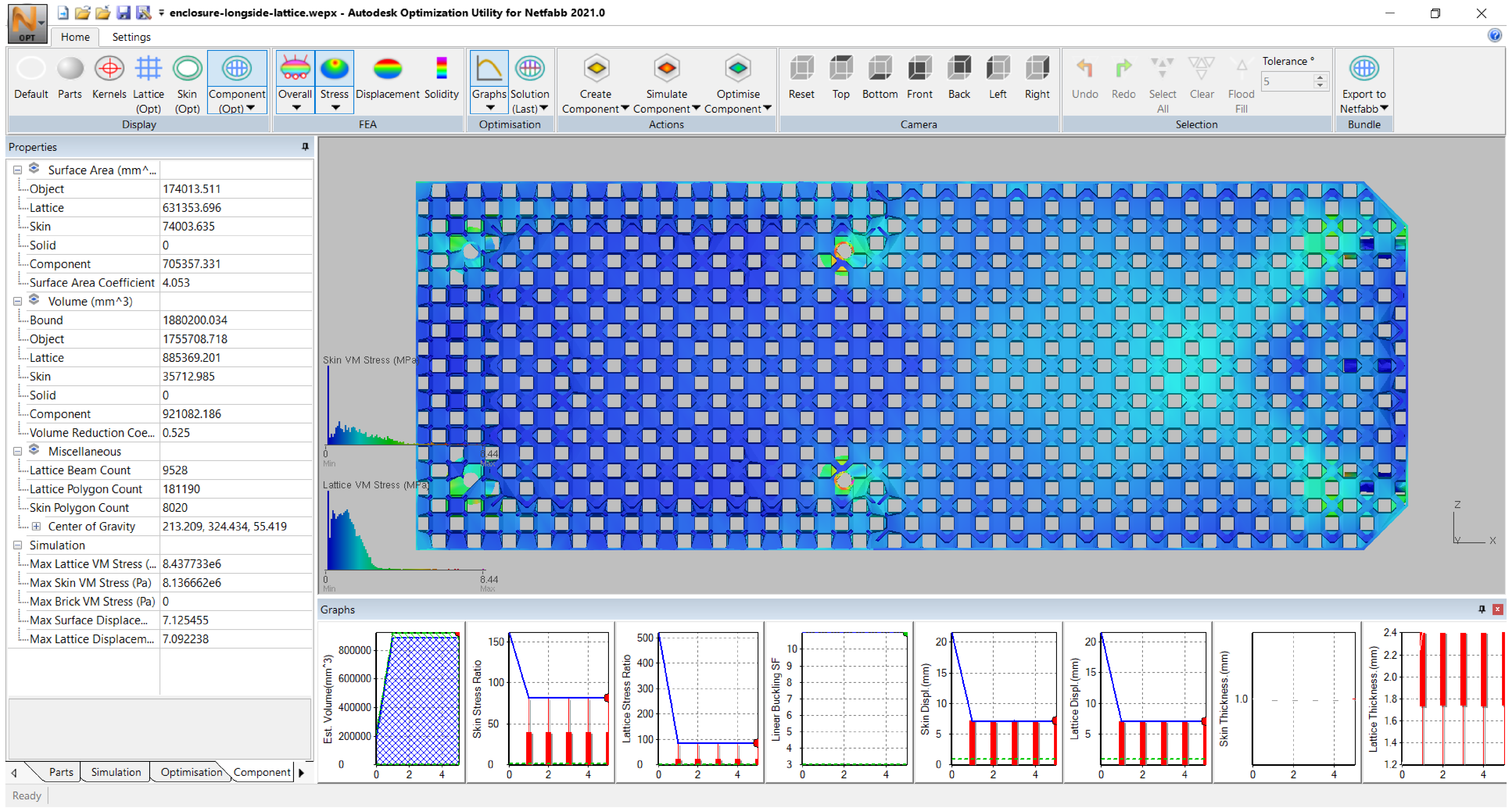
Enclosure Assembly: Level 2 DfAM

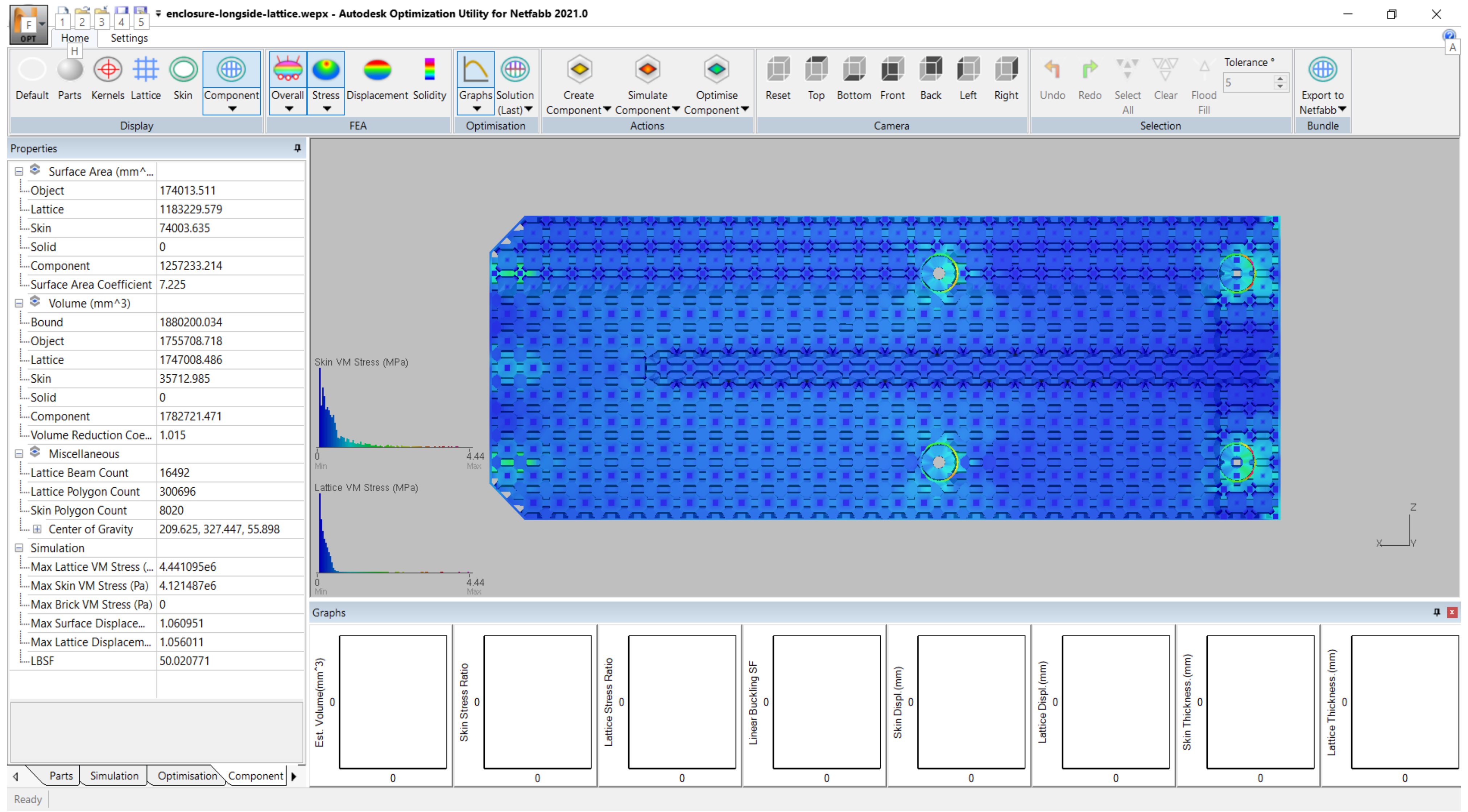
- Surfaces can be thickened where required or left hollow
- Surface lattices are also available

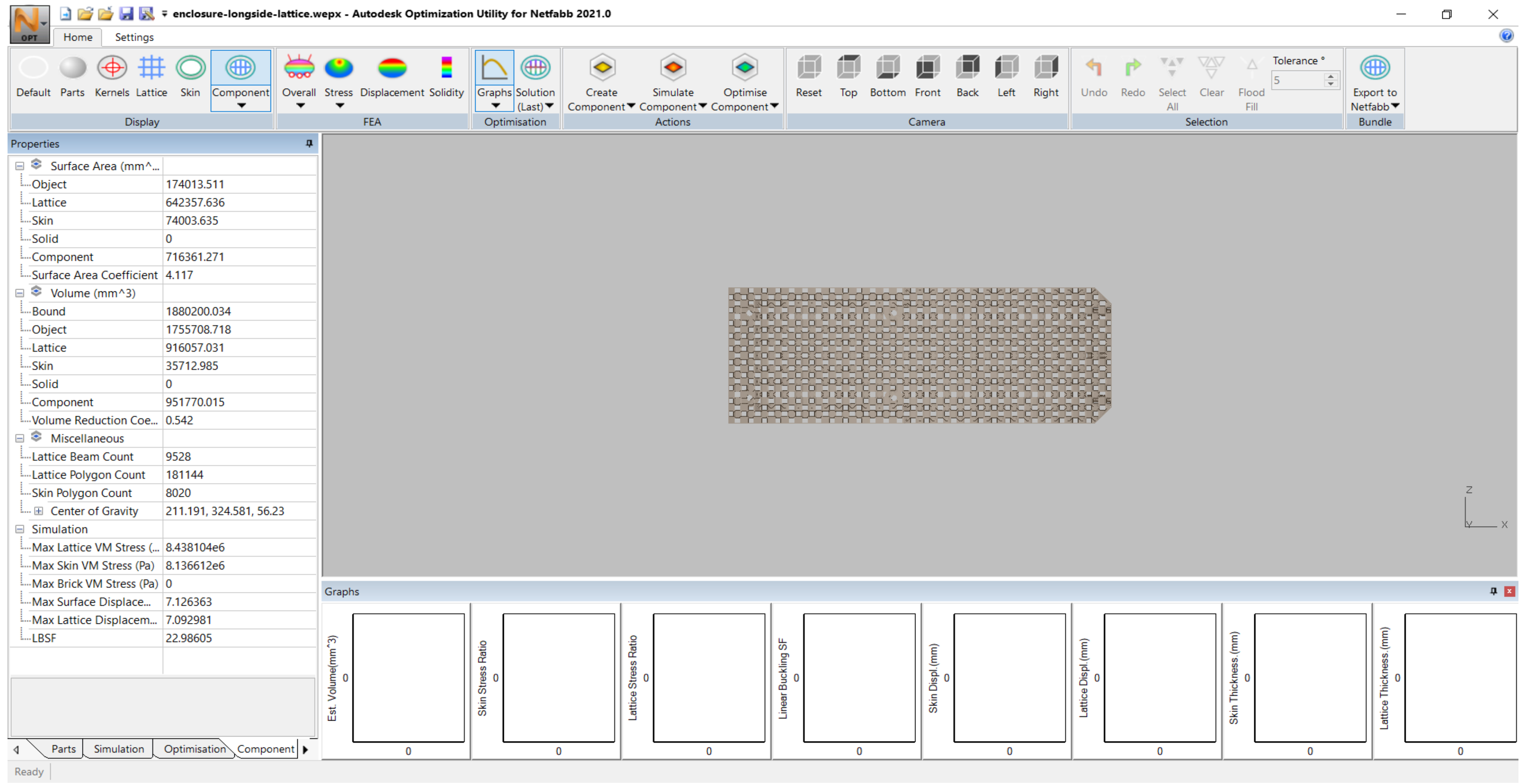


Enclosure Assembly: Level 2 DfAM

- Optimize lattice for applied load
- Set material
- Nastran solver
- Variable thickness of skin
- Variable thickness of lattice



