



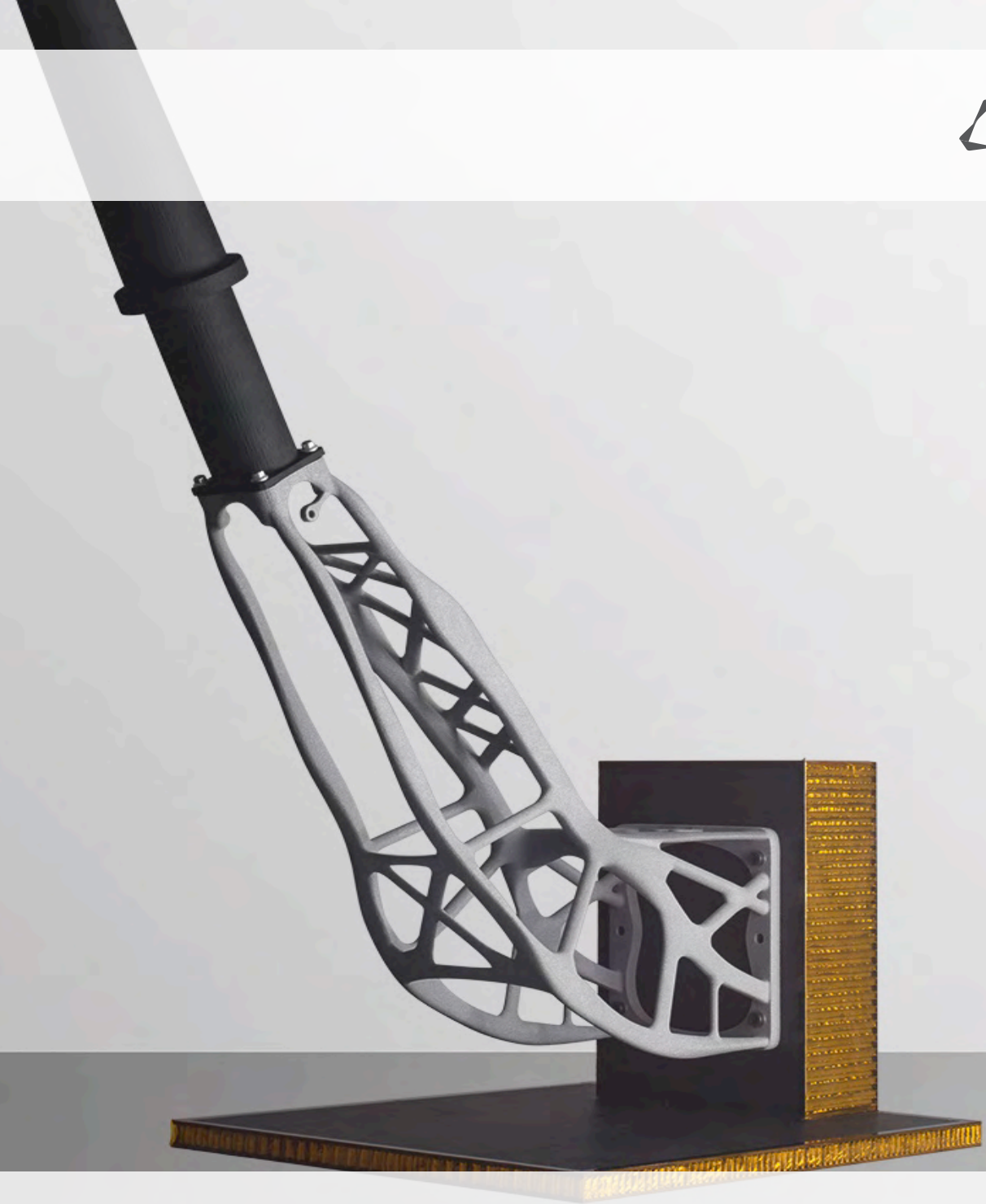
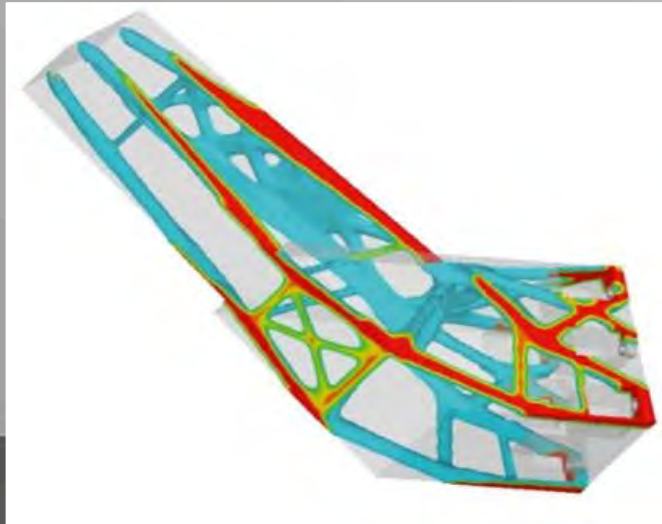
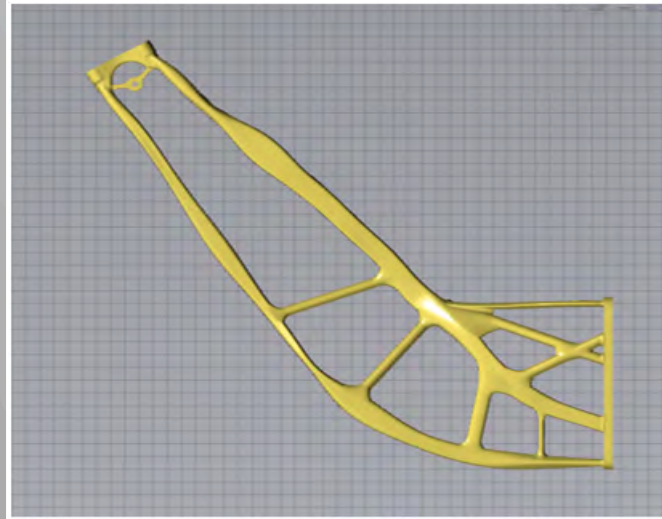
**Altair**

Innovation Intelligence®

## **Unlocking the Design Potential of Additive Manufacturing**

**Dr. Robert Yancey**

# RUAG Space



Altair ProductDesign helps RUAG Space to design and optimize one of the longest components ever manufactured by industrial 3D printing for use in space – **50% weight reduction**

## Design Challenges

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# Major Challenges in the design process:

How to get the Digital File?

Reverse Engineering Geometry Capture – CT, Laser, CMM

## Reverse Engineering

- Laser Scanning
- White Light Stereo Scanning
- CT
- Coordinate Measuring Machines



Point Cloud

STL File



Surfaces

CAD

## Design Challenges

### Major Challenges in the design process:

How to get the CAD?

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How to come up with the best shape possible?

Topology Optimization

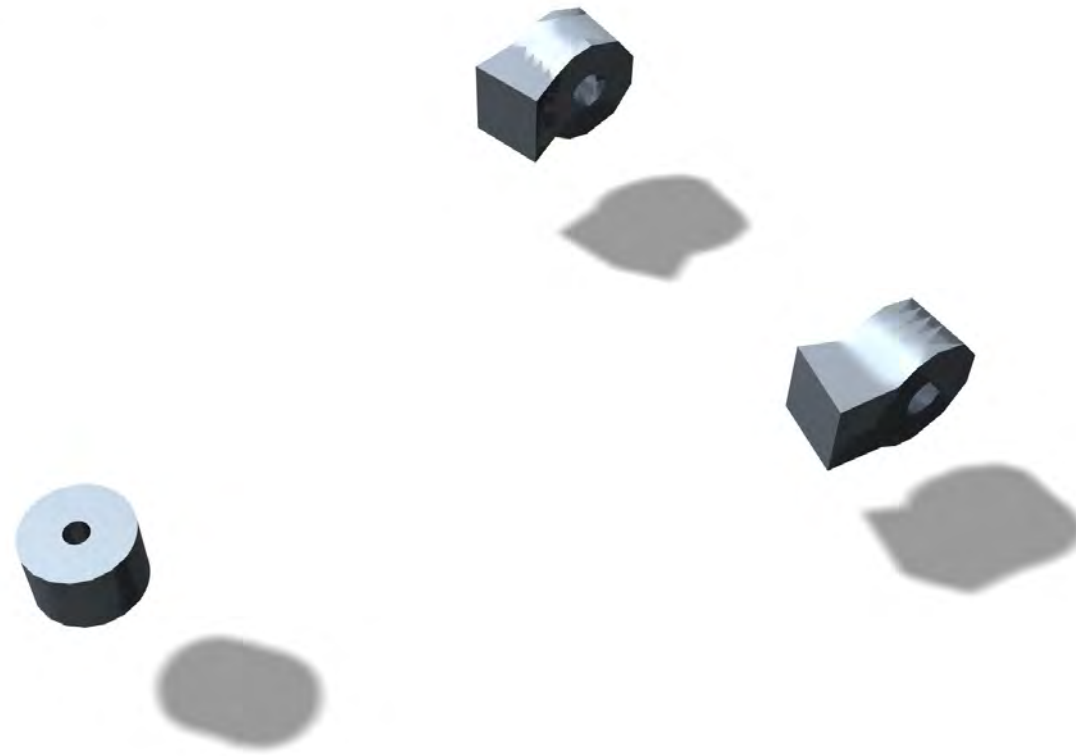


## The Additive Manufacturing Design Challenge

Solution:

