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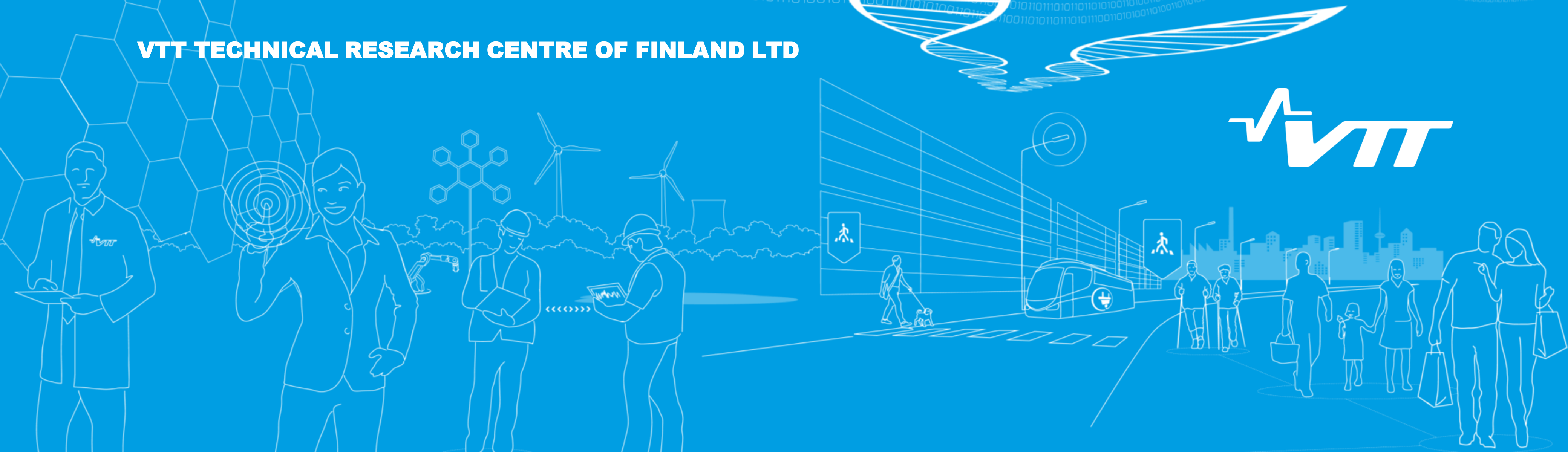
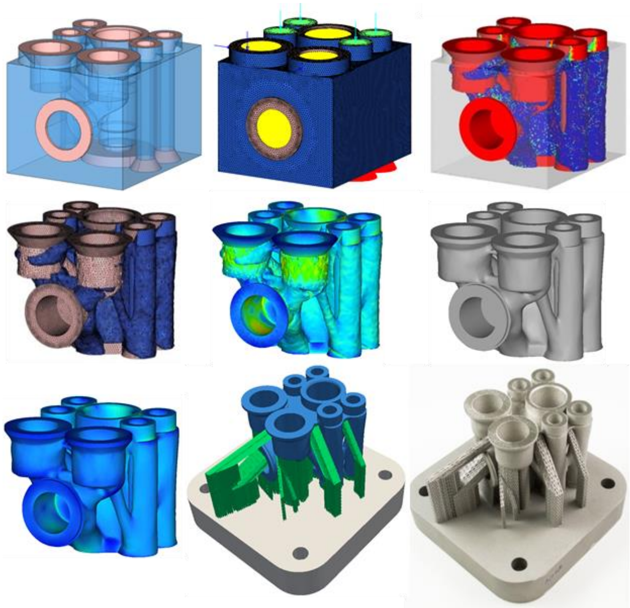




Component Design for Metal AM

Erin Komi

Structural Dynamics & Vibroacoustics

VTT Technical Research Centre of Finland Ltd

VTT Technical Research Centre of Finland Ltd

- A leading R&D organisation in Nordic countries
- As primarily scientists and engineers with a wide variety of backgrounds, we provide expert services for our customers and partners

TOP 2
VTT is second most active patenting organisation in Finland (2014)

36%
of Finnish innovations include VTT expertise

We use
4 million hours
of brainpower a year to develop new technological solutions

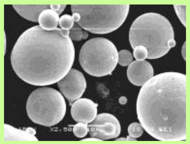
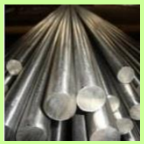
Net turnover and other operating income 272 M€ for VTT Group in 2015
(VTT Group's turnover 185 M€ in 2015)

Personnel 2,470
(VTT Group 31.12.2015)

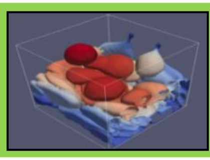
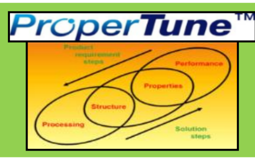
Unique research and testing infrastructure

Wide national and international cooperation network

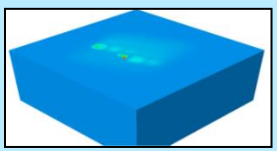
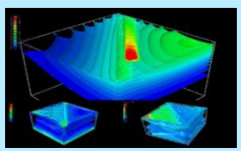
AM at VTT: From Raw Materials to Final Component Design


Experimental: materials, process, post-treatments

Powder & alloy design

Process simulation




Component optimization & design

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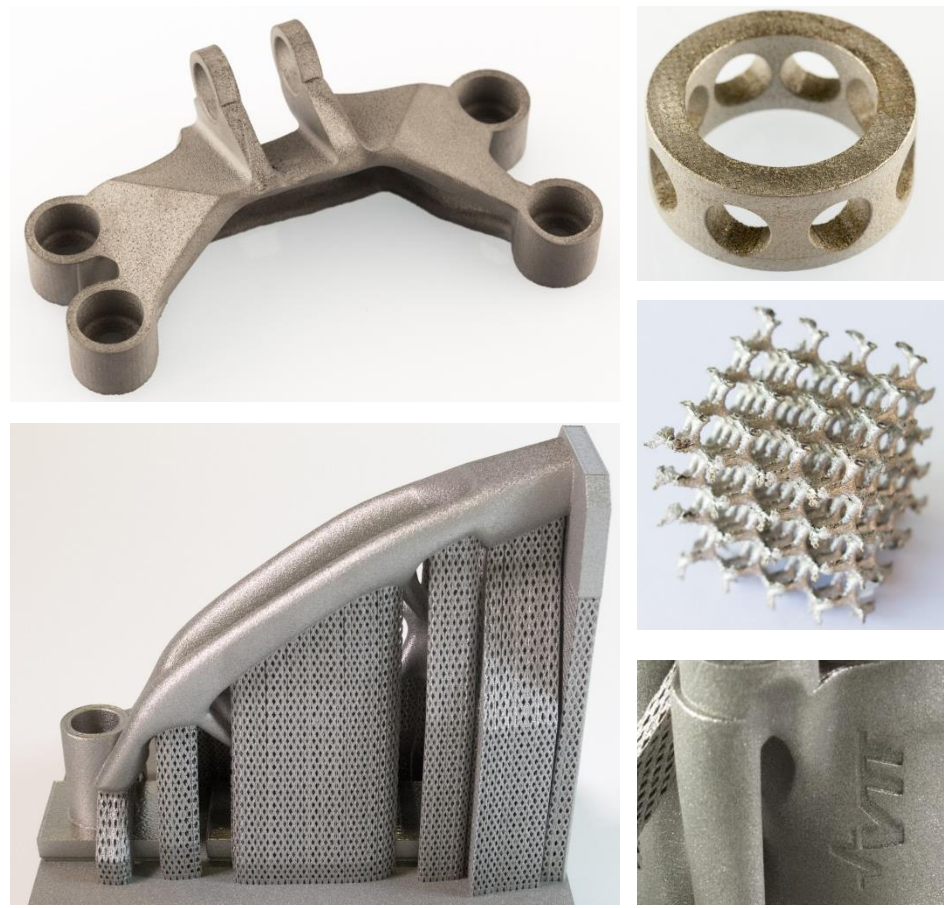
Motivation & Lesson Learned

- Geometric freedom that AM provides should be utilized fully in order to see the benefits from this manufacturing approach
  - Innovation
  - Functionally superior
  - Parts consolidation
  - Lightweight structures
- Must understand the manufacturing process (and its limitations)!