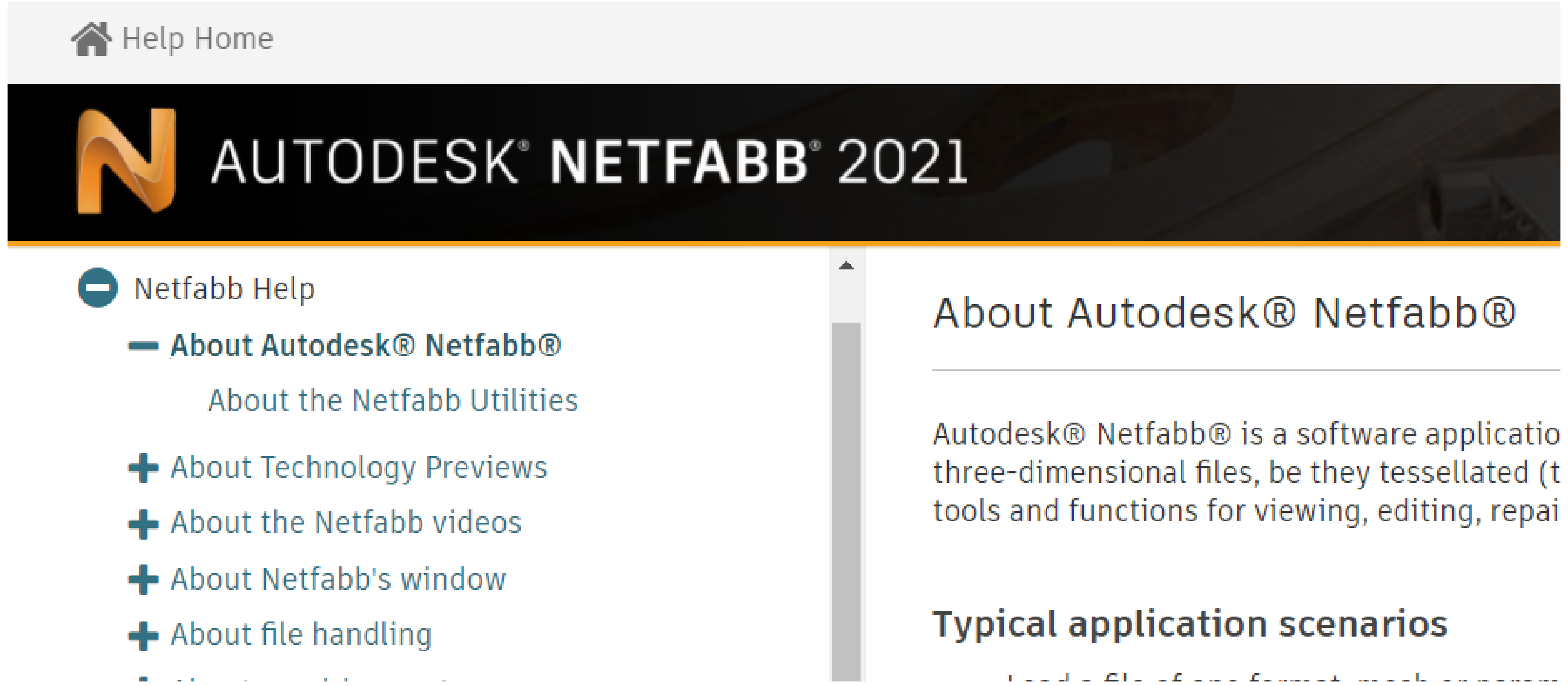




Level 2 DfAM: Learning Resources

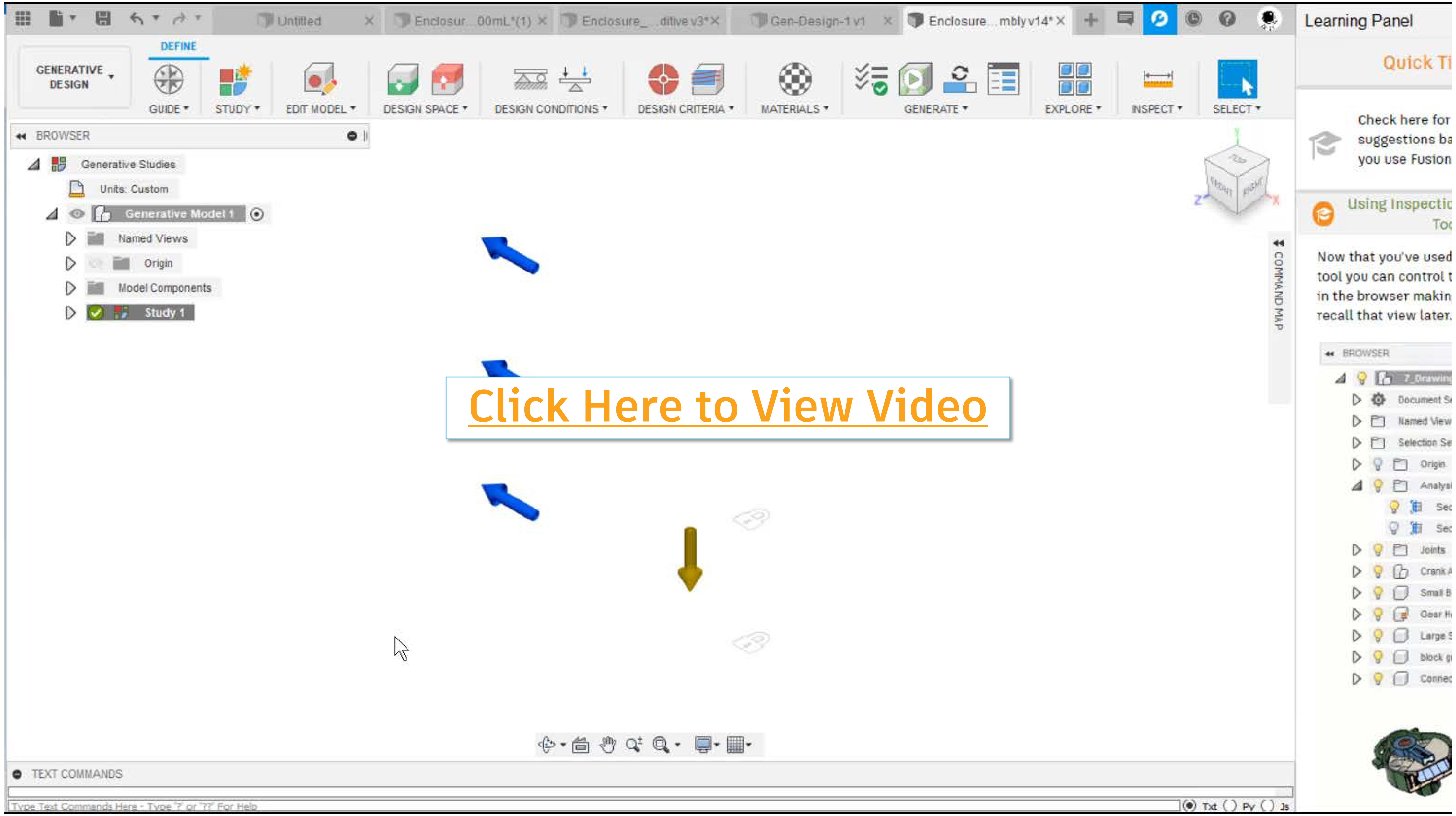
Use the following resources to learn more about Netfabb

- Learn about Netfabb workflow
  - o https://help.autodesk.com/view/NETF/2021/ENU/?guid=GUID-E48353B3-E8BE-4D1C-8C2E-E207DAA32CBE
- Learn about Lattice commander
  - o https://help.autodesk.com/view/NETF/2021/ENU/?guid=GUID-7C5857A1-501E-406B-9632-6EEBD603FE29
- Learn about Netfabb Optimization utility
  - o https://help.autodesk.com/view/NETF/2021/ENU/?guid=GUID-F9E8CC95-6E45-44DD-8836-049557E71F2A



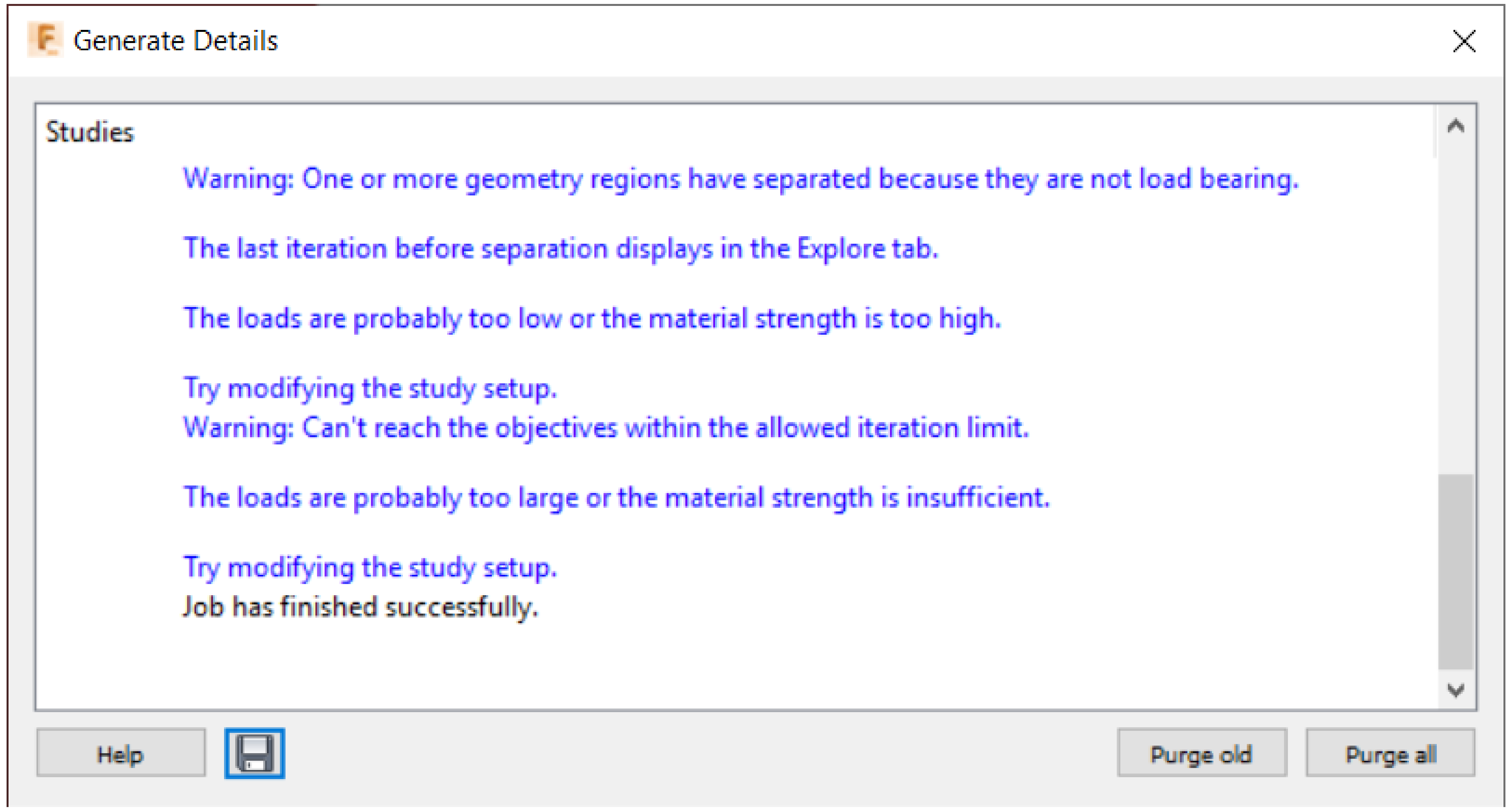
Enclosure Assembly: Level 3 DfAM

- **Gen Design**
  - Edit Geometry
  - Preserve Geometry
  - Load cases
  - Starting Geometry
  - Obstacle Geometry
  - Generate results