Biomimicry Software

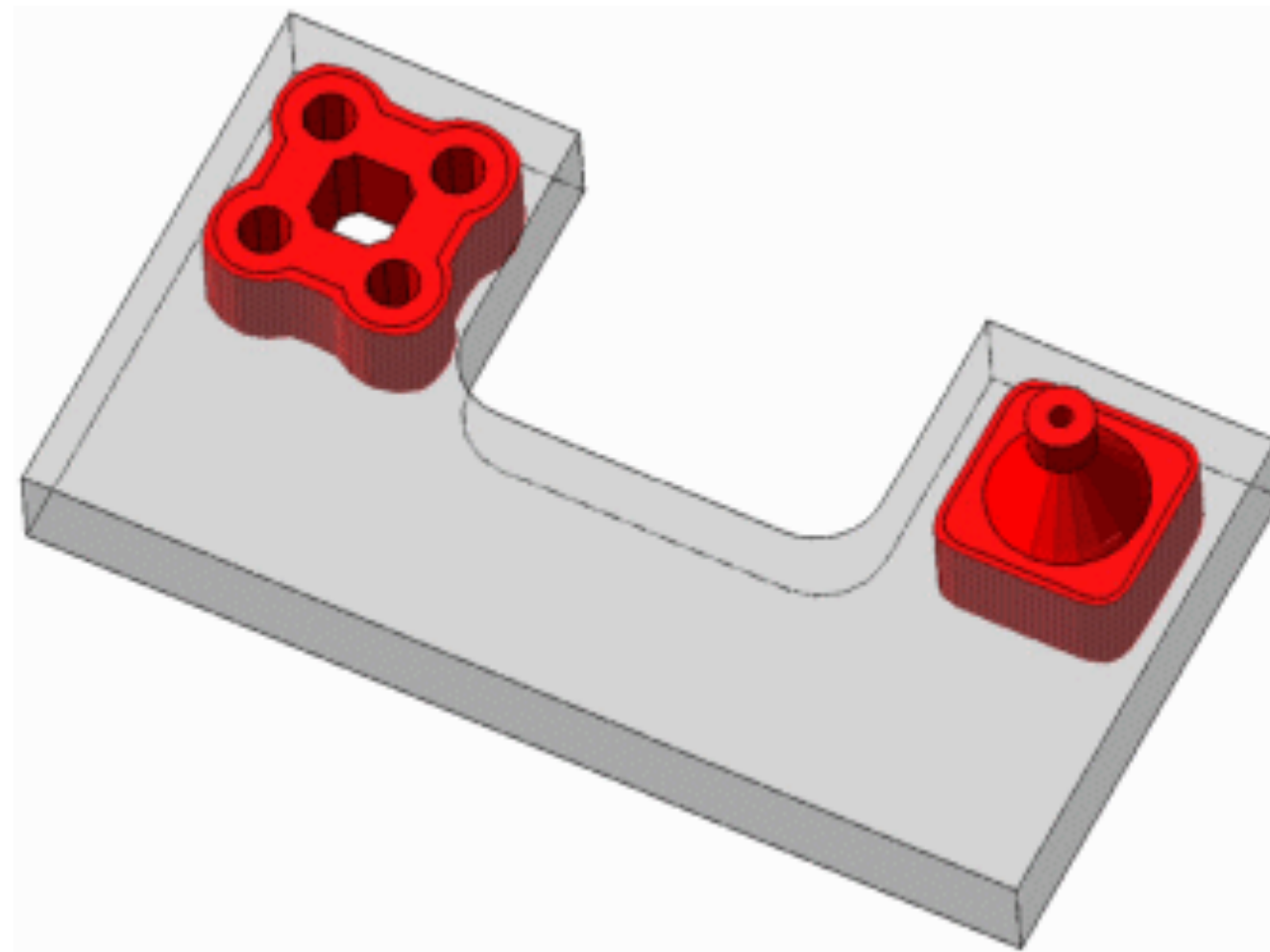
ADDIT UNREGISTERED - www.gf-animat.com





## The Additive Manufacturing Design Challenge

# Underlying Technology: “Topology Optimization”



# “Industrialization” of Topology Optimization





# Engineering ability – Topology Optimization

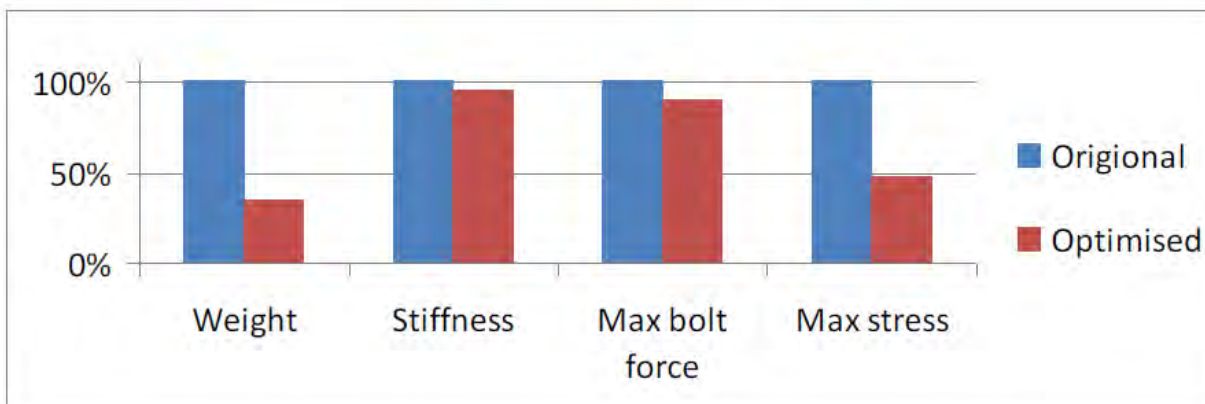
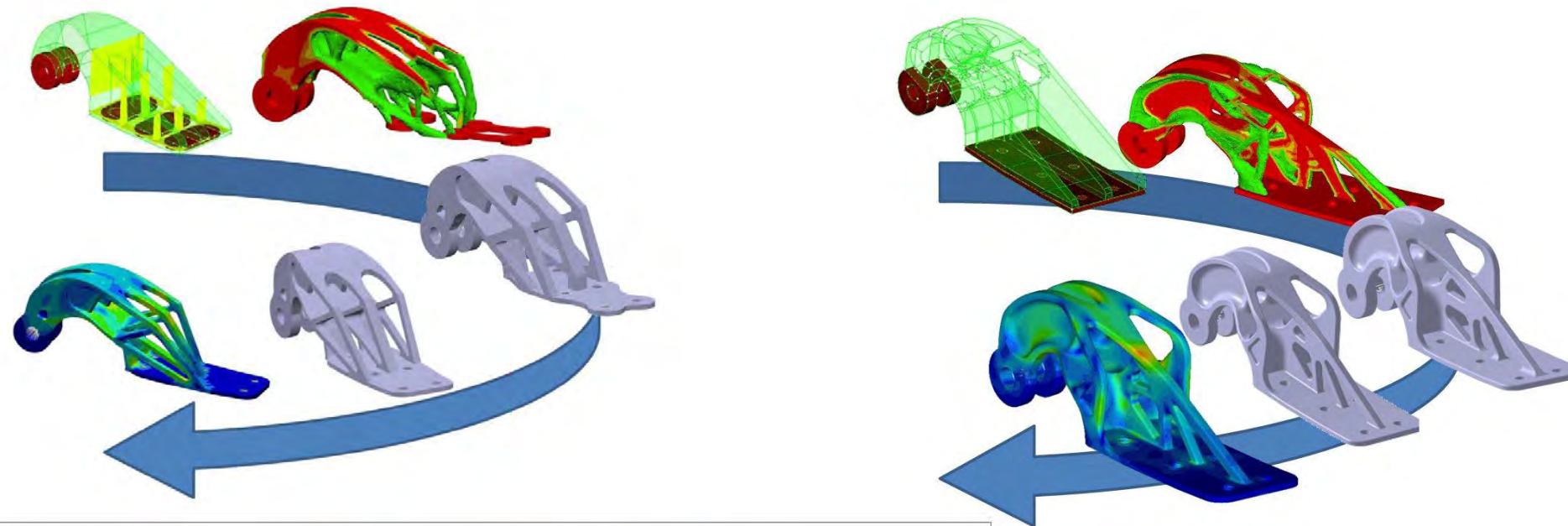