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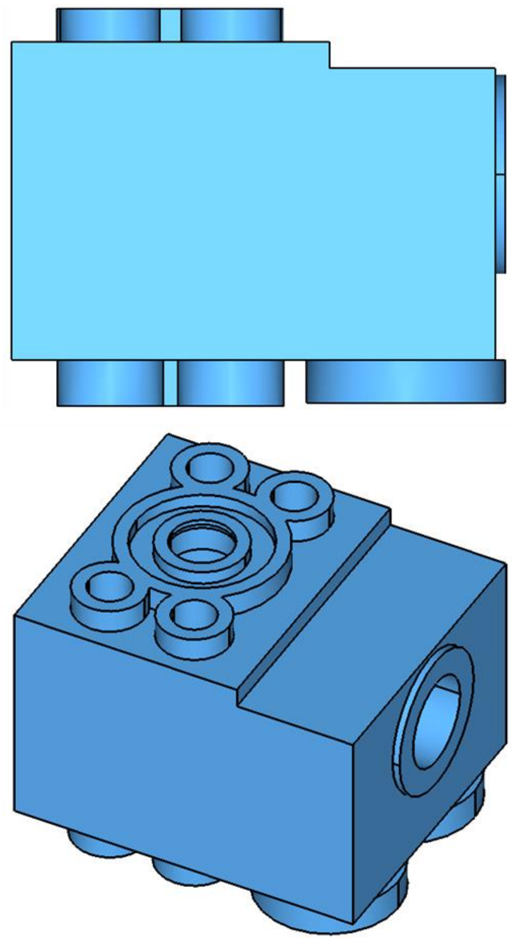
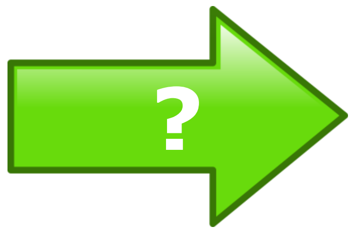
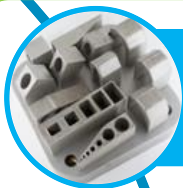
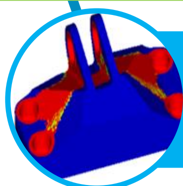
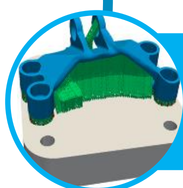
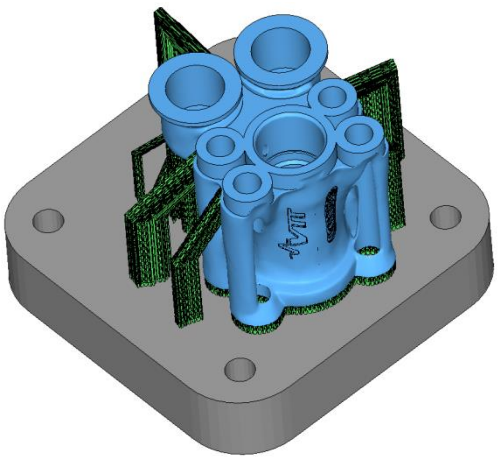
Presentation Overview





-  Understanding the AM process
-  Design approaches & tools
-  Print preparation
-  Examples

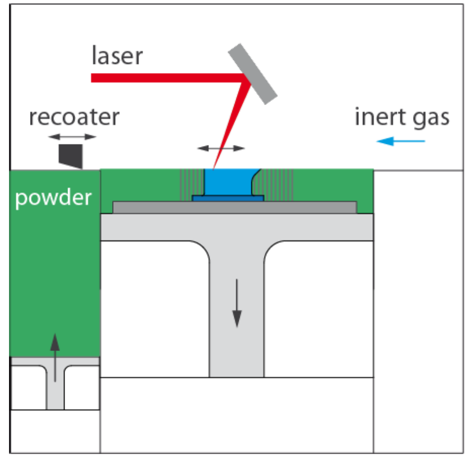
Selective Laser Melting (SLM)



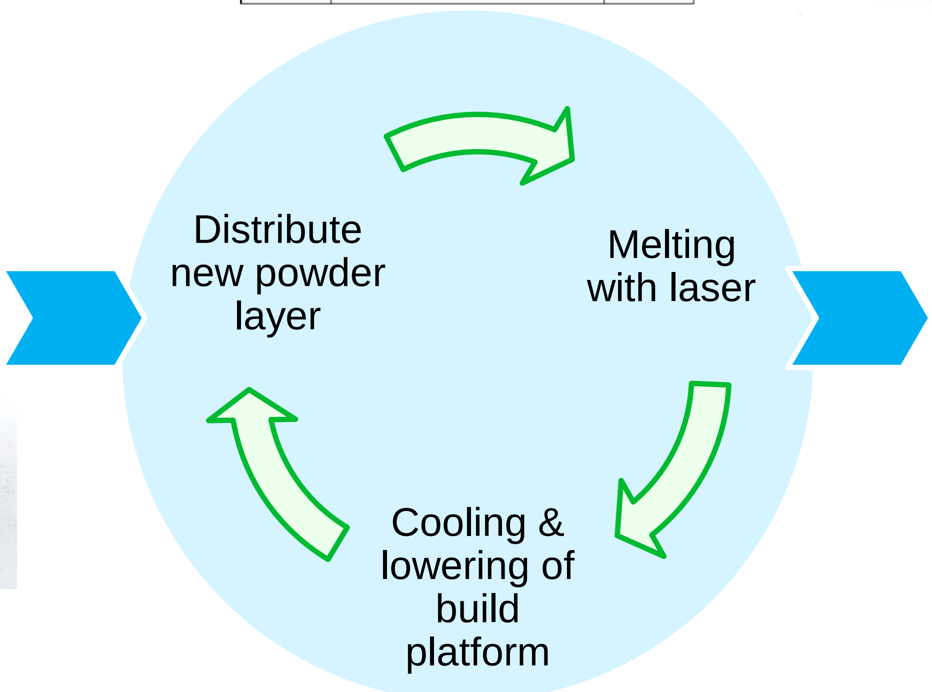
Sliced 3D CAD Model

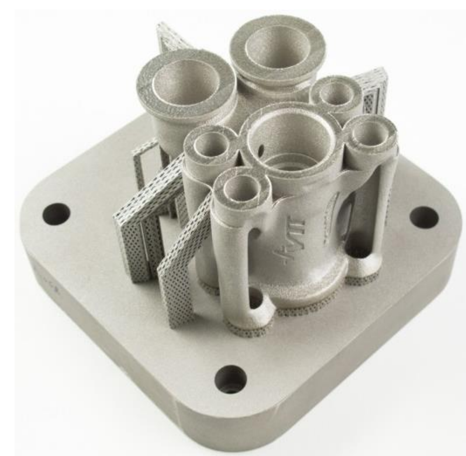
Metal Powder

Image from http://www.lpwtechnology.com/



SLM 125
- Powder bed fusion technology
- Maximum build size: 125x125x125 mm
- Materials: stainless steels, tool steels, Inconel, cobalt-chromium, aluminum, titanium, etc.

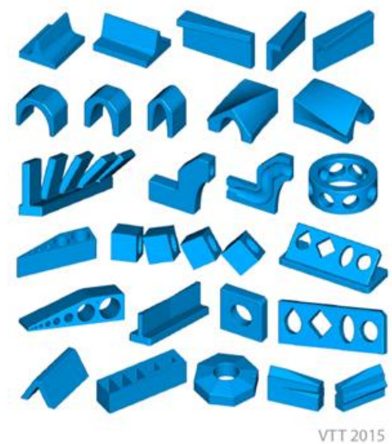




SLM Manufacturability Tests & Design Guidelines

- Series of test geometries created for assessment of AM limitations for creation of design guidelines
- Minimum limit values
  - Self-supporting
  - Features (e.g. fillet radius, hole size, wall thickness, etc.)
- Dimensional accuracy
- Material quality (e.g. defects & microstructure) & effect on fatigue strength
- Mechanical properties
- Considered several materials; optimized process parameters
- Reported in P. Kokkonen, et al., “Design guide for additive manufacturing of metal components by SLM process,” VTT-R-03160-16, Espoo, 2016.