Enclosure Assembly: Level 3 DfAM

- **Analyze results**
  - Accept and download result
  - Pay careful attention to result report
  - No convergence
- **Back track to Level 2**

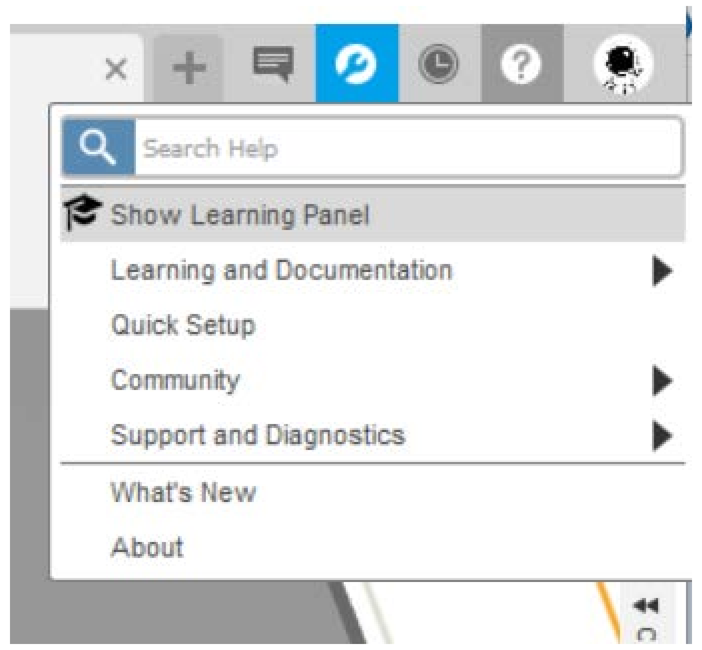


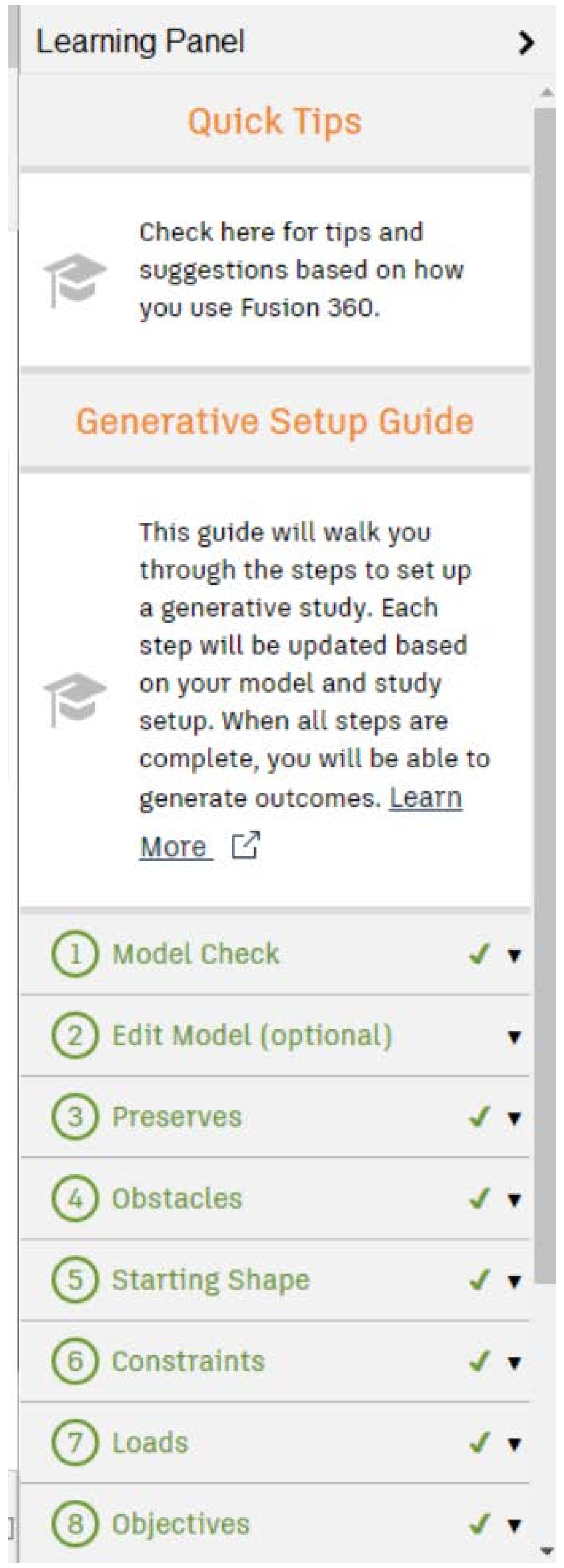
Level 3 DfAM: Learning Resources

Use the following resources to learn more about Generative Design

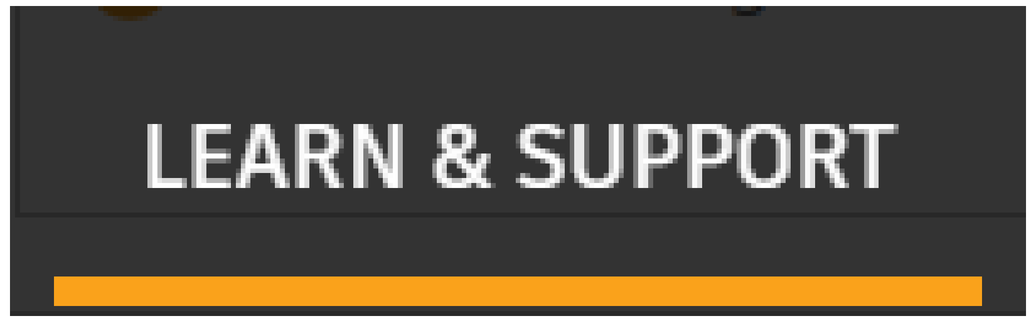
- Learning Panel within Fusion 360

Turn on Learning panel





- Self paced training Via Autodesk Learn & Support
  - https://help.autodesk.com/view/fusion360/ENU/courses/#generative-design



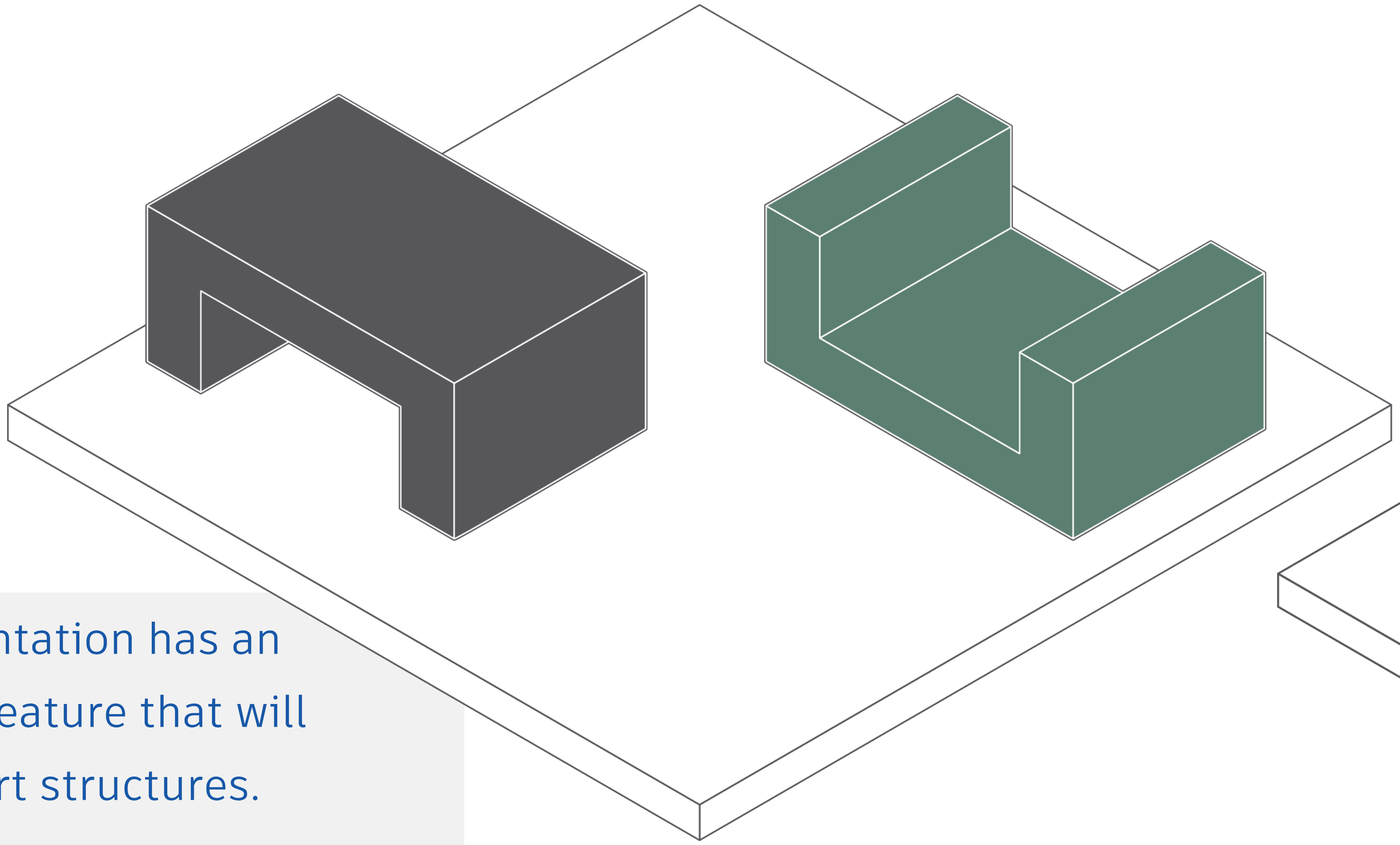
- Via Autodesk Design Academy
  - https://academy.autodesk.com/curriculum/generative-design-additive-manufacturing