Figure 10: Performance comparison of original and new design

**Altair**  
The 7th Altair CAE Technology Conference 2011

## Topology Optimization of an Additive Layer Manufactured (ALM) Aerospace Part

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EADS

EADS

### Abstract

As part of research into the benefits of Additive Layer Manufacturing (ALM) manufacturing process, an Airbus A320 nacelle hinge bracket was optimized, incorporating a topology optimization method. The design freedom of the ALM process meant that a significant proportion of weight could be saved in the part, while also reducing maximum stress and maintaining stiffness. Optimization of small-scale parts presents a large opportunity for weight saving, and may become economically viable if tools are developed to reduce the man-hours used in the design process.

Keywords: Optimization, OptiStruct, topology.

### 1.0 Introduction

Metallic Additive Layer Manufacture (ALM) technology is a relatively young technology in the early stages of being implemented into the manufacture of aircraft. The main benefits of the ALM process come in design flexibility, low material waste, low CAD-to-part time and cost of producing parts from hard materials that are otherwise difficult to machine. ALM is currently a comparatively expensive process, but this expense is acceptable in high-value applications where specialised materials are used or where a customer requires a complex part.

Because of the design freedom available with ALM, it is a perfect application for topology optimization. Where usually a topology optimization has to be 'interpreted' and sacrifices in the design have to be made for manufacturability. With ALM, the principal is that the topology optimized shape can be maintained and the final weight and structural properties can be closer to that of the optimized shape.

Reducing weight also means that the part manufacture costs less. As ALM is an additive process the part cost is proportional to the volume of the part. The more material used, the more expensive the part will be. This is opposed to how many parts are currently made. Subtractive processes (e.g. milling) are often used to reduce weight, these incur a trade-off between cost and weight, this does not happen with ALM.

## Design Challenges

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### **Major Challenges in the design process:**

**How to get the CAD?**

**Reverse Engineering Geometry Capture – CT, Laser, CMM**

**How to come up with the best shape possible?**

**Topology Optimization**

**How to generate a geometry from the organic like structural concept?**

**Direct Modelling Tools instead of conventional CAD**

## The Additive Manufacturing Design Challenge

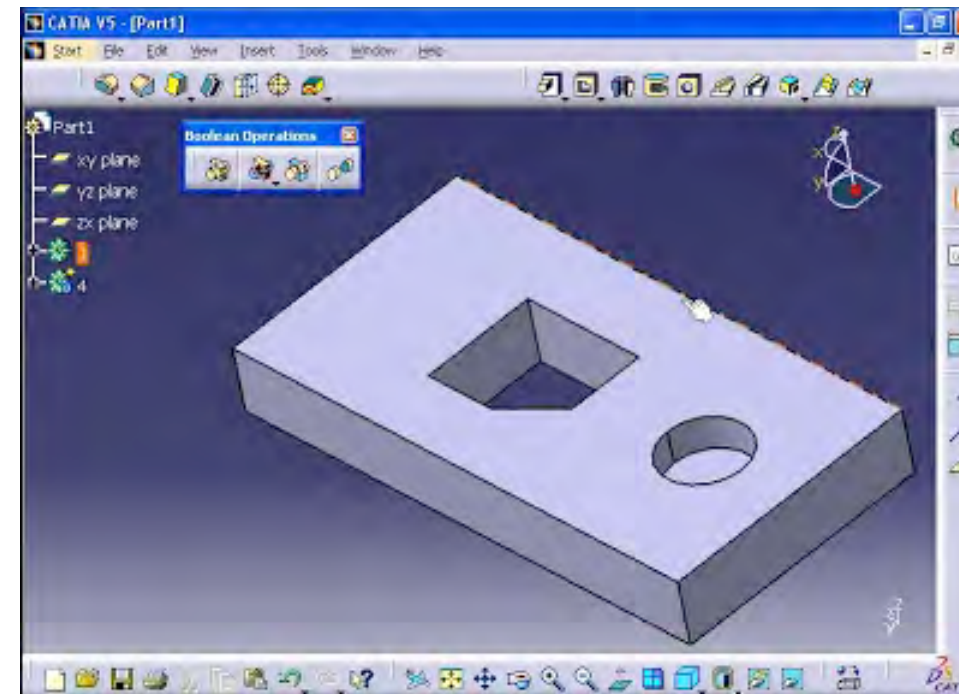
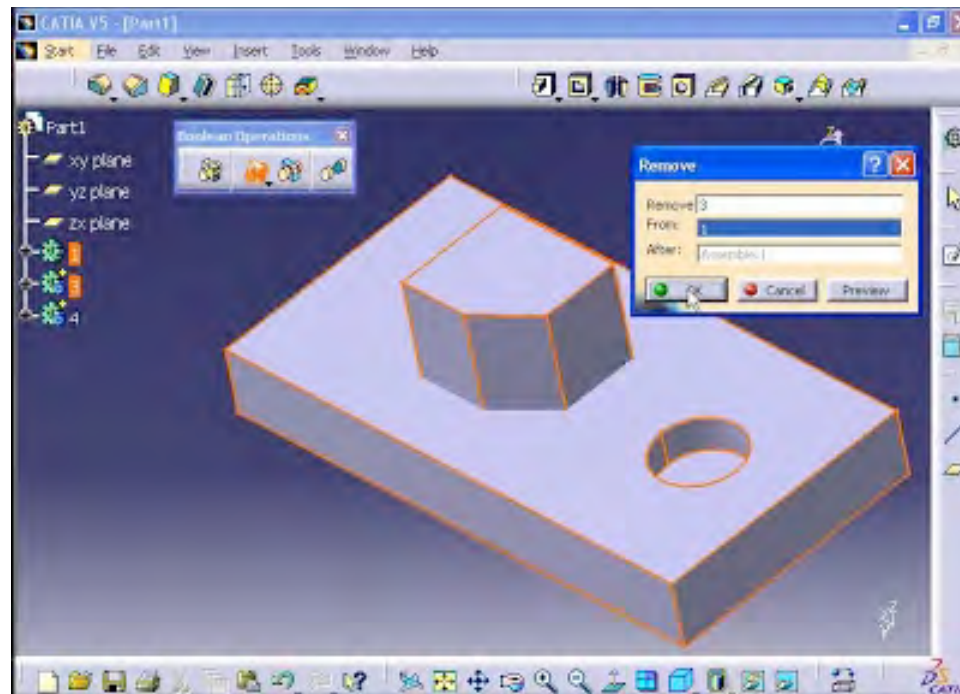


How can the engineer draw it in a CAD system?



## The Additive Manufacturing Design Challenge

**Problem:**  
Conventional CAD systems rely on boolean operations of simple geometric entities





## The Additive Manufacturing Design Challenge

So “drafting” something like this  
can take weeks with a conventional system:



pictures by courtesy of Laser Zentrum Nord 



## The Additive Manufacturing Design Challenge

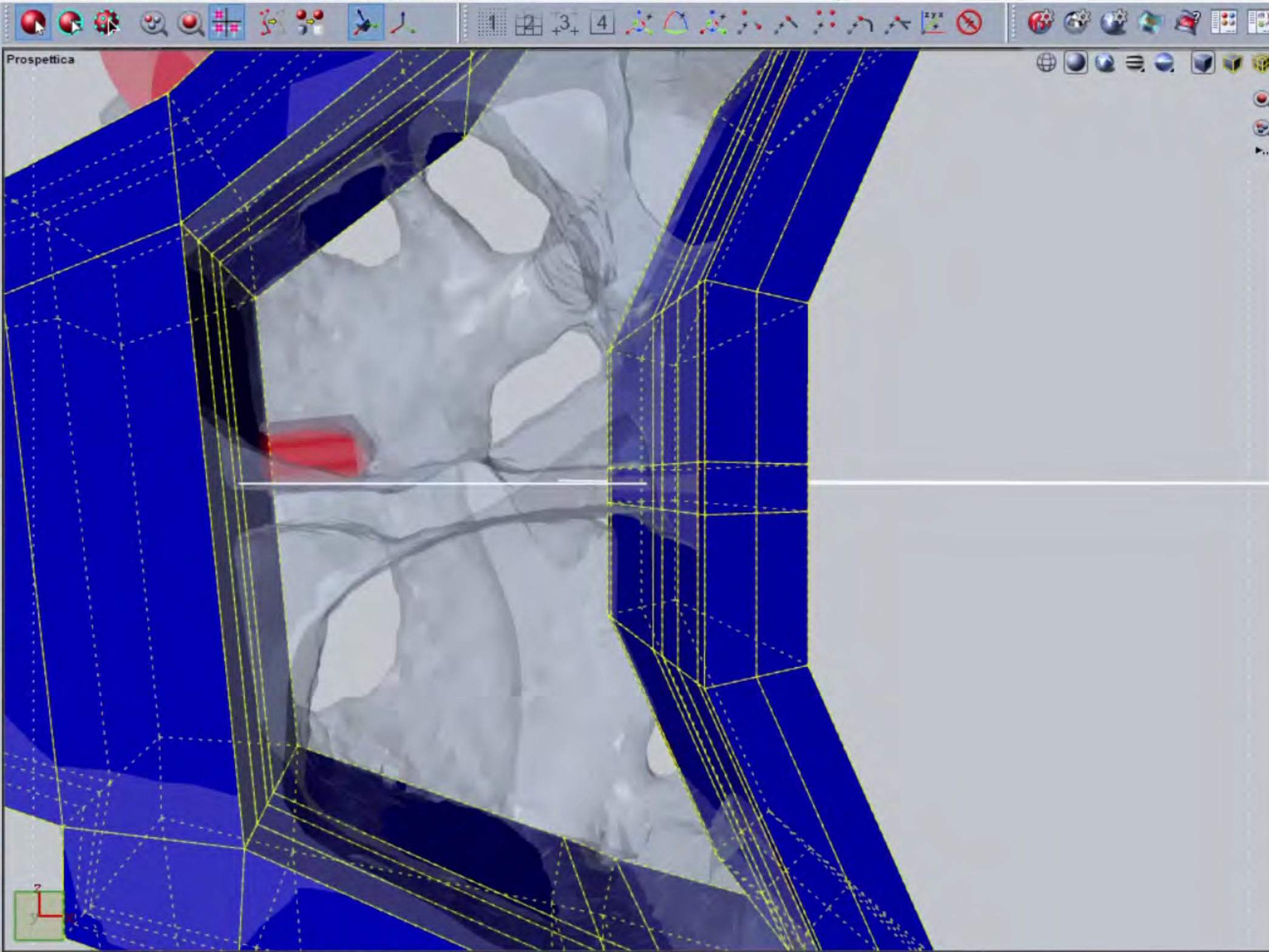
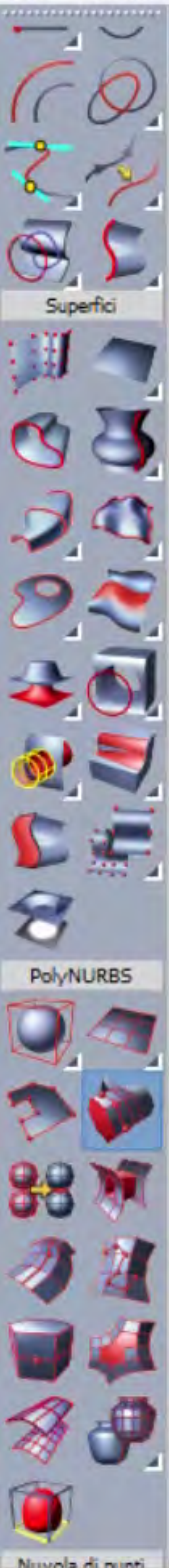
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**Solution:**

**Direct Modelling**

**New  
Polymesh Design Technology**



**Modifica PolyNURBS**

Pulisci

Nurbify

Modifica

- Vertici
- Bordi
- Facce

Vertice

x 4.600 y -2.350 z 0

Selezione

Seleziona tutto

Seleziona bordi

Inverti Selezione

Cancella

Unisci bordi

Unisci selezionati

Unisci selezionati tol.

Tolleranza 0,001 cm

Attiva levigatura

Fattore di levigatura 0,500

Conserva vertici esterni

Attiva levigatura

Mostra normali sui vertici

Info

Vertici 384

Bordi 768

Polynurbs

Scena 3D

- nondesign\_spaces.x\_t
- Max Stiffness Mass By Parts (2)
- PolyDisco #2

PolyDisco #2

# Performance Comparison



Direct Modeling		Traditional CAD
363 Hz	1 <sup>st</sup> Frequency	313 Hz
539 psi (3.72 MPa)	Max Stress	534 psi (3.68 MPa)
8.62e-5 in (2.19e-6 m)	Max Displacement	9.62e-5 in (2.44e-6 m)
.100 lb (.045 kg)	Weight	.108 lb (.049 kg)
8 hours	Design Time	24 hours





## Design Challenges

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### Major Challenges in the design process:

How to get the CAD?

Reverse Engineering Geometry Capture – CT, Laser, CMM

How to come up with the best shape possible?

Topology Optimization

How to generate a geometry from the organic like structural concept?

Direct Modelling Tools instead of conventional CAD

How to deal with the new manufacturing constraints?


Design rule catalogues

Manufacturing constraint implementation in Design


# The Additive Manufacturing Design Challenge

## How to consider the NEW Manufacturing Constraints?

Types of support

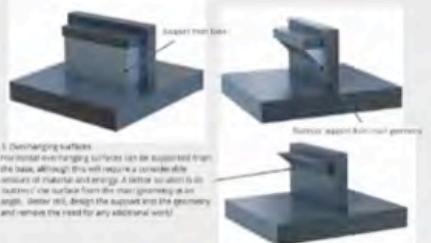


**1. Simple fill in:**  
The most simple form of support is to fill in the area that needs support, and then cut this out when the build is complete by wire cutting or machining. If the support area is to be removed with wire cutting, a small hole needs to be placed in the support area to allow the wire to be located.

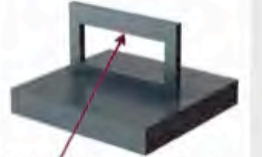


**2. Other support:**  
Other supports require machining. They are...

Downward facing surfaces

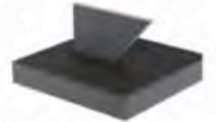


**3. Overhanging surfaces:**  
Overhanging surfaces can be supported from the base, although this will require a considerable amount of material and energy. A better solution is to support the surface from the main geometry at an angle. (Later on, design the support into the geometry and remove the need for any additional work.)

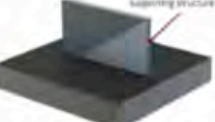


Any downward facing surface will require support. Support structures will need to be removed by wire cutting or machining, which will increase the energy and waste involved in the process.

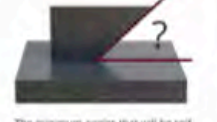
Angled surfaces and holes




The powder in the build chamber does not provide any support to the part as it builds, so any angled surfaces will ideally be self-supporting.




If the angle is too acute, the surface will need a supporting structure built in as part of the model. This supporting structure will then need to be removed by machining or wire cutting, increasing energy use.



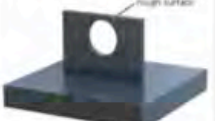
The minimum angles that will be self-supporting are approximately:  
 - Stainless steel: 30 degrees  
 - Inconel: 45 degrees  
 - Titanium: 25-30 degrees  
 - Aluminum: 45 degrees  
 - Cobalt, Chrome: 30 degrees




If the angle is near the point where it needs supports, the downward facing surface will become rough and may require considerable post-finishing.




Small holes can be accommodated easily. Holes of less than 6mm diameter are ideal.




Larger circular holes will result in a rougher surface at the top which may need post-machining.



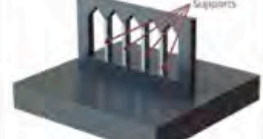
Large holes will require support structures to be added in the centre to prevent the part collapsing or becoming distorted during the build process. These supports will need to be removed by wire cutting or machining.



If the hole has an angled or arched upper area it will probably not require any supports. This is one of the features of DMLS that can have a significant impact on the design process.



An alternative to this approach will be to turn the part through 45 degrees to make all the surfaces angled and remove the need for supports. Orientation is a major issue in finding the most efficient build method - please see item 3 in Other issues (below) for more details on the limits and possible pitfalls of using angled edges like the ones shown above...