Design of test geometries



SLM printing

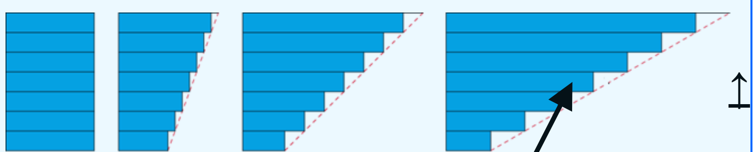
Evaluation of test prints

Limitations Important to Component Design

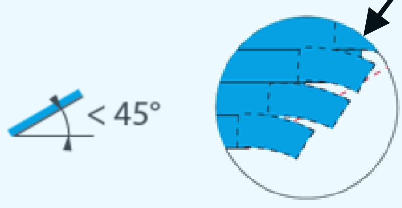
From report: P. Kokkonen, et al., “Design guide for additive manufacturing of metal components by SLM process,” VTT-R-03160-16, Espoo, 2016.

- Self-supporting build angle: 45° is good rule of thumb in SLM design, lower angles possible in controlled cases

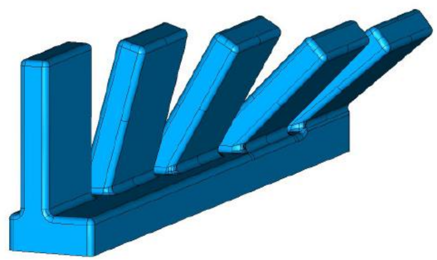
Decreasing angle between surface & build platform increases the area of unsupported material on the next layer

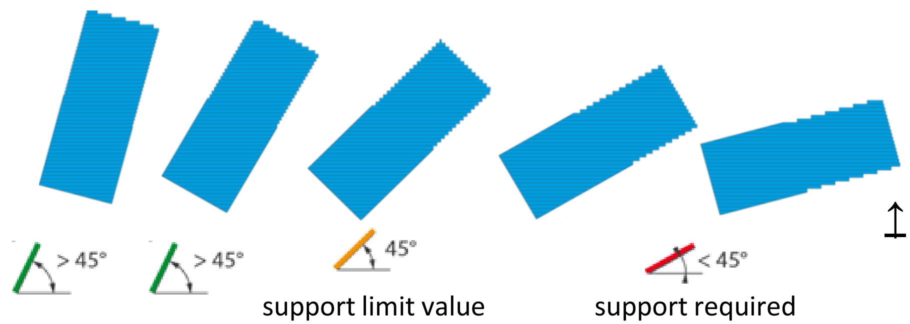


if previous layer does not provide enough support…



…melt pool begins to sink partly into the powder bed
(layers may curve upwards or downwards)





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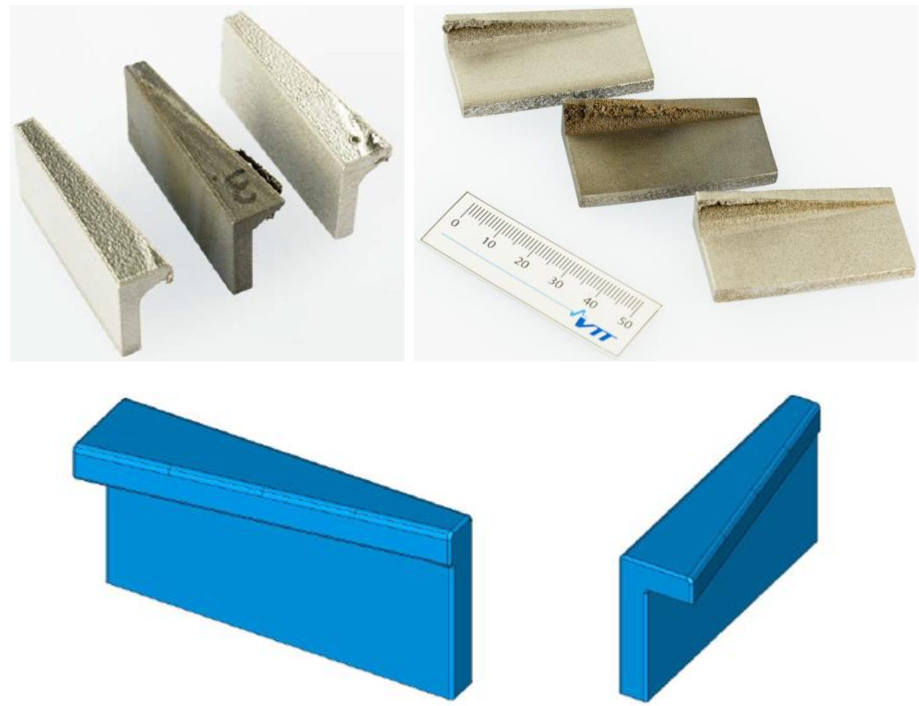
- Self-supporting build angle: 45° is good rule of thumb in SLM design, lower angles possible in controlled cases
- Overhangs: maximum unsupported overhang is a few mm, large overhangs lead to recoater wiper failure; fillets help
- Wall thickness: minimum wall thickness of 0.15 mm achievable, but slightly irregular
- Self-supporting holes: round holes up to Ø25mm, tear drop, diamond or oval for larger diameters; dross at top of hole
- Internal channels: avoid small holes for long channels, slight dross formation at top of cross-section; abrasive flow machining for dross removal and finishing of inner surfaces



Overhang with varying length

Limitations Important to Component Design

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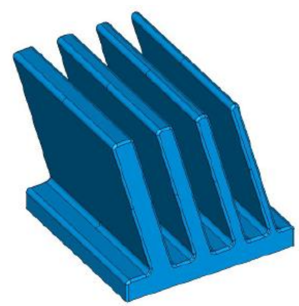
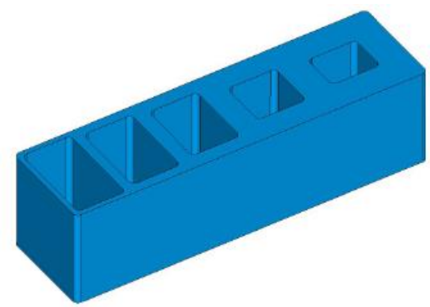


Slightly inclined plates (75°) of varying thickness (5, 4, 3, 2 mm)



Rectangular holes with varying wall thickness

Limitations Important to Component Design

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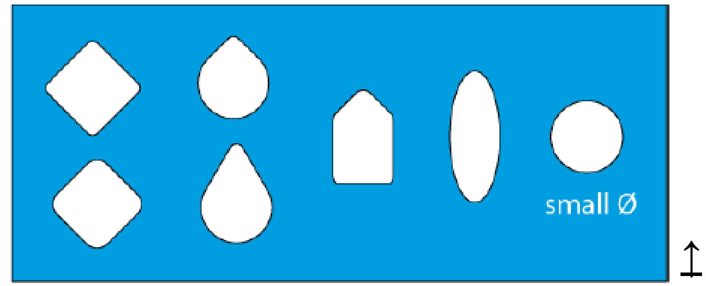
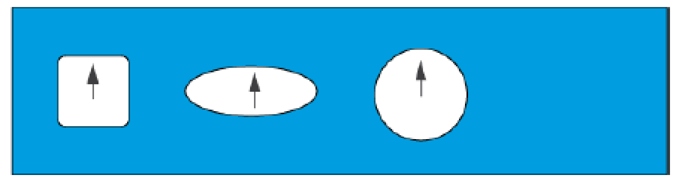
-