AUTODESK Design Academy

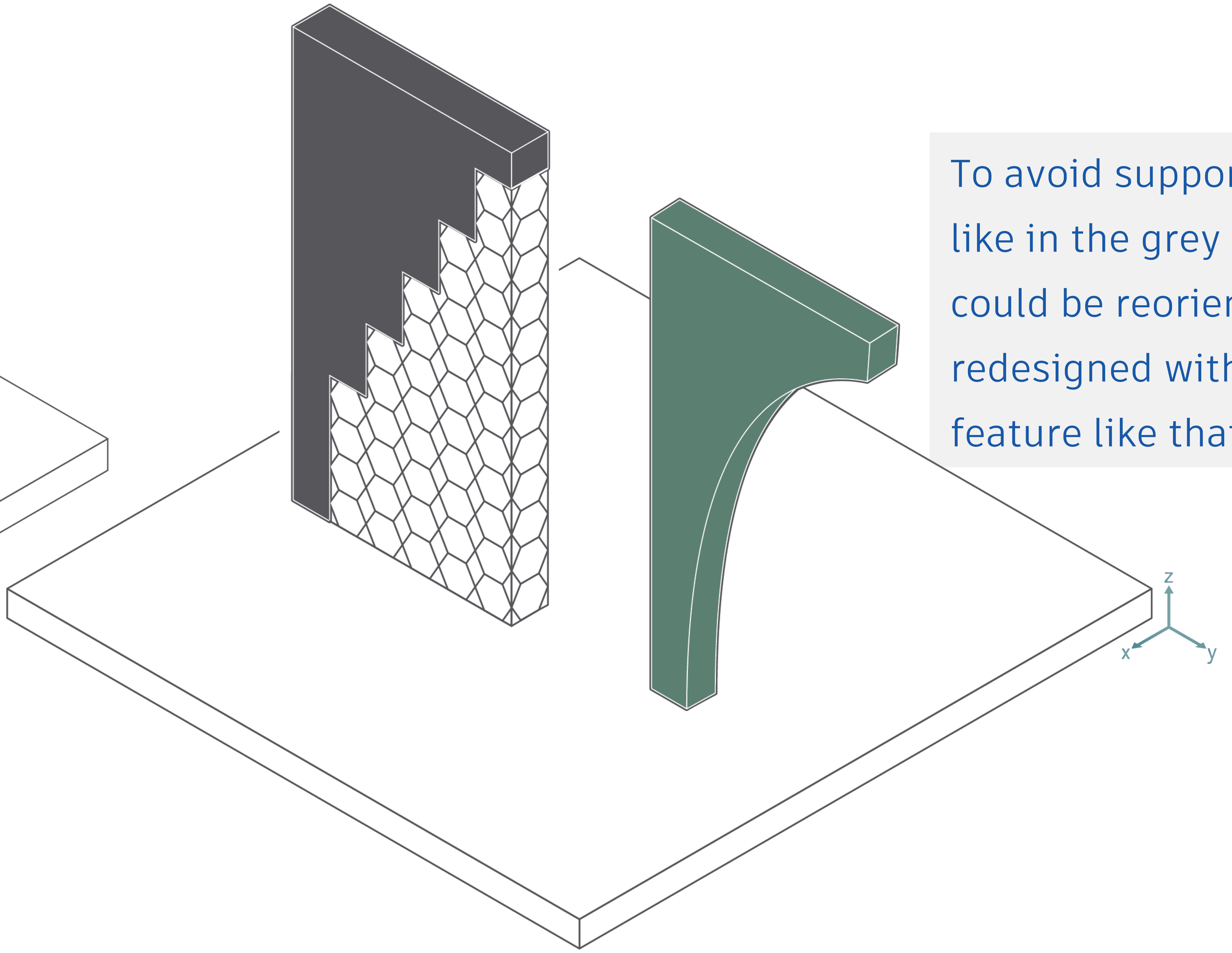
Part Orientation and How it can Affect Build Quality and Success

Support Structures effecting Part Orientation

- **Part orientation will effect the location and amount of support structures required to print successfully**
  - Removing support structures, especially metal 3D Printing, can be difficult and often leaves marking behind
  - If part orientation is considered while designing a part, unneeded over hanging features can be removed or converted to self supporting features.



- This grey orientation has an overhanging feature that will require support structures.
- By flipping the orientation like the green, no supports are required



To avoid supports on the part like in the grey model the part could be reoriented or redesigned with a self support feature like that in the green

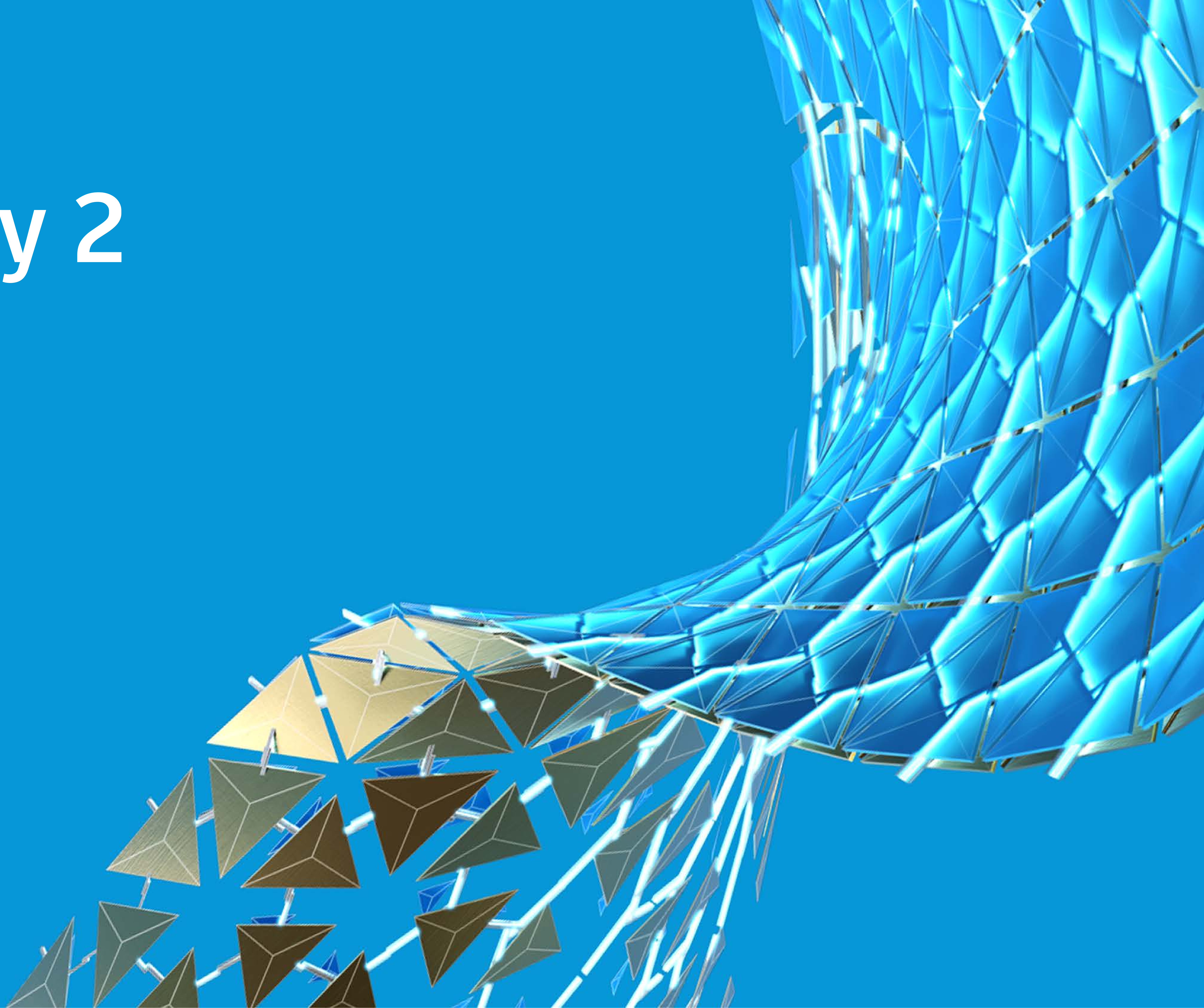
Time and Cost with Part Orientation

- **Build time generally increases due to the following**
  - More material to print (including support structures)
  - Taller the builds (for most resin and powder bed technologies)
- **Cost increases for numerous reasons**
  - More material to print
  - Larger post processing and finishing operations
- **If printing a large quantity of parts, it is often advantageous to pack the build plate due to the time it takes to prep and unload a build.**
  - Part orientation for a single part vs many can often vary