If the top surface of the hole can be made of a series of angles (which are self-supporting) the supports can be minimised to the base of each angled surface.



# Design Rules Catalog for Laser Additive Manufacturing



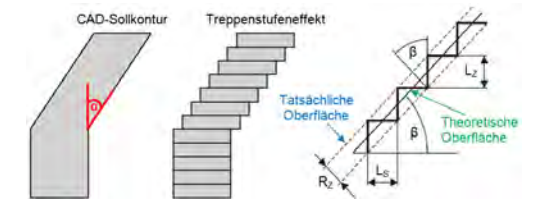
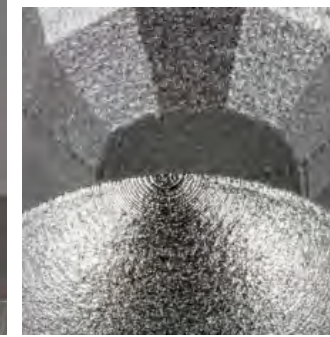
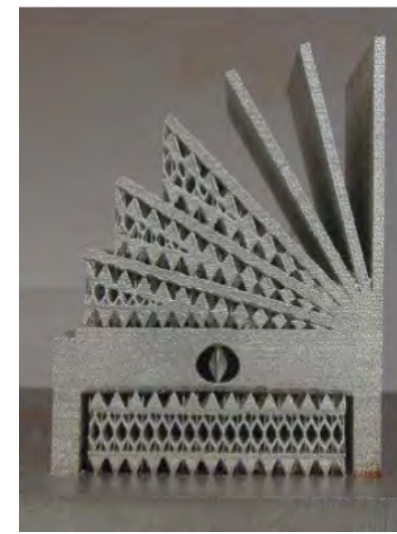
## "Design guidelines for laser additive manufacturing of lightweight structures in TiAl6V4"

J. Kranz, D. Herzog, and C. Emmelmann

<http://scitation.aip.org/content/lia/journal/jla/27/S1>

- Heat induced Stresses
- Support Structures
- Holes
- Overhangs
- Building Sizes
- Surface quality
- Building cost

structure	structure		explanation	restrictions and recommendations
	unfavourable	favourable		
Design Process – TiAl6V4	part placement	part alignment		<ul style="list-style-type: none"> <li>• place thin walls perpendicular towards recoater</li> <li>• do not place large filigree crosssections parallel to the recoater</li> </ul>
		filigree parts		
	general	typical target figures: <ul style="list-style-type: none"> <li>• max. support area</li> <li>• min. contact with supports</li> <li>• min. roughness of interfaces</li> <li>• min. support volume</li> </ul>		
package density			<ul style="list-style-type: none"> <li>• consider free space between manufactured parts in order to ease final machining</li> <li>• to close packaging can lead to thermal interaction of parts</li> </ul>	<ul style="list-style-type: none"> <li>• sufficient distance between parts minimizes thermal influences</li> <li>• TiAl6V4: ca. 5 mm; no powder bed heater</li> </ul>



# AM Overhang Angle – Fused Deposition Modelling (FDM)

## Modification of topology design to enable support free AM structures

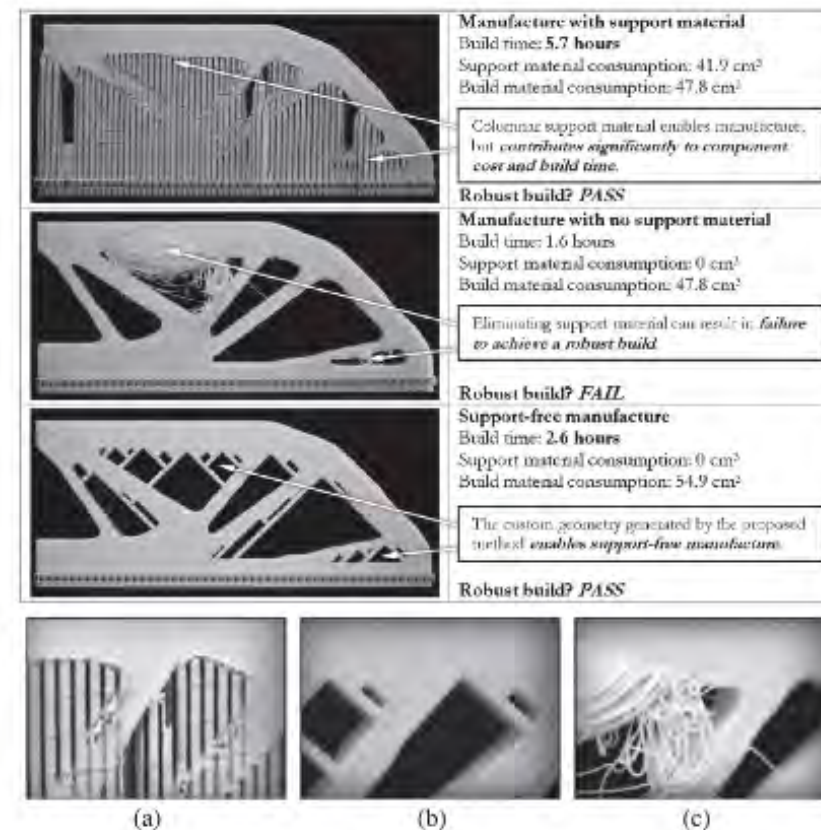
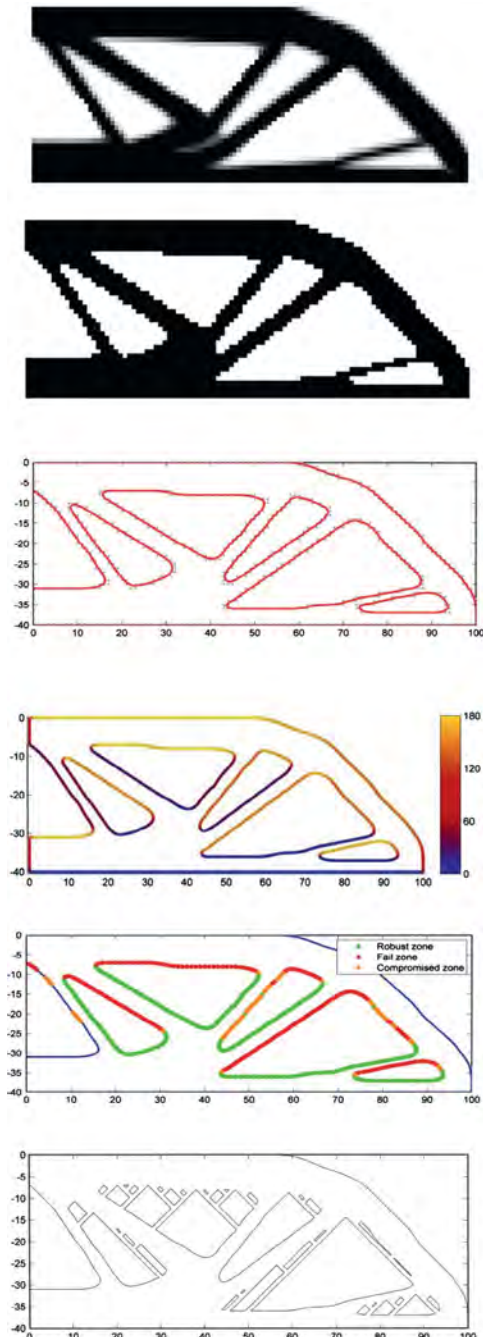


Fig. 16. Orientation 1 ( $\theta = 0^\circ$ ). Details: (a) Machine support. (b) Optimal support. (c) No support = Failed.