Self-supporting cross section for holes & channels



Holes requiring support during printing

Limitations Important to Component Design

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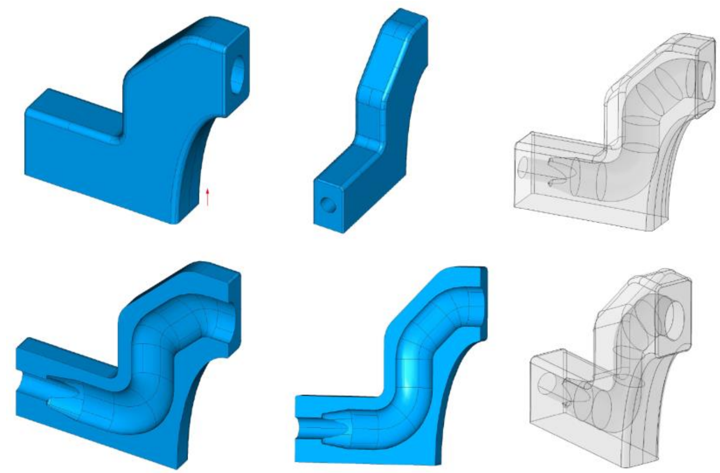

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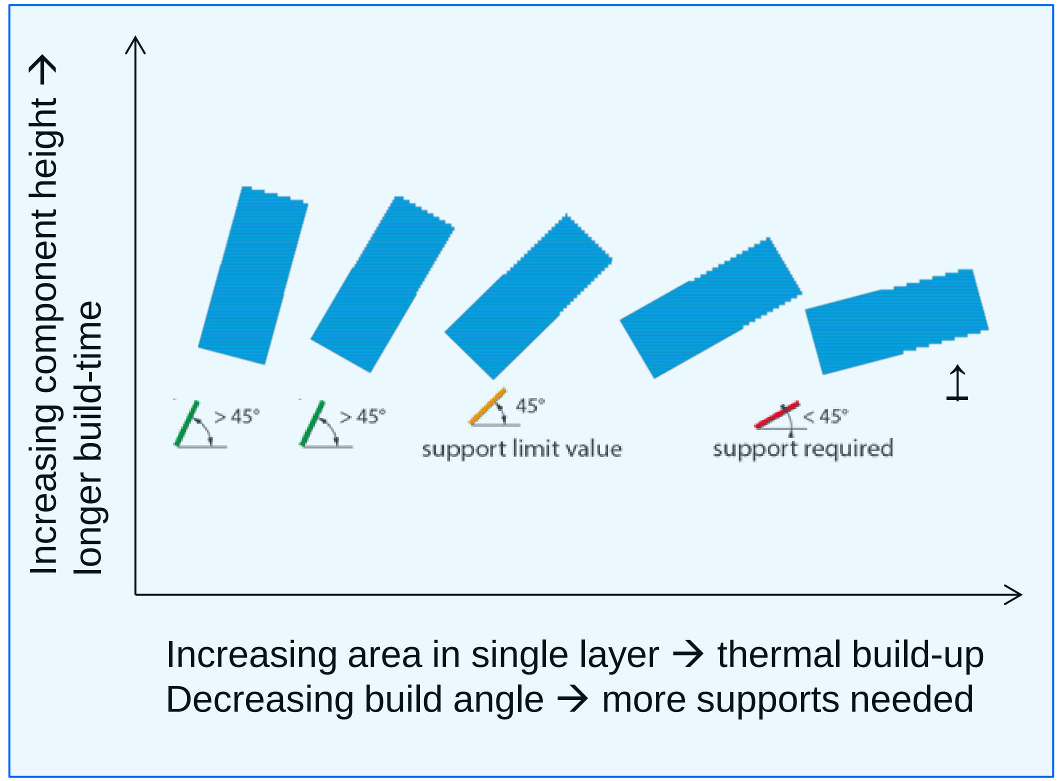
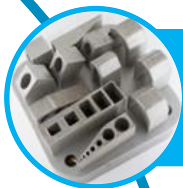
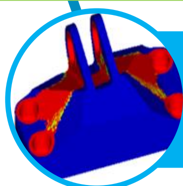
Effect of Layered Manufacturing Process on Print Preparation

- Component orientation on build platform affects:
  - Manufacturing cost (print time)
  - Post-processing costs (support removal)
  - Thermal build-up (large lasered region in single layer) → distortion, residual stresses
  - Printability of certain features (e.g. internal channels)
  - Surface quality

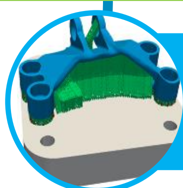




Understanding the AM process



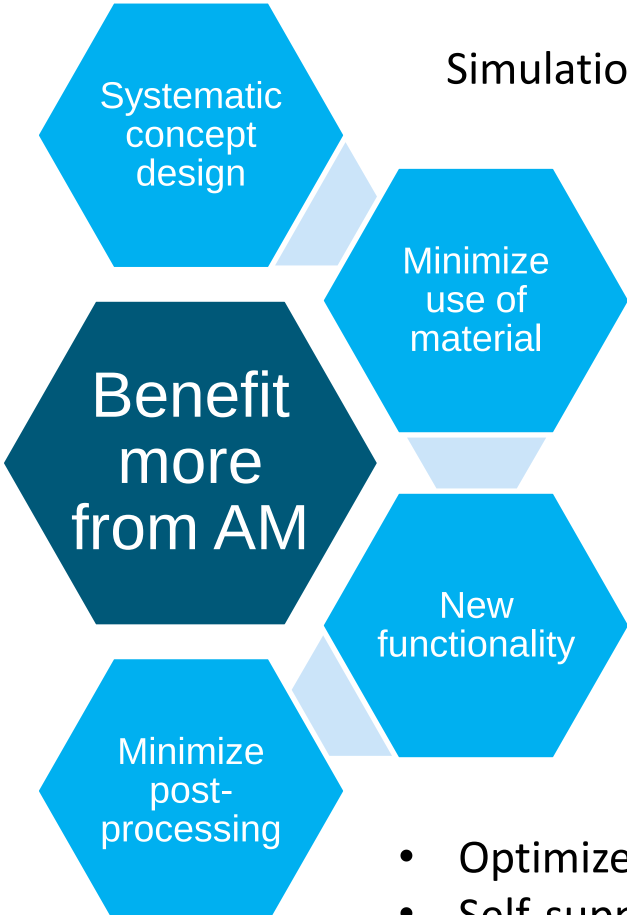
Design approaches & tools



Print preparation

Examples

Design Approach



Simulation based design

Optimize: topology, shape, size

Take advantage of geometric freedom

- Lattice structures
- Internal channels
- Internal cavities
- Part consolidation

- Optimize print orientation
- Self-supporting shapes

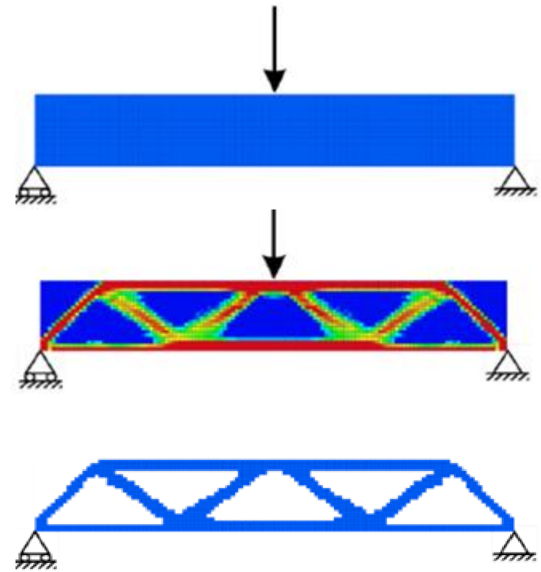
Properties of a successful AM product

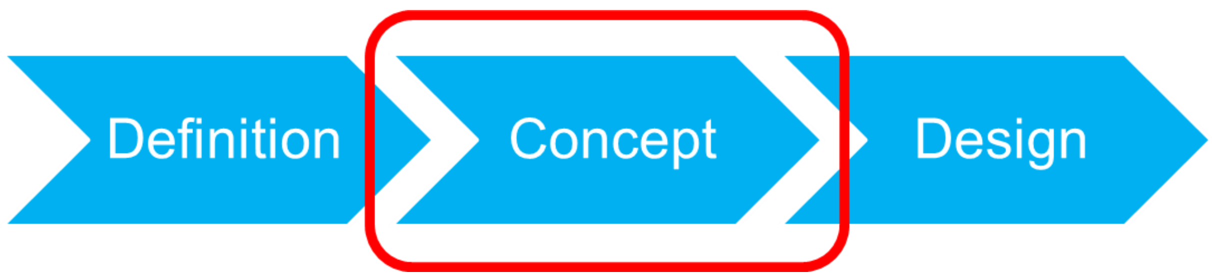
- New functionality
- Lightweight, compact
- Short build time
- Single consolidated part
- No assembly needed
- Minimal machining & finishing