Image Source: Renishaw

Case Study 2

Part Orientation

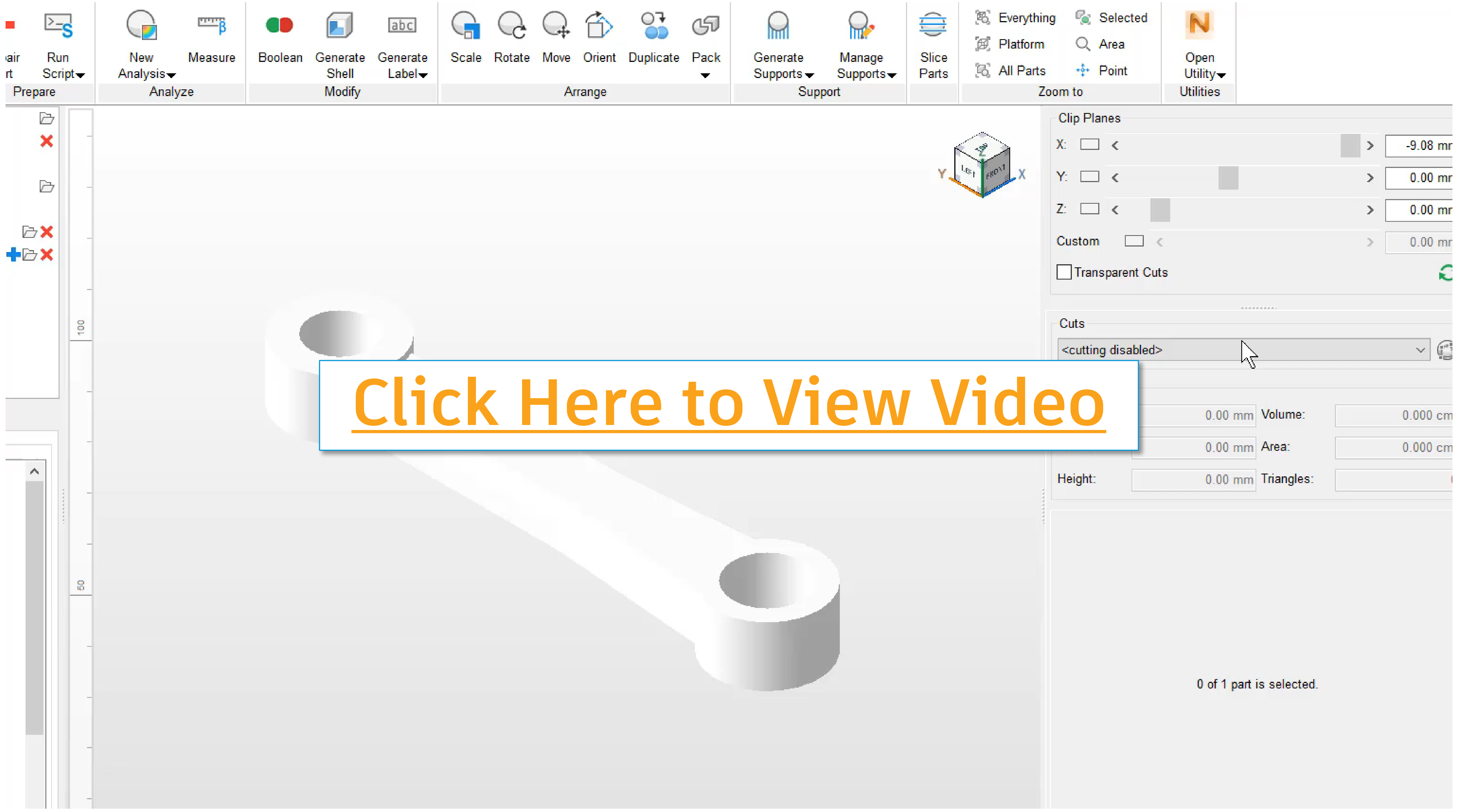


Part Orientation Case Study

- **Orientation seems straight forward in this example**
  - You don't need just 1 con rod, you need **as many** as possible
  - More parts on a single build plate drives down cost per part (one of the only ways to scale 3D printing)
  - Holes need to be drilled regardless of finish quality
  - Contoured neck is difficult to machine

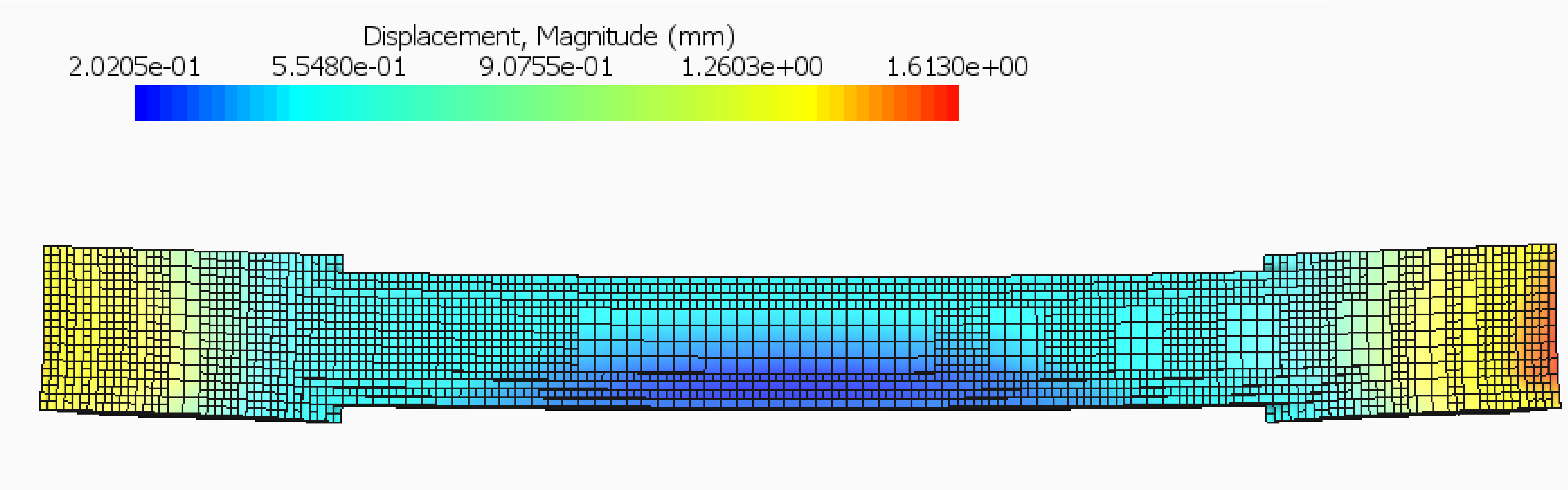
- **Orientation can be optimized by weighting key objectives**

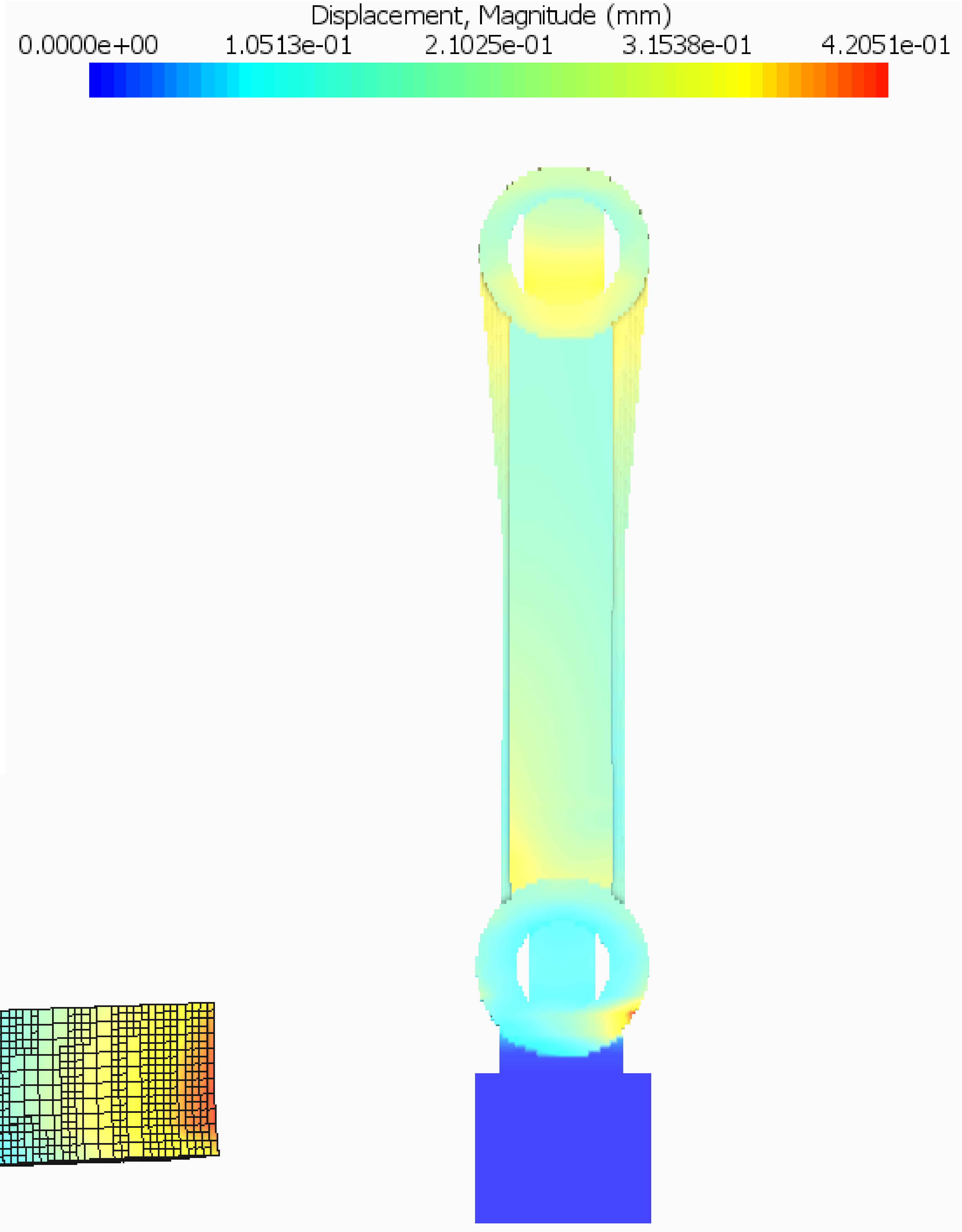
- **Close packing ensure even heat distribution on build**