Martin Leary, Luigi Merli, Federico Torti, Maciej Mazur, Milan Brandt – “Optimal topology for additive manufacture: A method for enabling additive manufacture of support-free optimal structures”, 2014



## AM Overhang Angle

# Constraining topology design to allow optimal support free layout

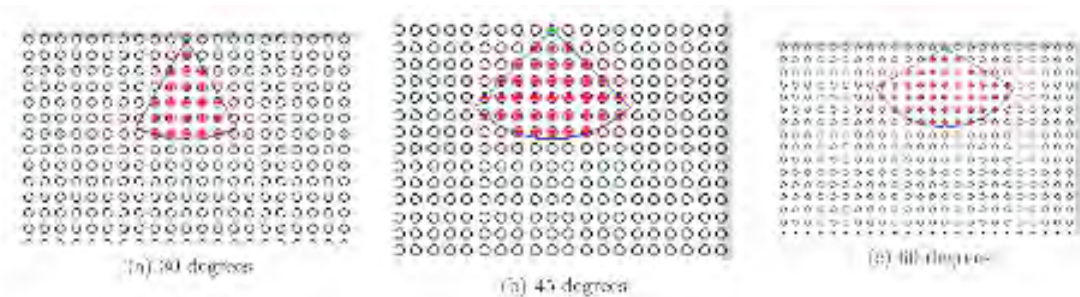
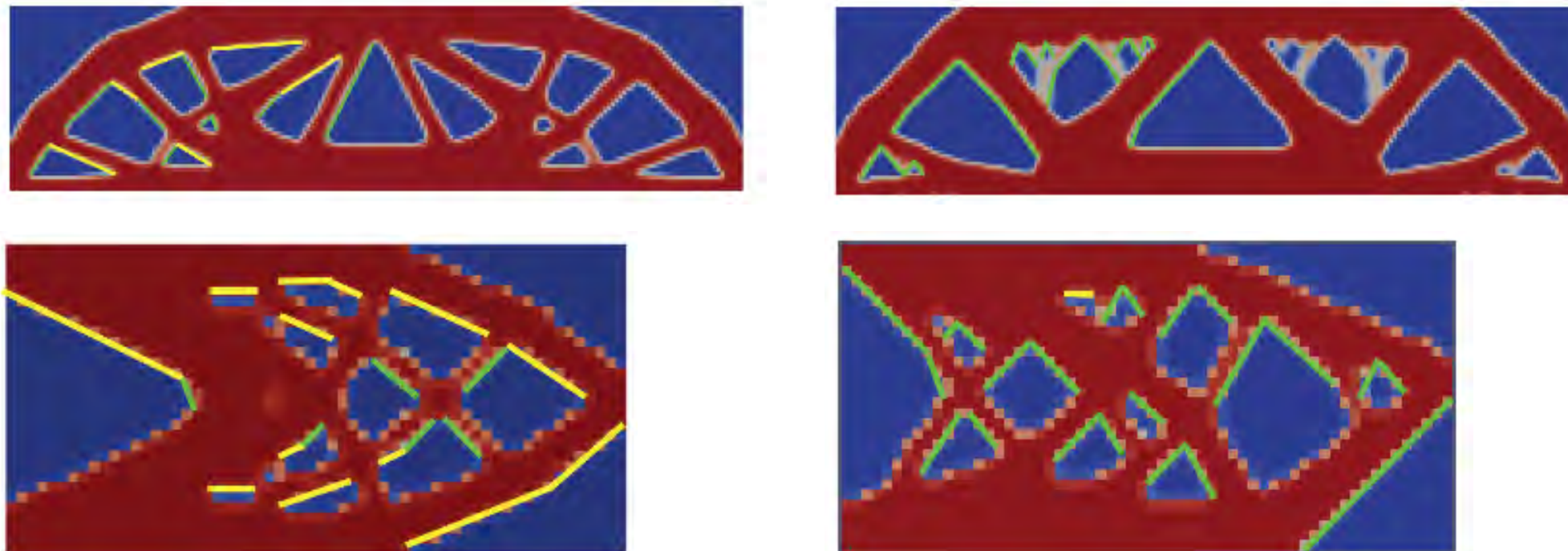
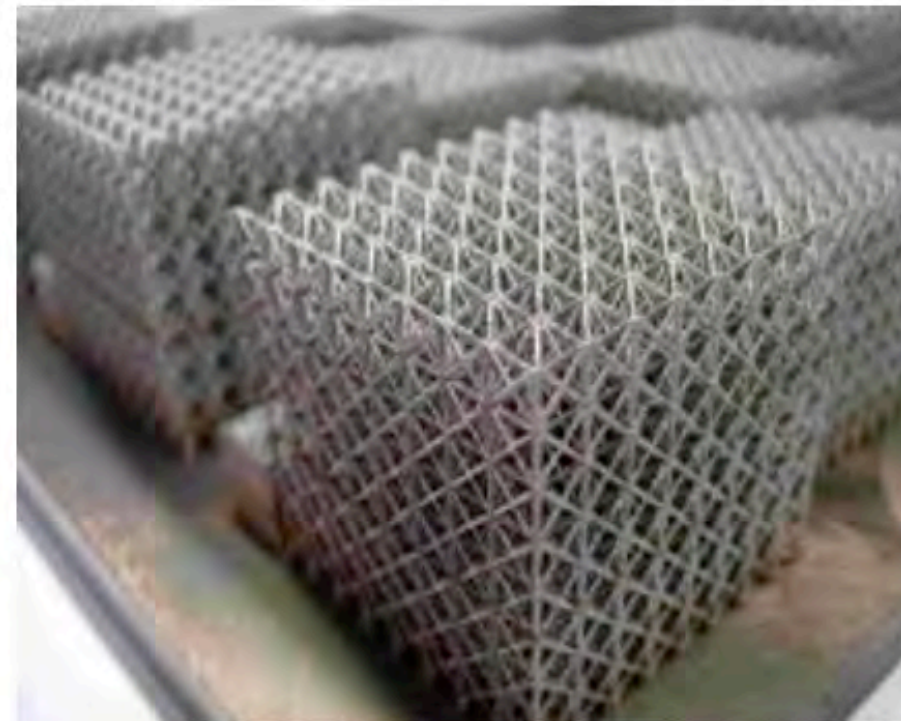


Figure 2: Overhang constraint: scanning range below  $\theta$  in various overhang angles.



# What's Next?

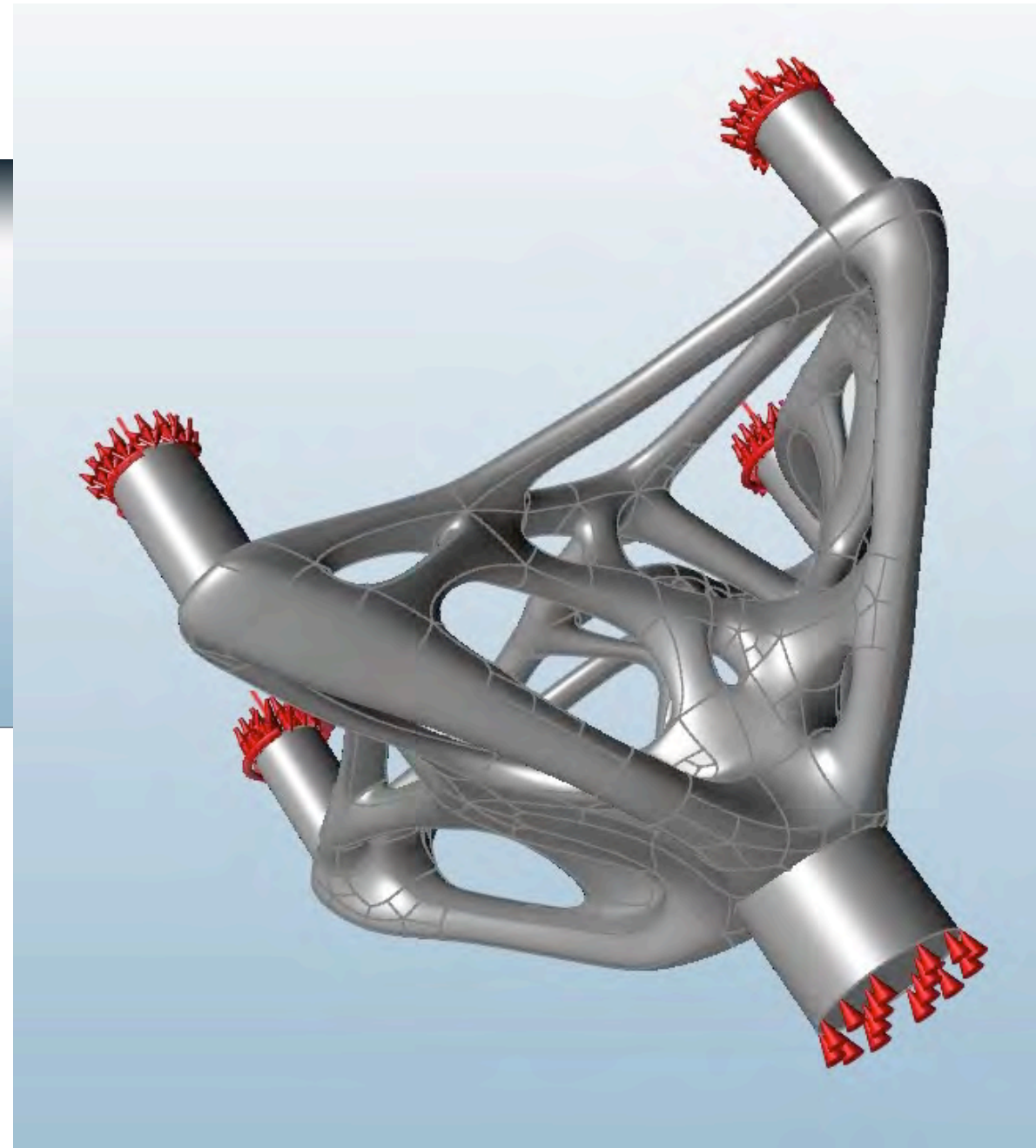
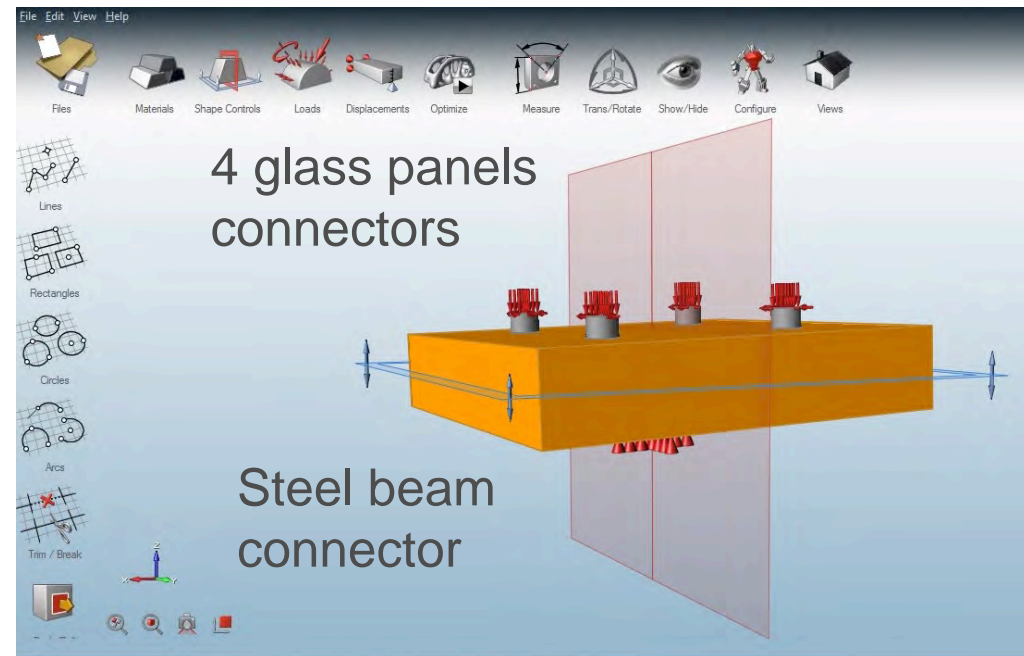
Topology optimized structures  
are pretty good,  
but lattice structures **could be even better:**