Design Tool: Topology Optimization

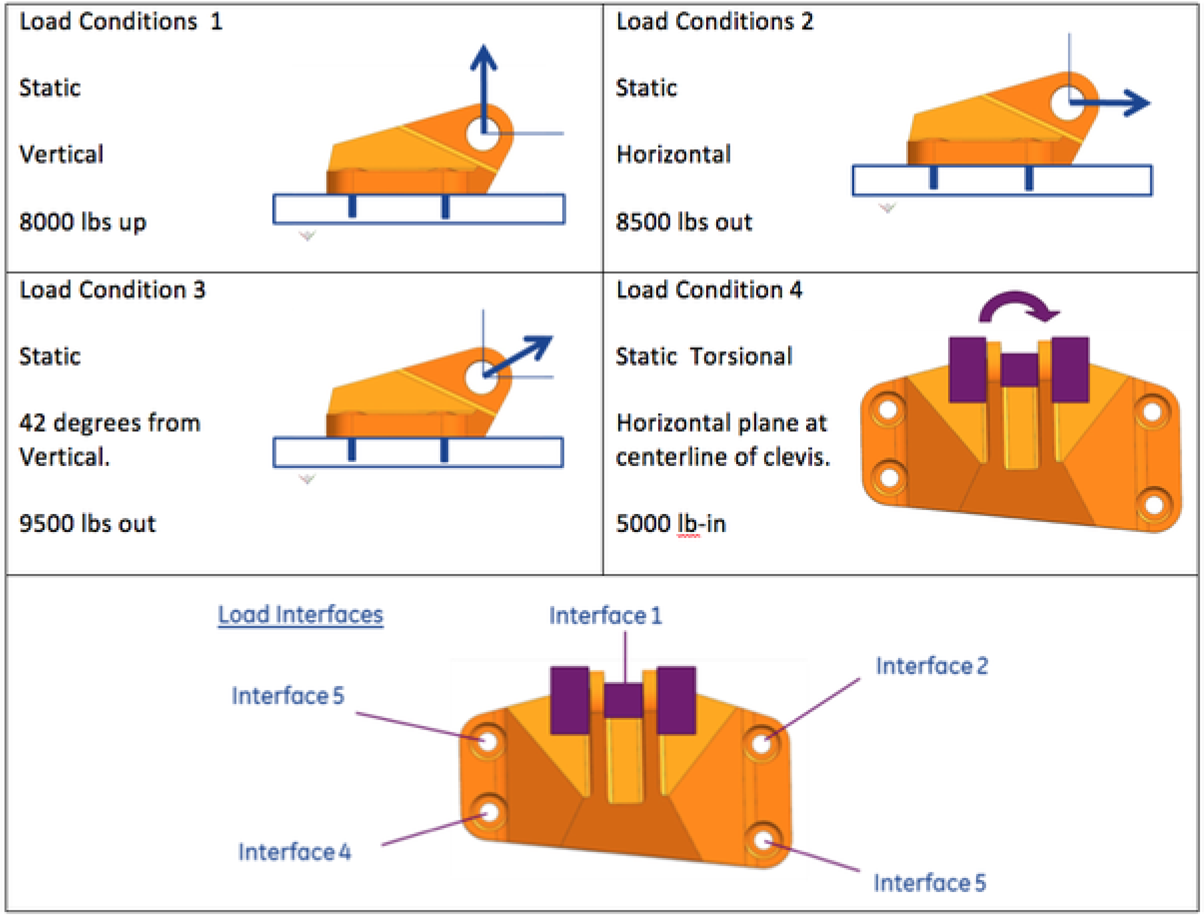
- Topology optimization is a process of finding the **optimal distribution of material and voids** in a given design space, dependent on loading and boundary conditions, such that the resulting structure meets prescribed performance targets

- Well-suited for early development stages
- Can produce design proposals or “ideas” about how a design within a given space might look
- Only need to define design space, loads and boundary conditions $\Rightarrow$ no need for detailed or parameterized CAD geometry models
- Not a tool for fine-tuning