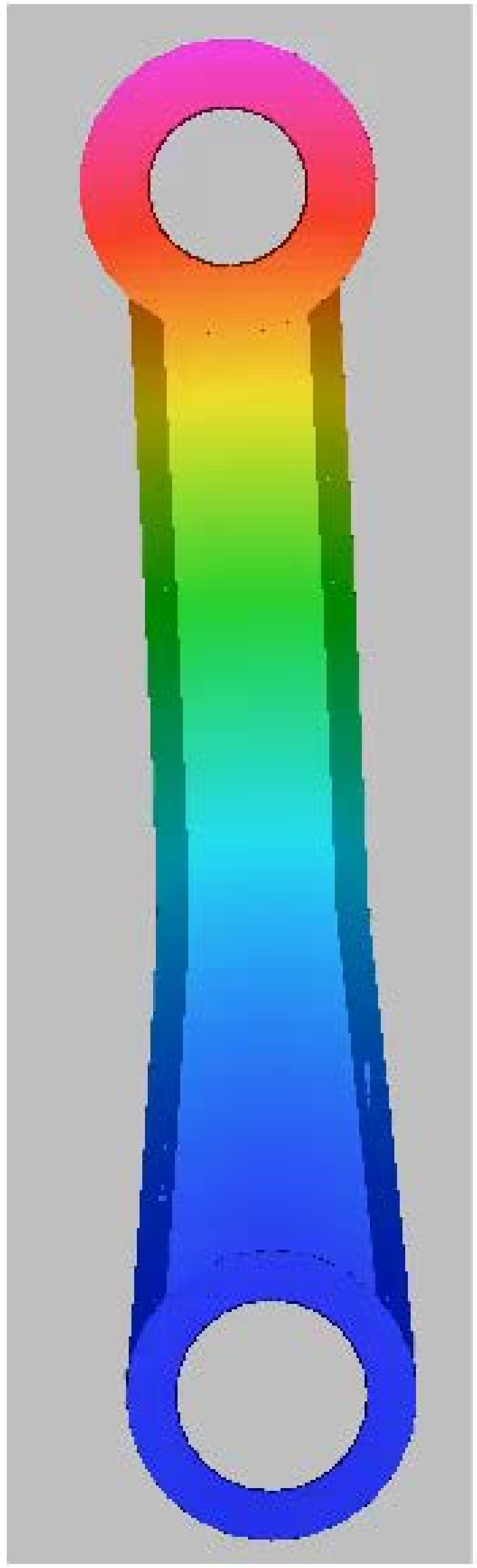


Part Orientation Case Study

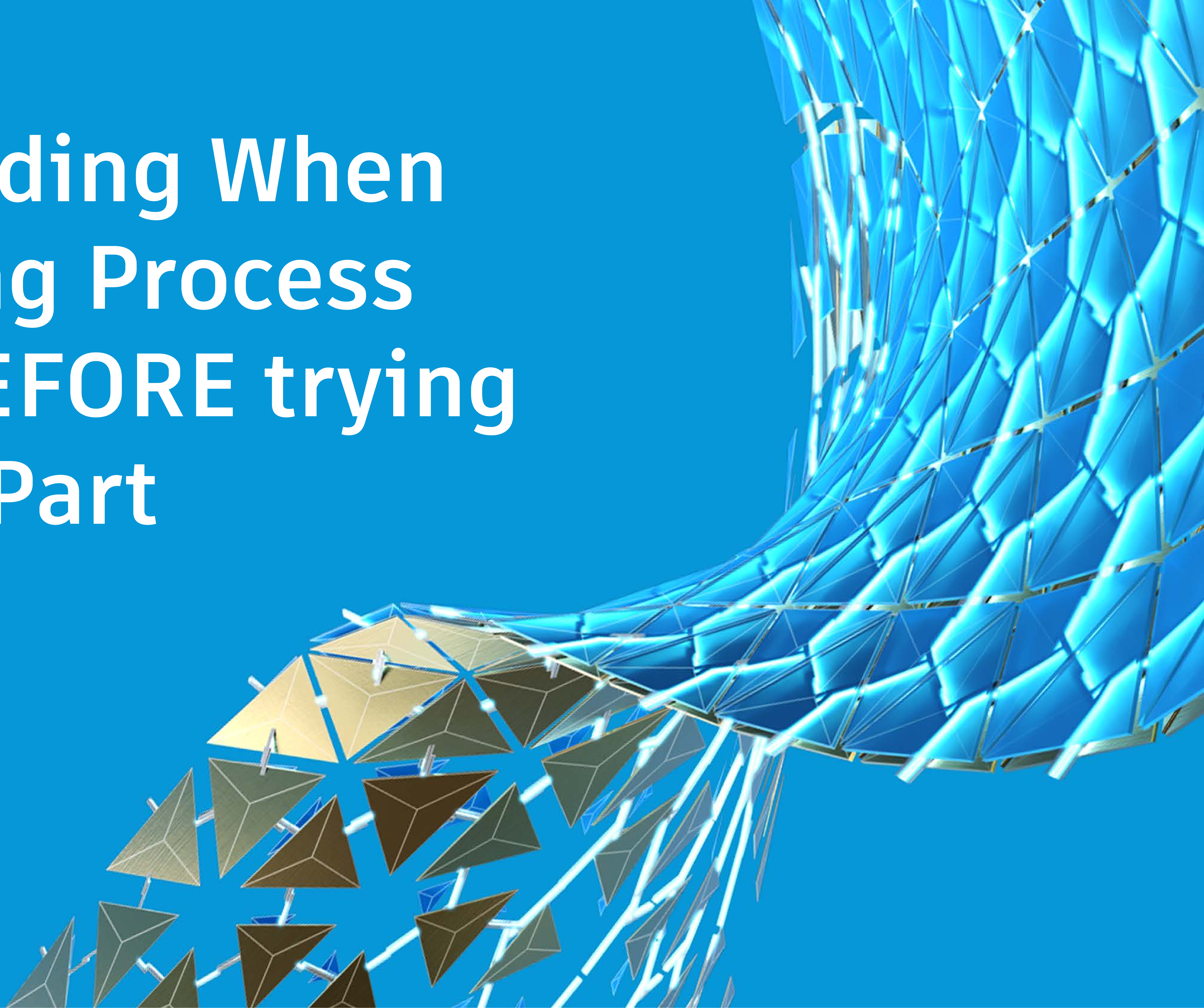
- **Material properties as a result of orientation**
  - Stress builds up in horizontal orientation
  - Part has more strength in horizontal orientation
  - Part at greater risk of shearing in vertical orientation