**So what if the design software could create  
lattice structures if needed?**

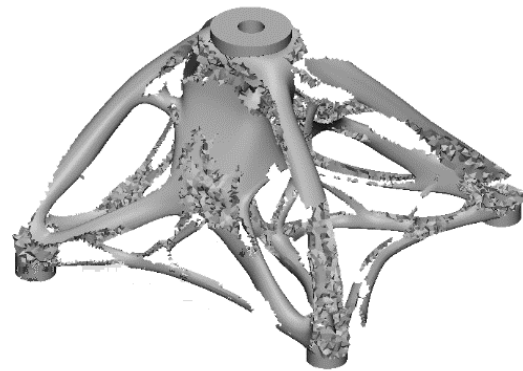
# Feasibility Study - Architectural Spider Bracket



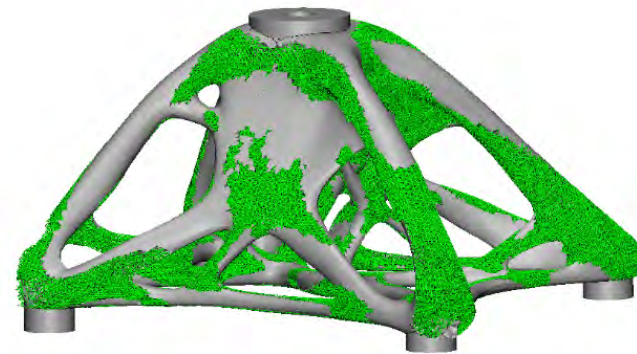
## Feasibility Study - Architectural Spider Bracket