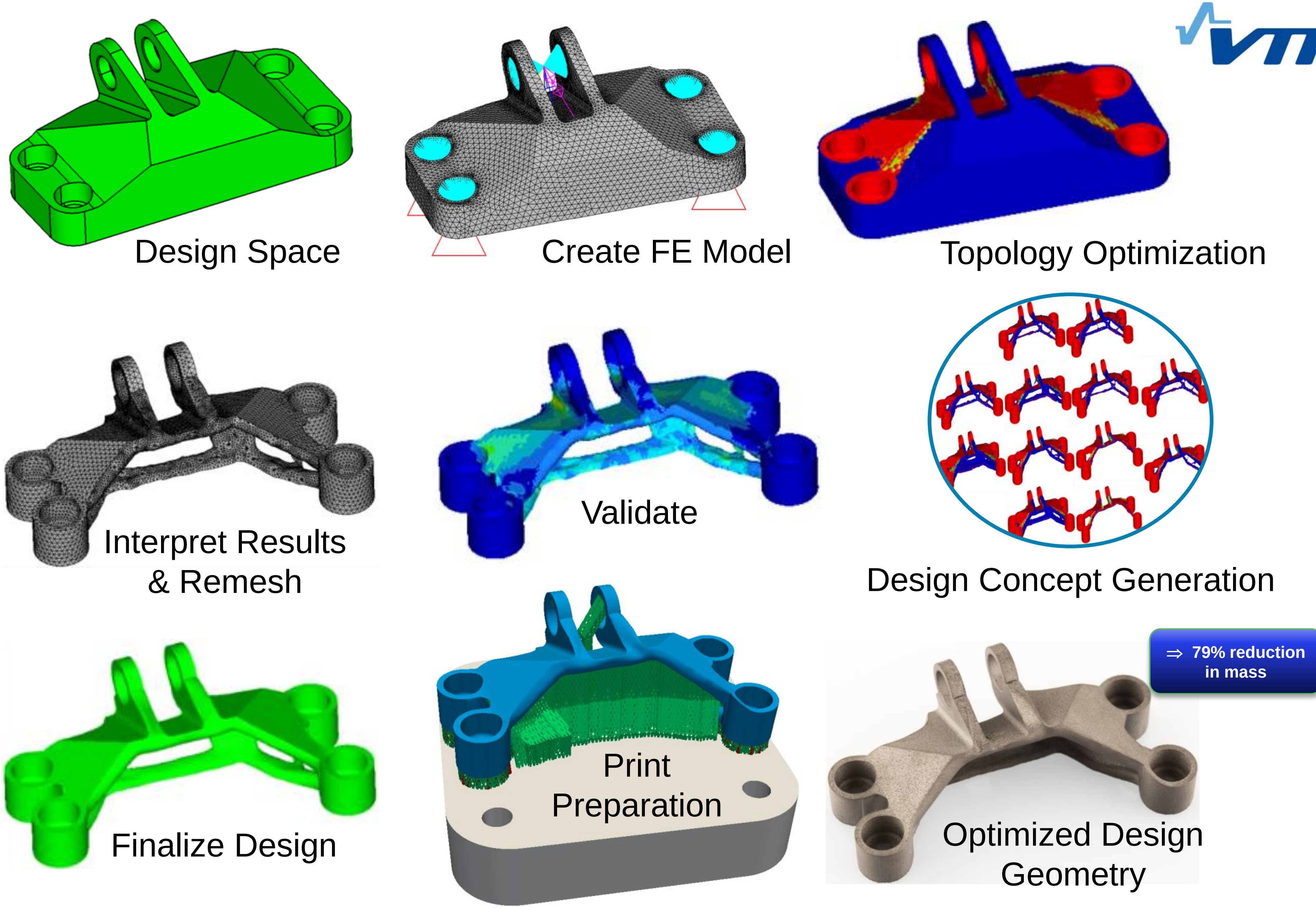


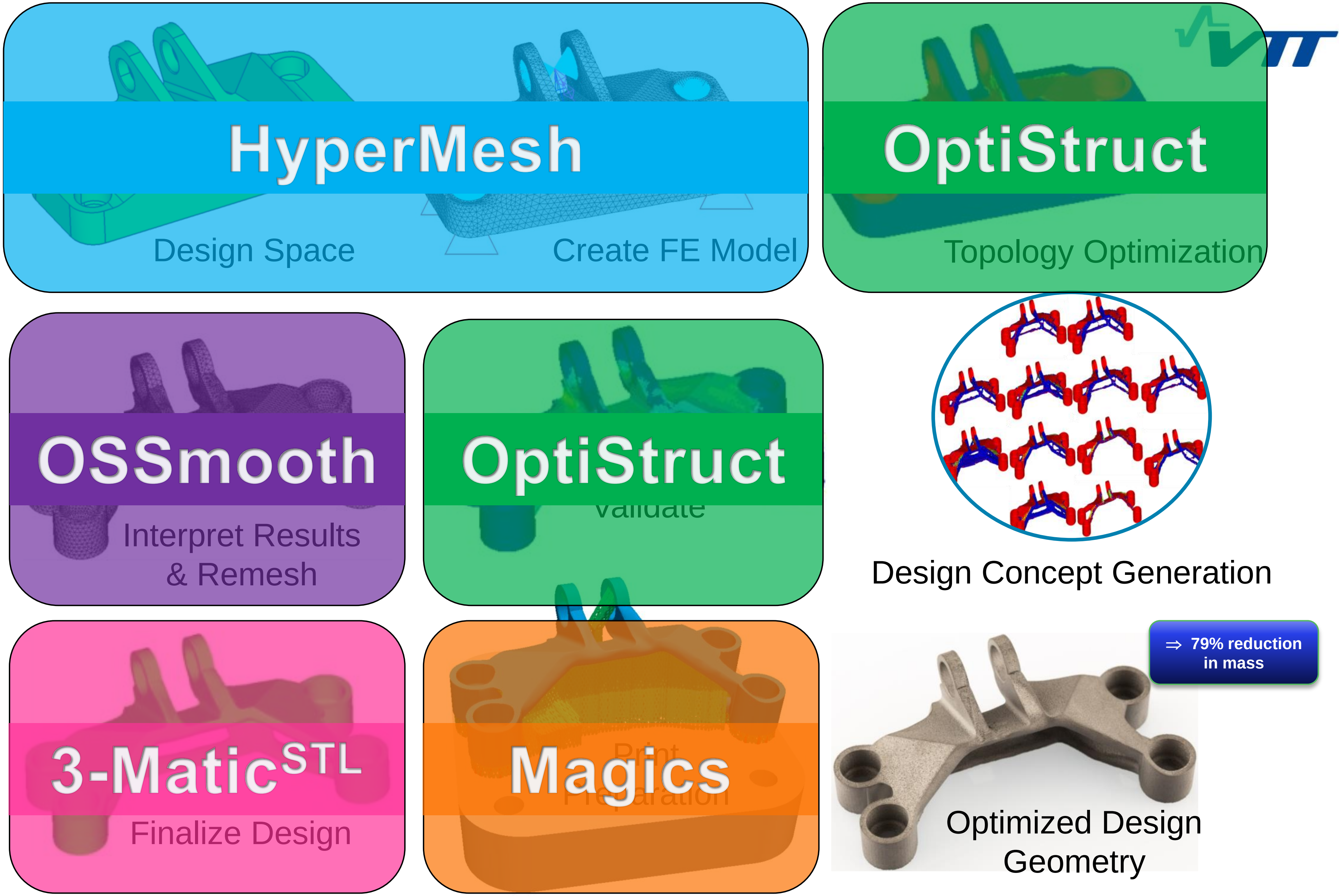


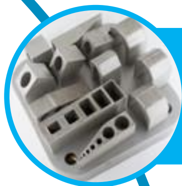
Example: GE Jet Engine Bracket



http://grabcad.com/challenges/ge-jet-engine-bracket-challenge


Design Space
Create FE Model
Topology Optimization
Interpret Results & Remesh
Validate
Design Concept Generation
Finalize Design
Print Preparation
Optimized Design Geometry
⇒ 79% reduction in mass


HyperMesh
Design Space
Create FE Model
OptiStruct
Topology Optimization
OSSmooth
Interpret Results
& Remesh
OptiStruct
Design Concept Generation
3-Matic^{STL}
Finalize Design
Magics
⇒ 79% reduction in mass
Optimized Design Geometry