Understanding When the Printing Process will Fail BEFORE trying to Build a Part

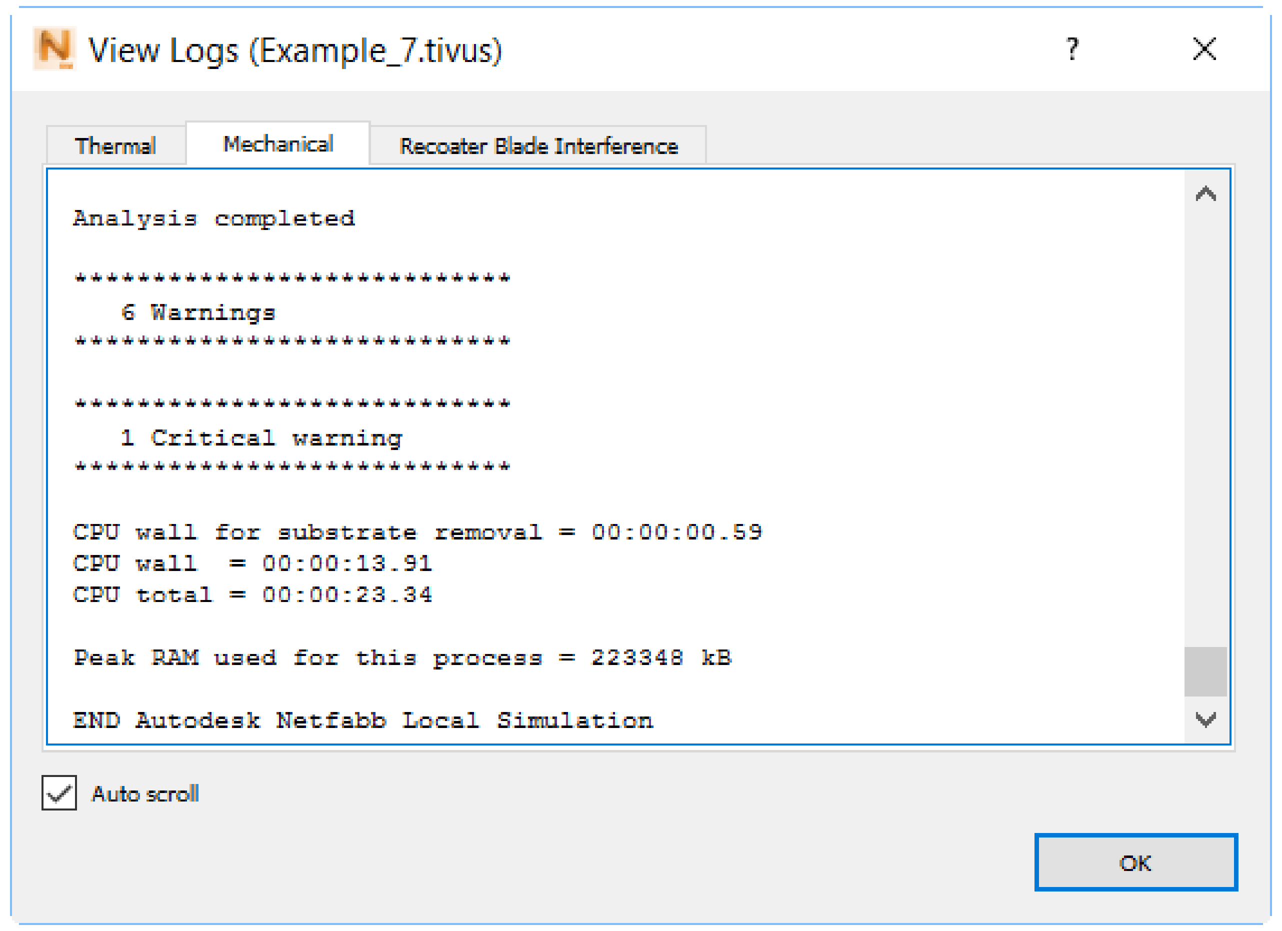


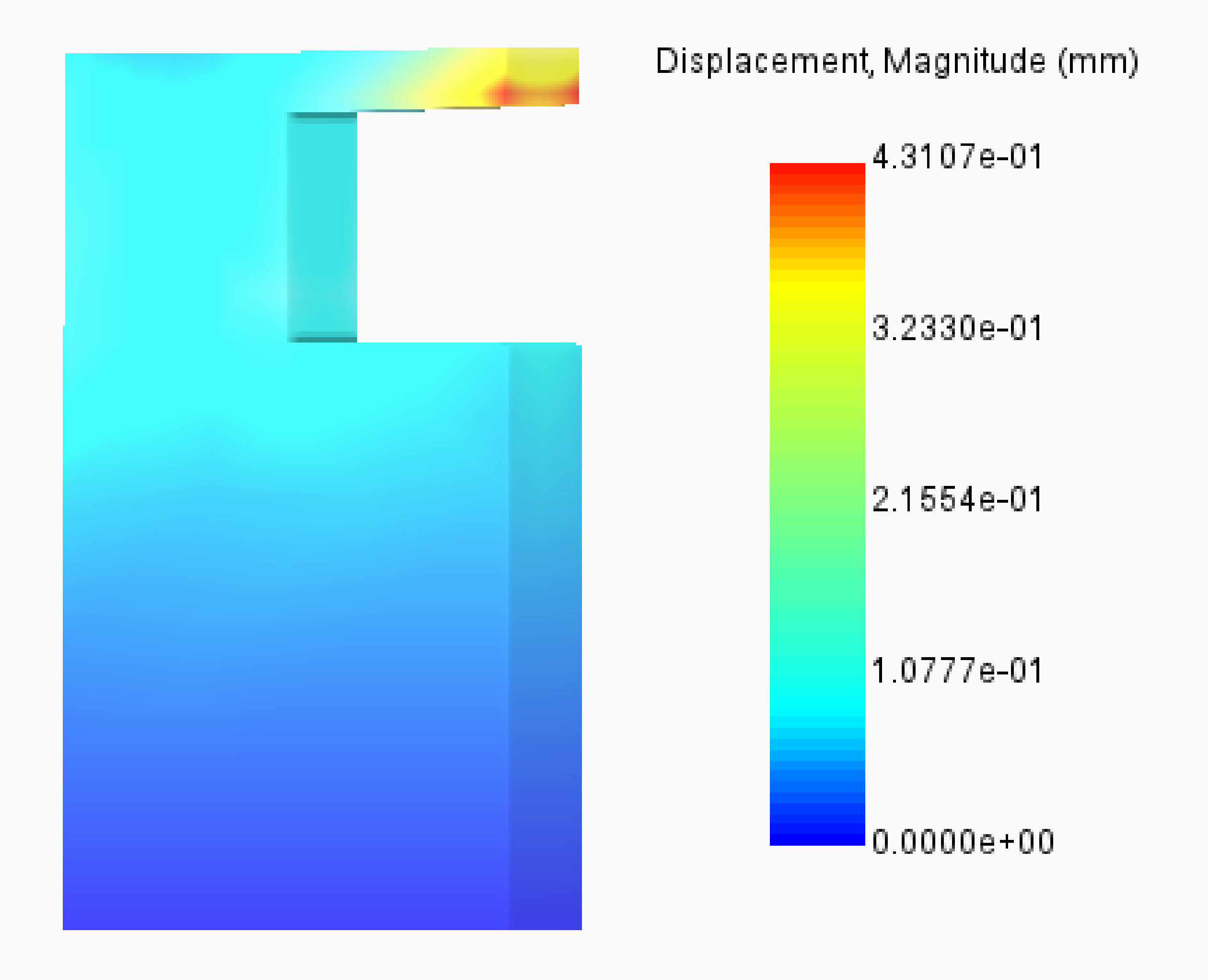
Recoater Blade Failure

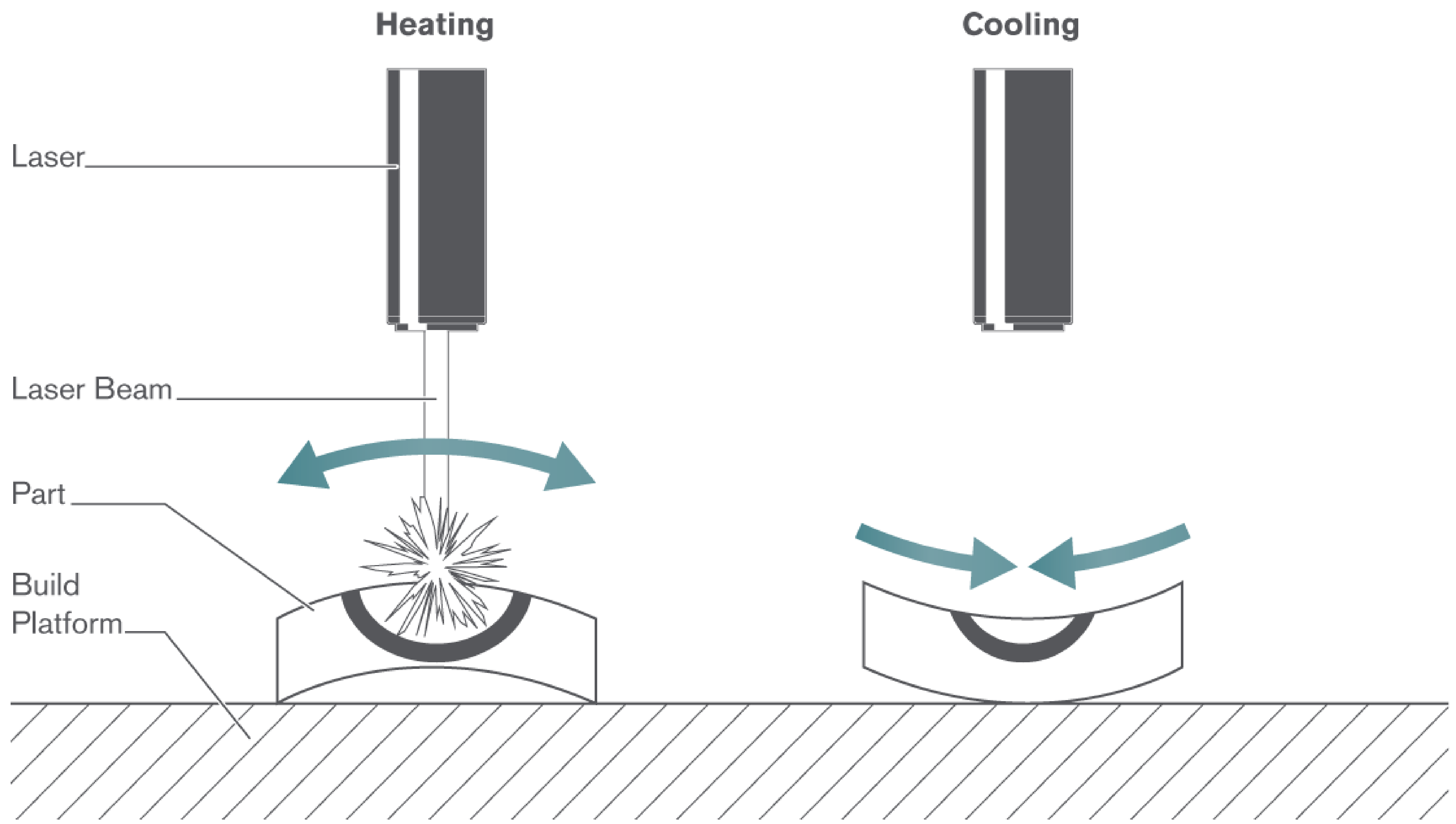
- **Due to the high temperature of metal 3D Printing, distortion and warpage can often happen due to delamination and other effects. If a rises above the intended height it can come into contact with the recoater blade and cause a print failure**
  - Minimizing print failure can be by orienting the part to avoid features parallel to the recoater blade
  - Simulation tools can be utilized to predict warpage and recoater blade collisions

Image Source: Crucible Designs

- The part to the left is parallel to the recoater blade and could cause a print failure
- By slightly rotating the part, as shown on the right, allows for the blade to contact a single point of the part versus the whole face

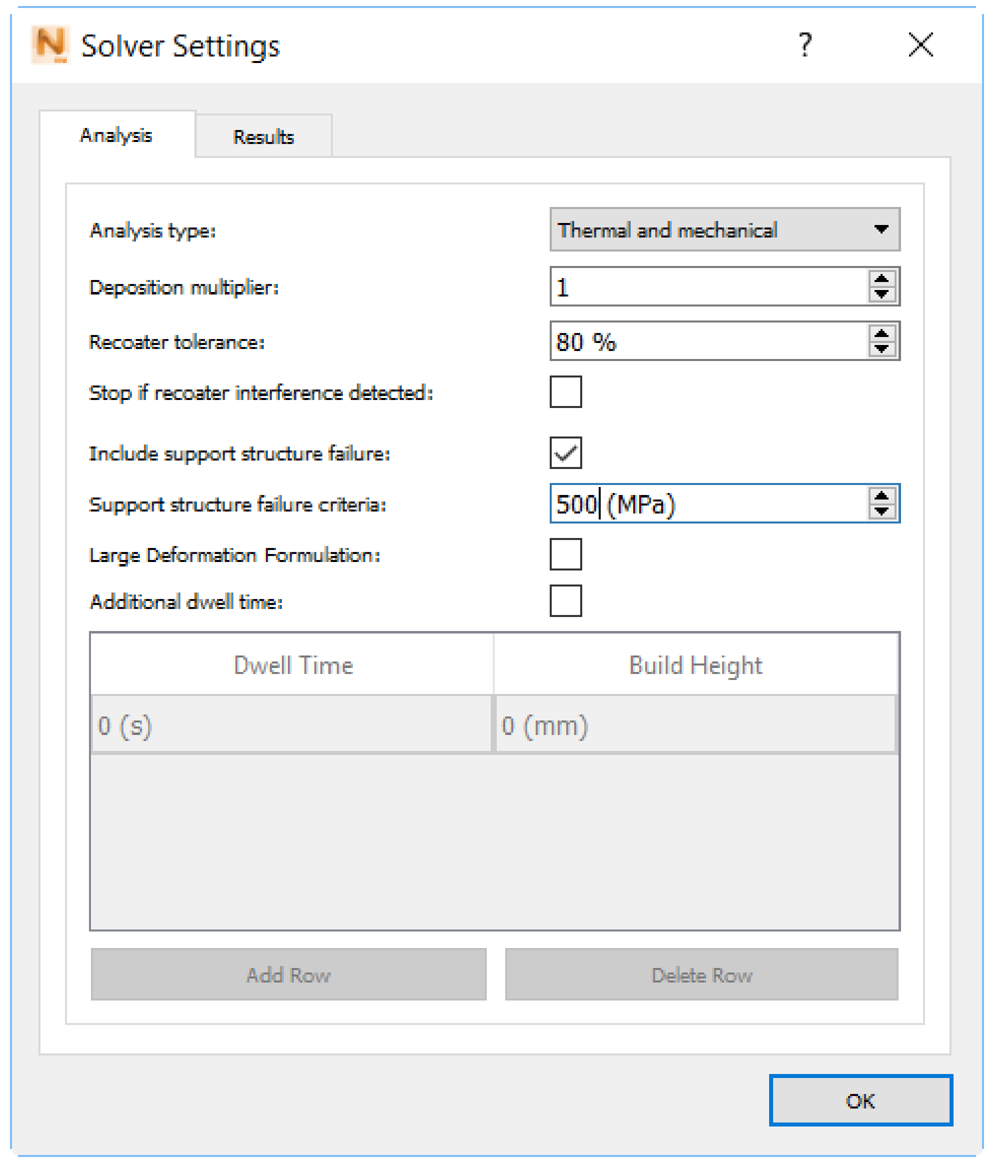






Lack of Support Structures

- **Support Structures in all printing help hold up overhanging features.**
- **When 3D printing metal, supports also act as heat sinks and help hold the part to the build plate.**
  - The high temperatures and rapid cooling and heating of the parts causes internal stresses to build.
- **When a layer in a part has a large amount of material to be sintered, then the stresses are often larger and require stronger and denser supports.**



High temperatures and weak supports caused the supports to detach from the parts or the build plate distorting the part and increasing risk for recoater blade collision. To avoid this, thicker support structures would be required or orienting the part to have less area per layer