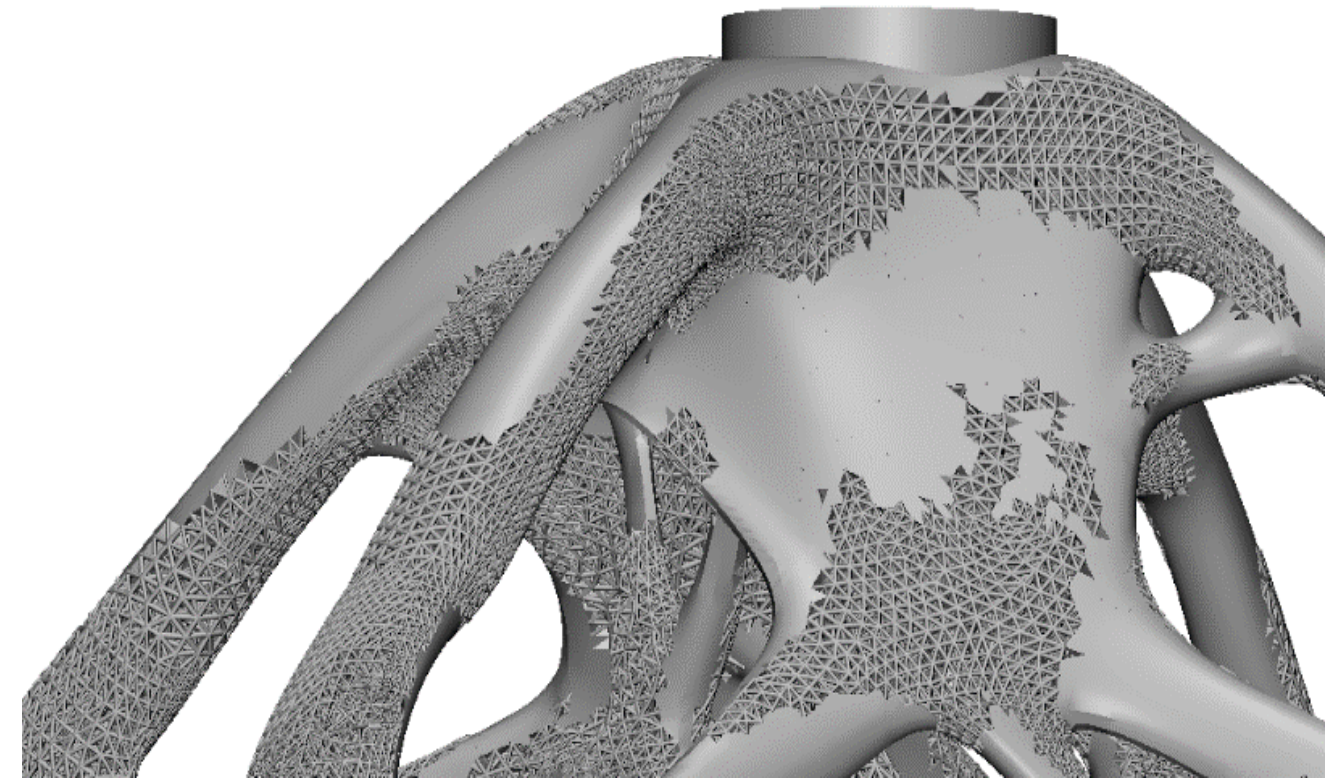
# 3-matic<sup>STL</sup>



*Optimized design* with some zones of solid using OptiStruct

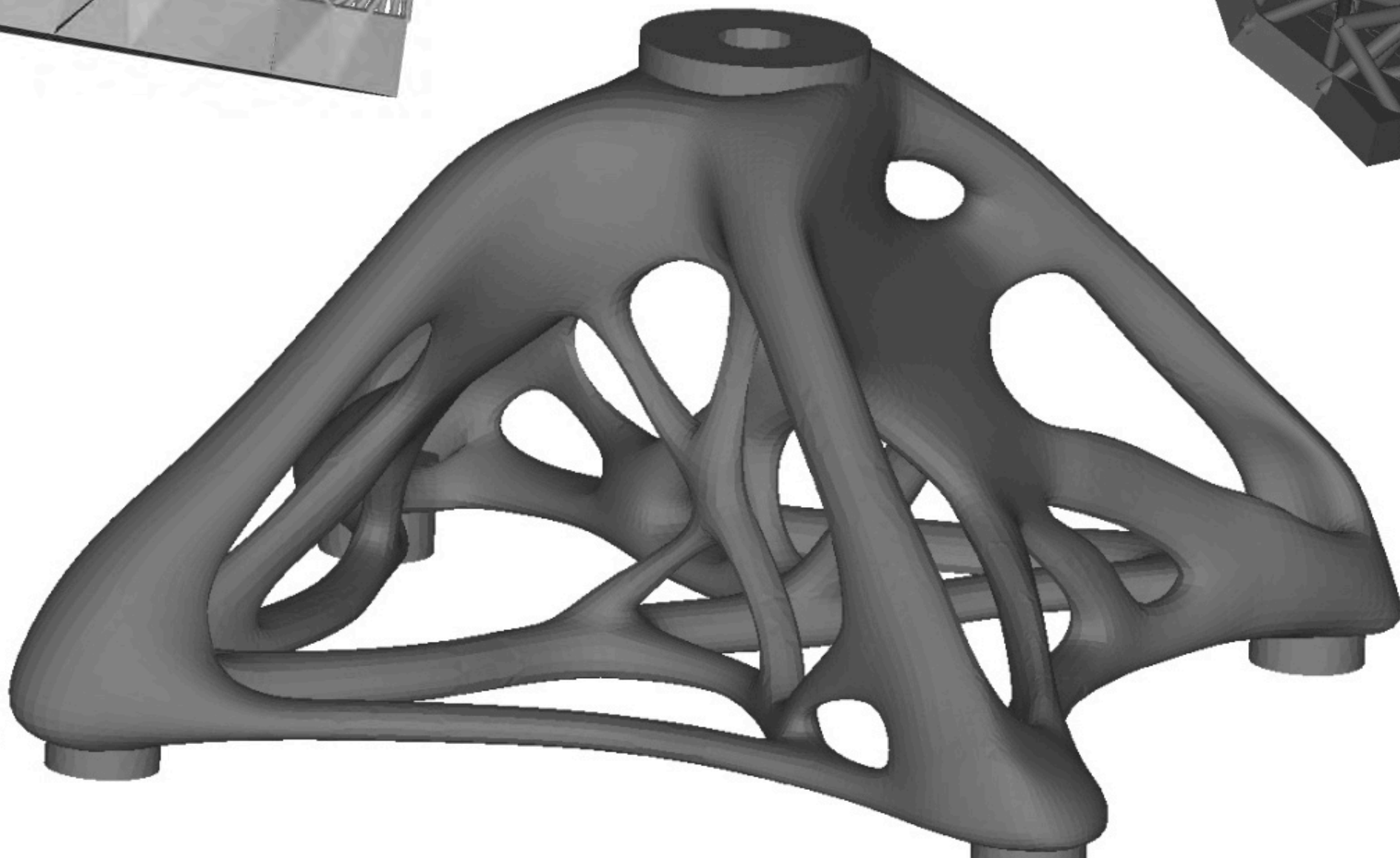
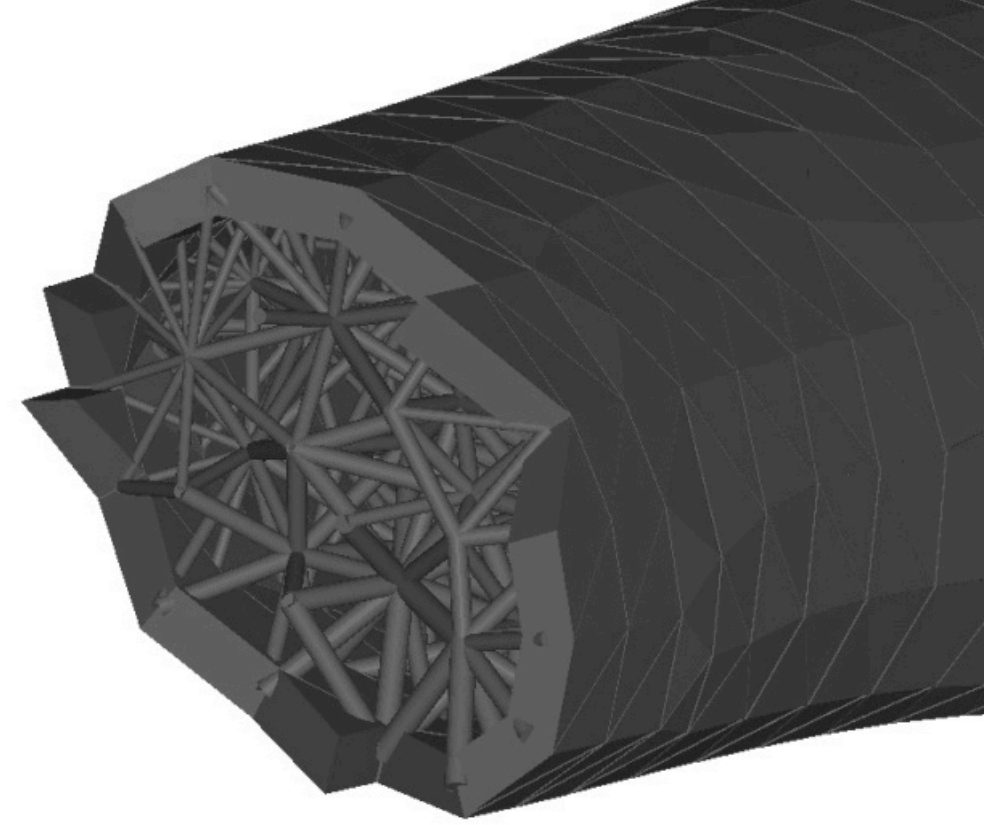
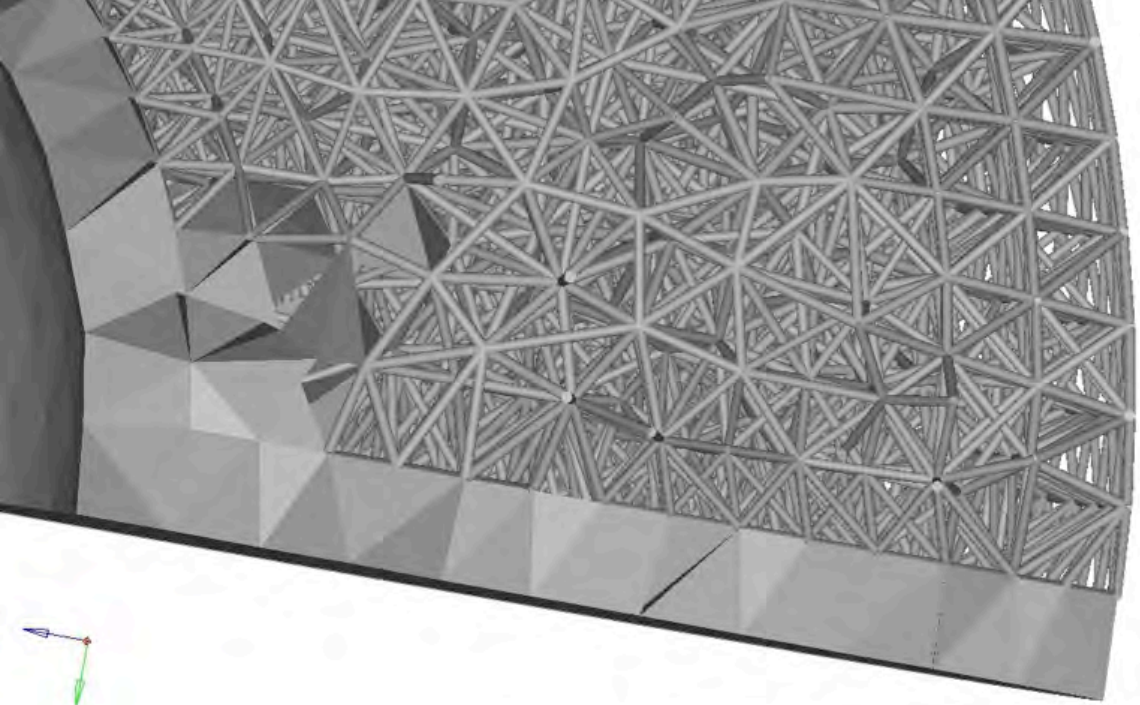


*Optimized design* with some zones of solid and some of structures using OptiStruct



*Seamless export* of structures from OptiStruct to 3-matic<sup>STL</sup>





z

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