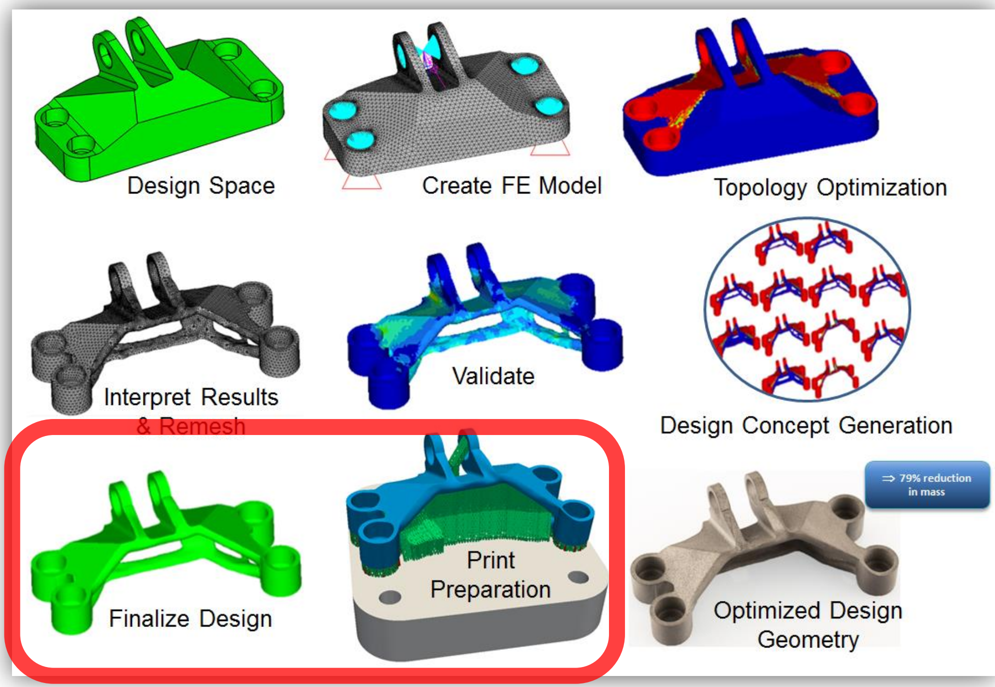
Understanding the AM process

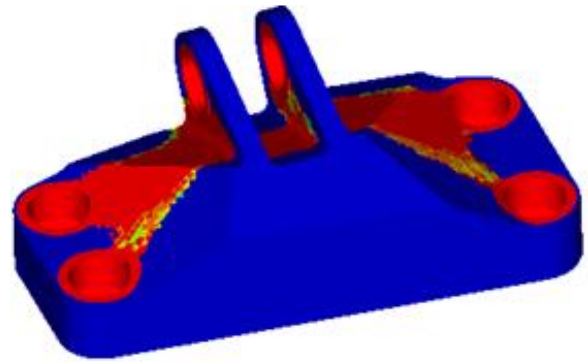
Design approaches & tools

Print preparation

Examples

Preparing Design for Printing



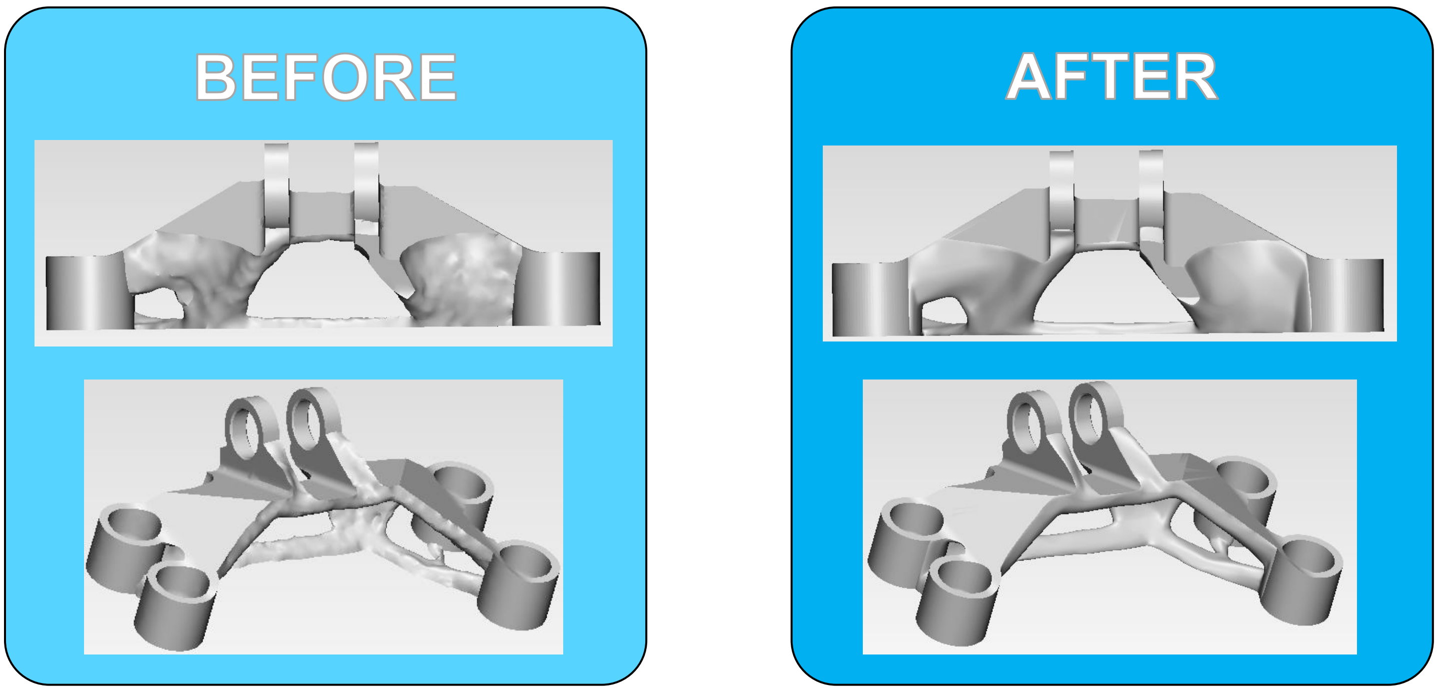


Topology Optimization Result

Final Printed Design

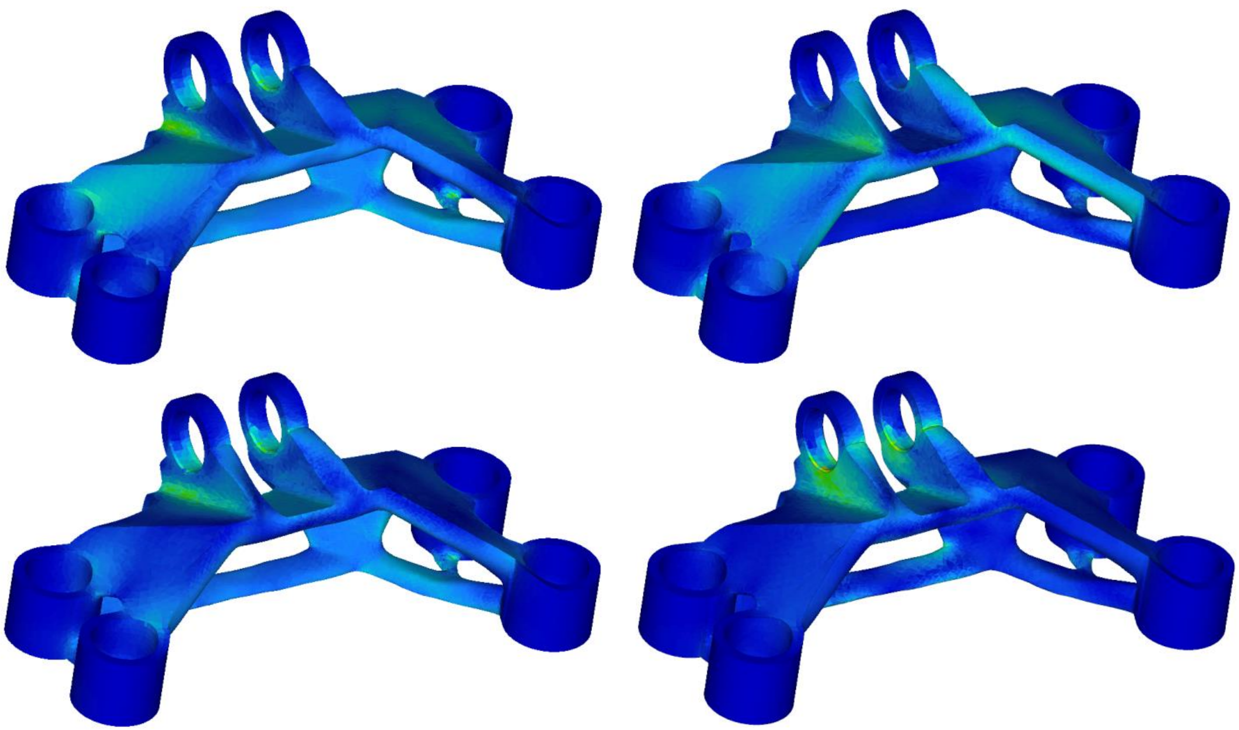
Step 1: Finalize Promising Design(s)

- Tools used: 3-matic^{stl}, solidThinking Inspire
- Functions: smoothing, and interpreting organic shapes from optimization results to produce stl or CAD geometries



Step 2: Validation

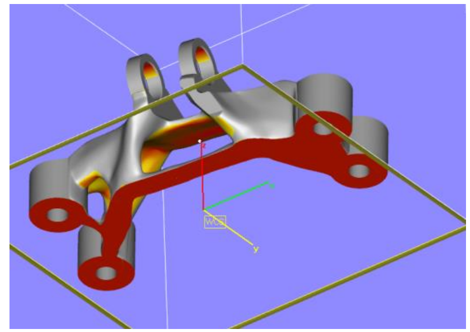
- Tool used: OptiStruct
- Purpose: ensure that final component meets all design criteria