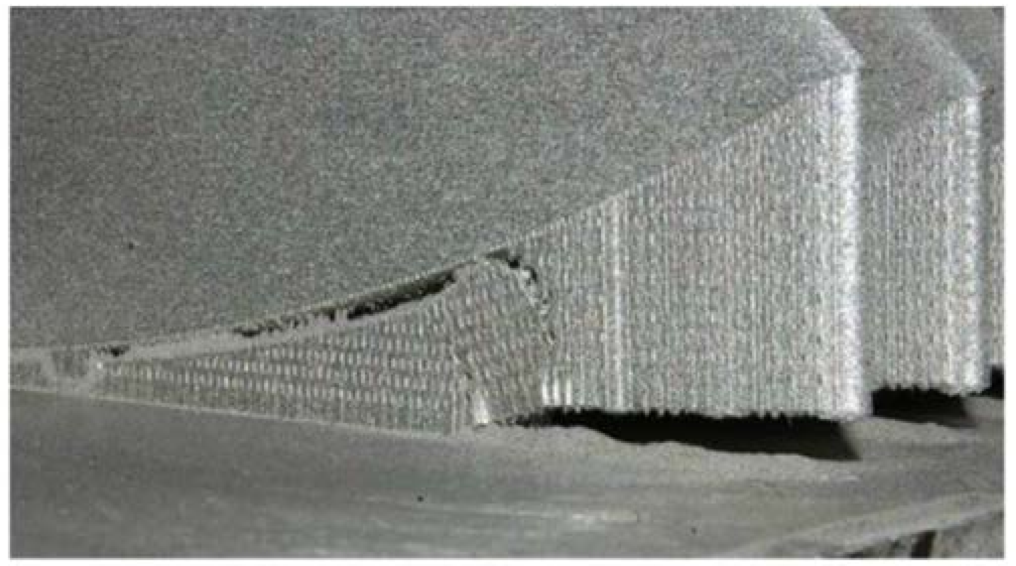
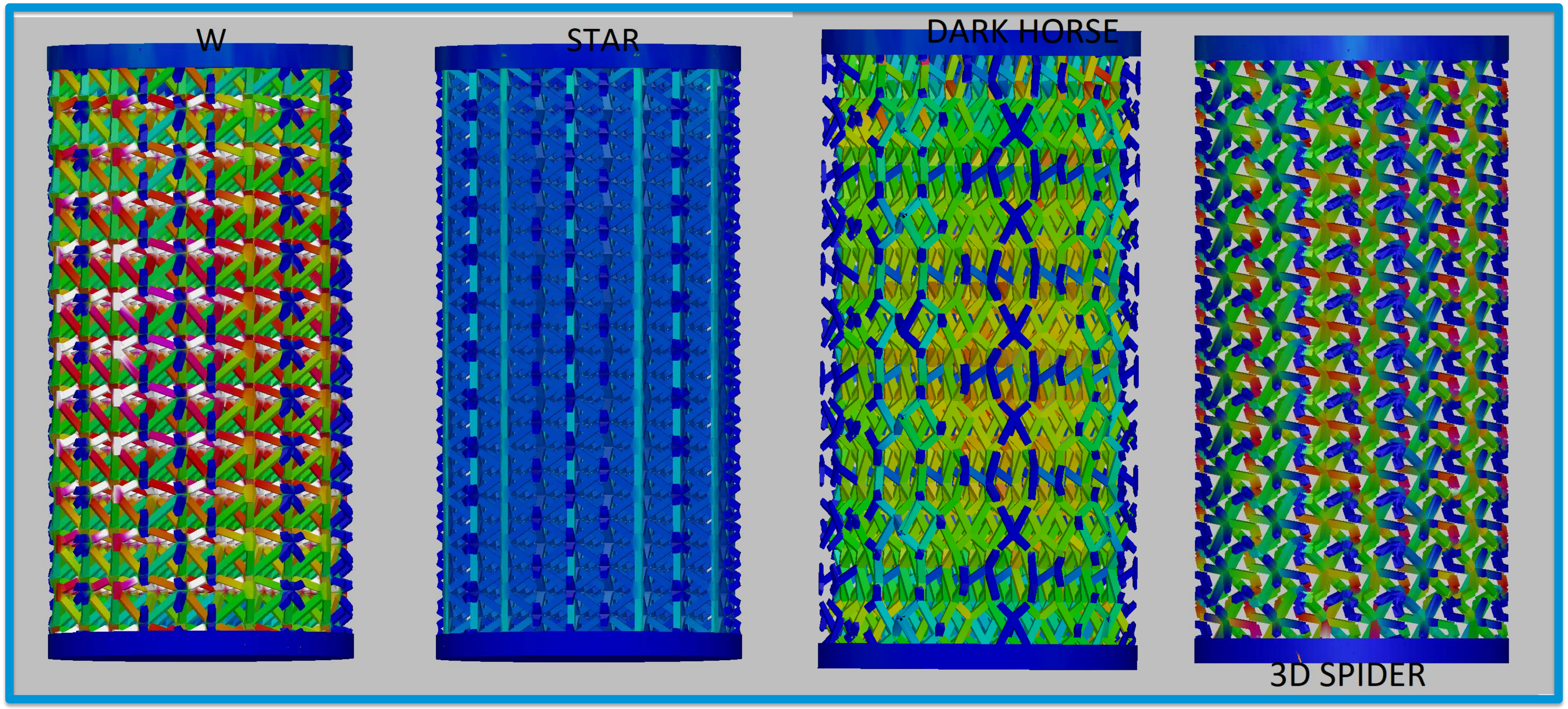
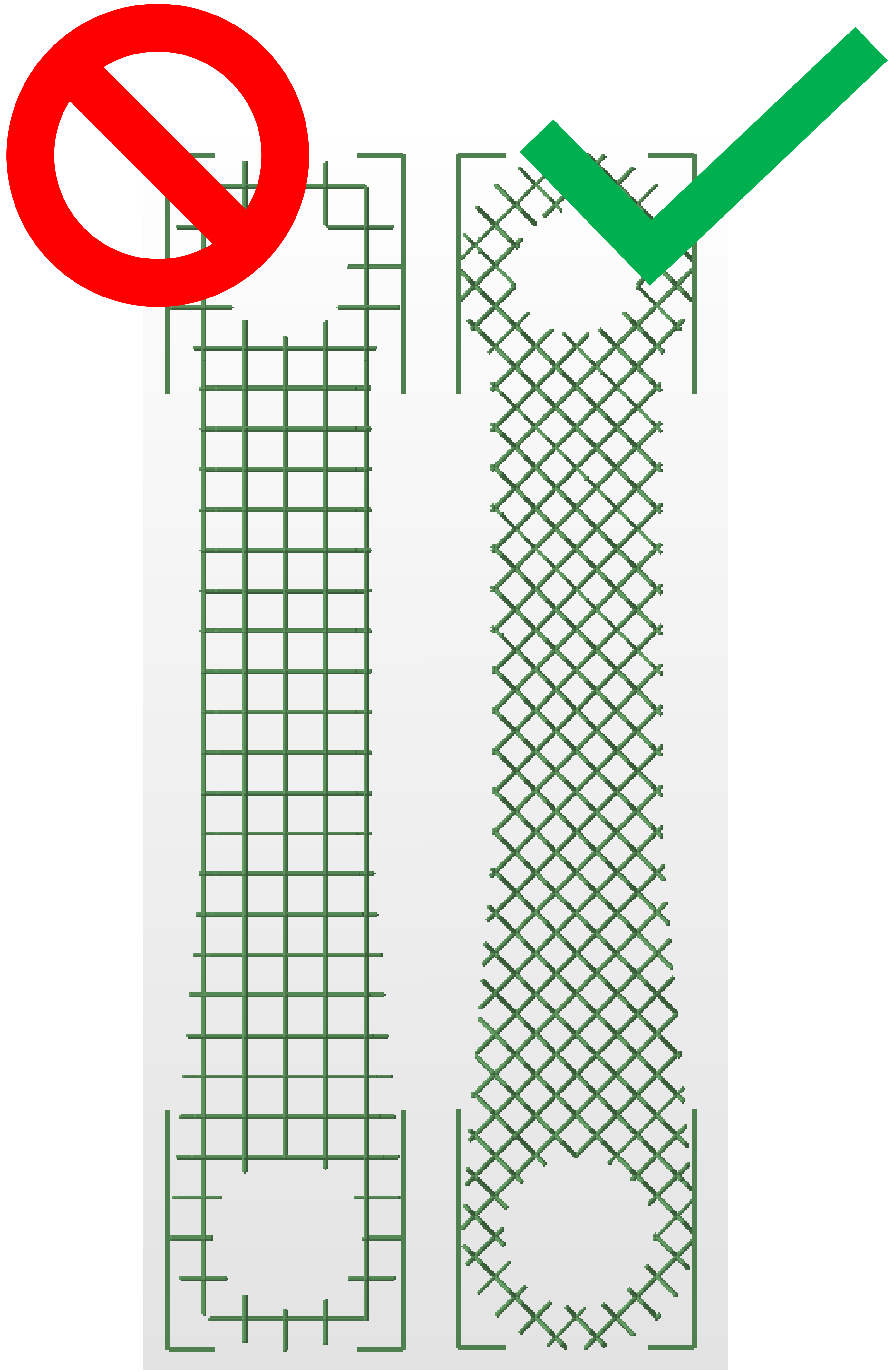


Image Source: Crucible Designs

Poor Lattice Structures

- Lattice that needs support
- Compression test for strength





Closing

- While additive allows for many new design possibilities previously not possible, there are many considerations that can facilitate a higher print success rate
- Hope this course and its hands – on examples helped open the door for future learnings and innovative solutions with additive manufacturing
- This course is just a highlight of the knowledge available on successfully utilizing additive manufacturing technologies

Image Source: 3D Hubs

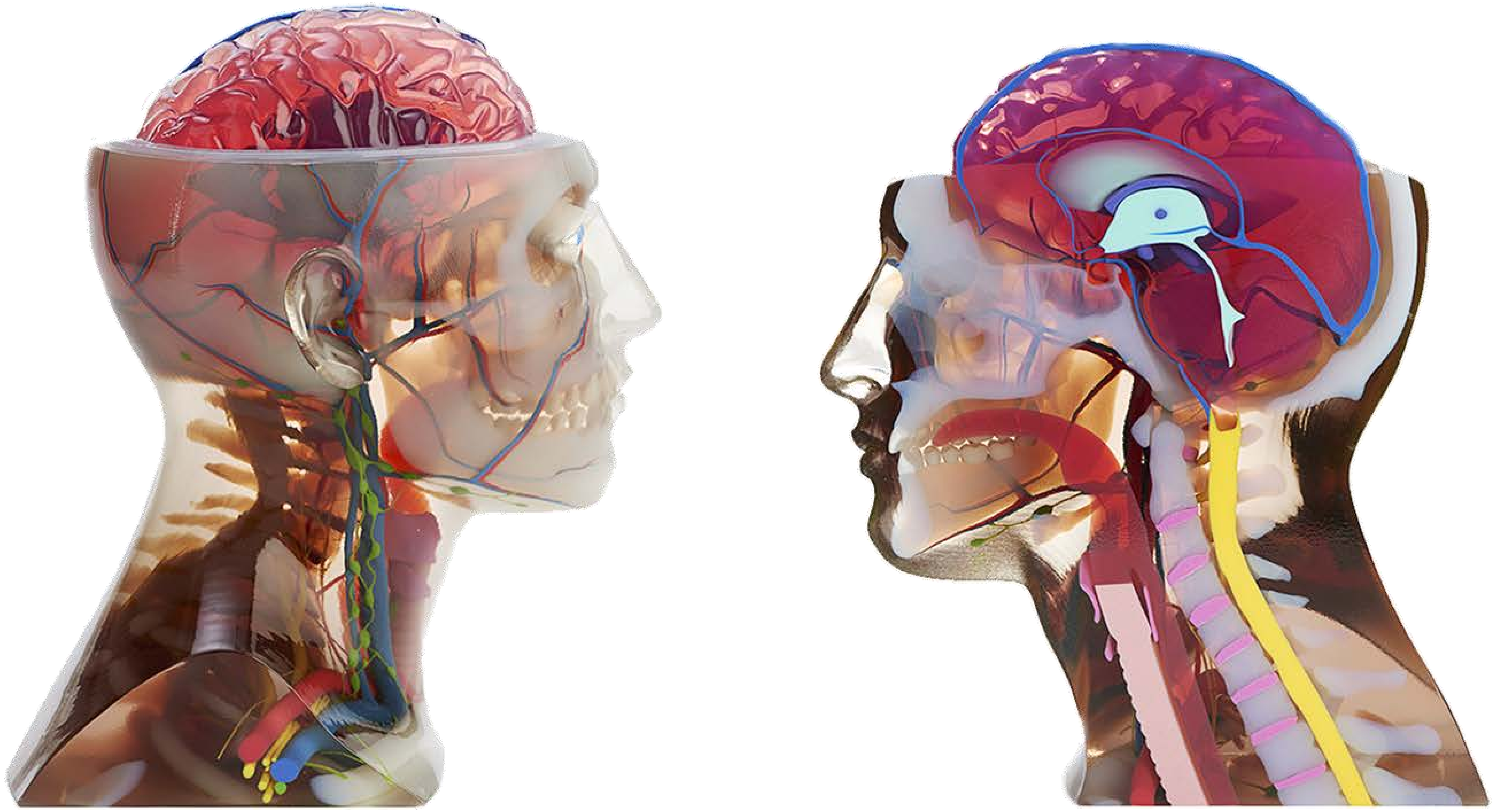


Image Source: 3D Hubs

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