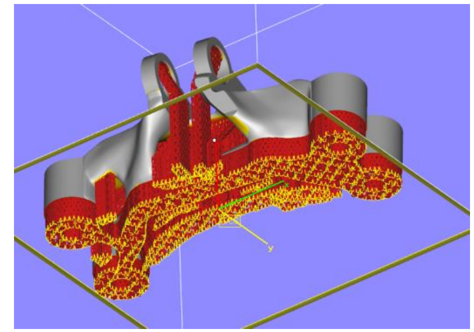
Step 3: Prepare for Printing

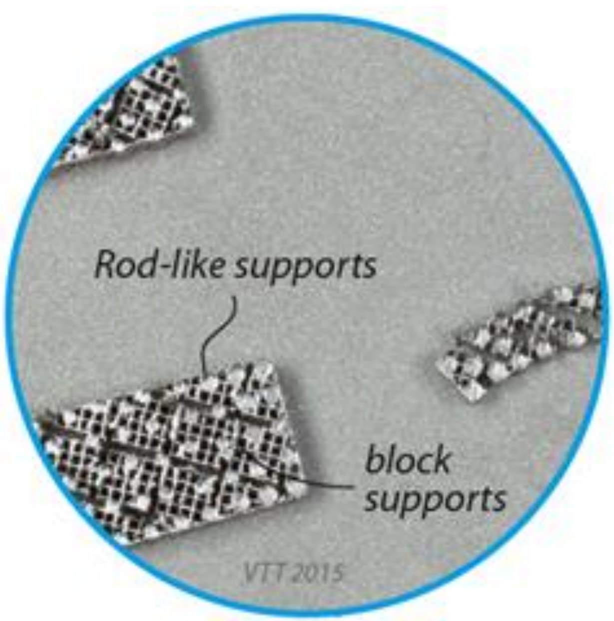
- Tool used: Magics
- Functions: position component on print platform, support generation, slicing, print-time estimation, etc.

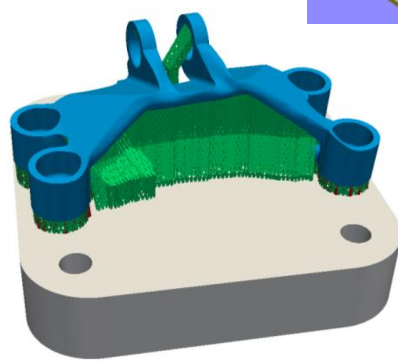
Supported area preview



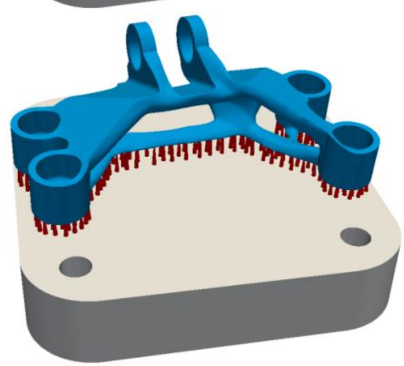
Automatic support generation







Block supports on downward facing surfaces for manufacturability, heat conduction, and attachment. Include teeth-shaped connections on part surface for easy removal



Cone (rod-like) supports for attachment and to prevent deformation by allowing heat transfer

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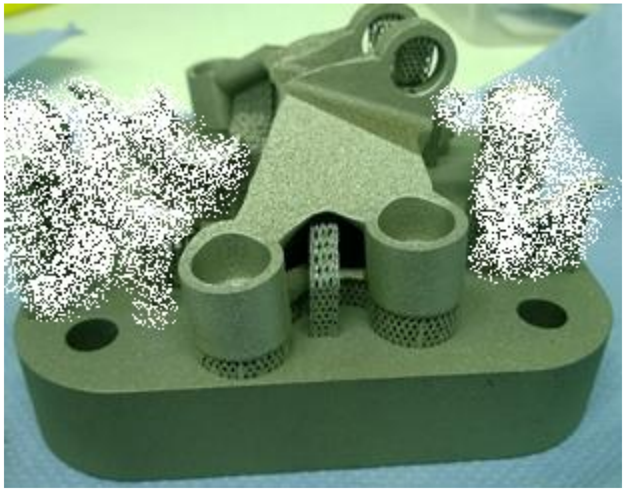
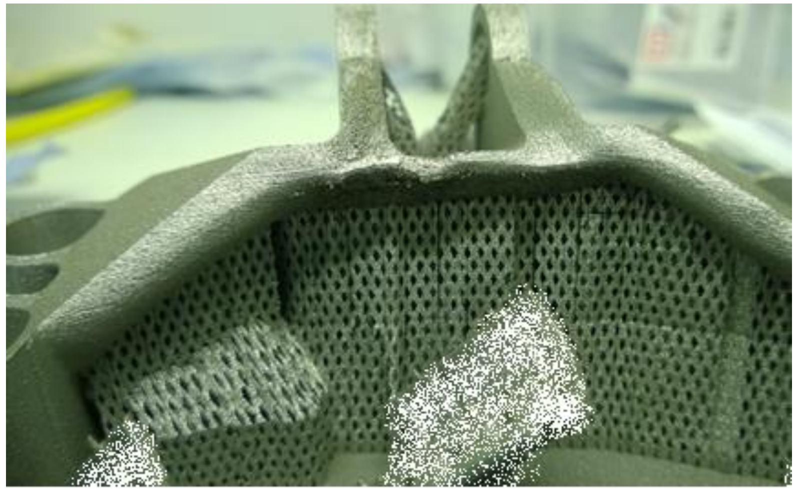
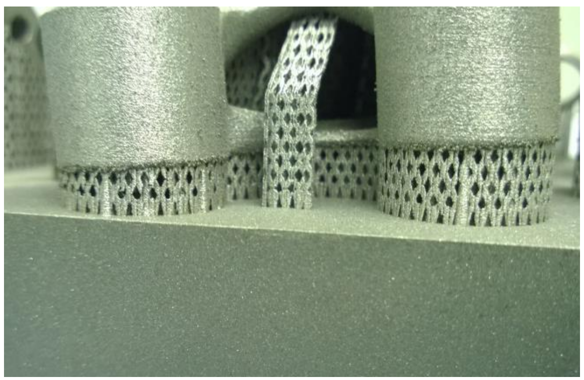
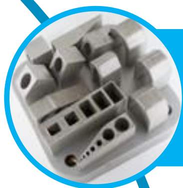
Printed Component





Understanding the AM process

Design approaches & tools

Print preparation

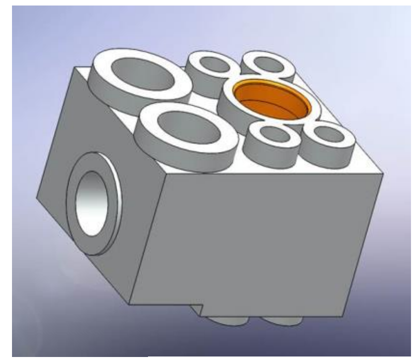
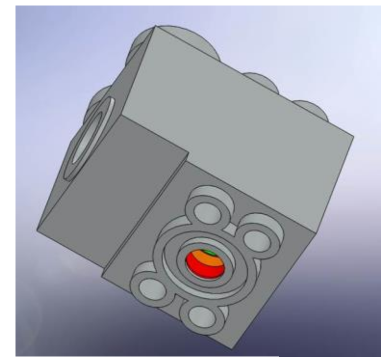
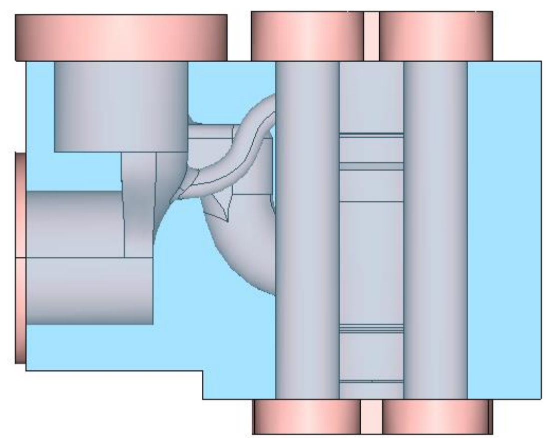
Examples

In cooperation with:

CHALLENGE

- **Redesign a hydraulic valve block to take full advantage of the benefits of additive manufacturing**
  - Produce small, tailor-made series to suit customer’s needs
  - Improve shape of internal channels for optimal flow
  - Eliminate need for auxiliary drillings – reduced potential for leaks
  - Reduce size and weight



Initial design space provided by Nurmi Cylinders Oy

SOLUTION

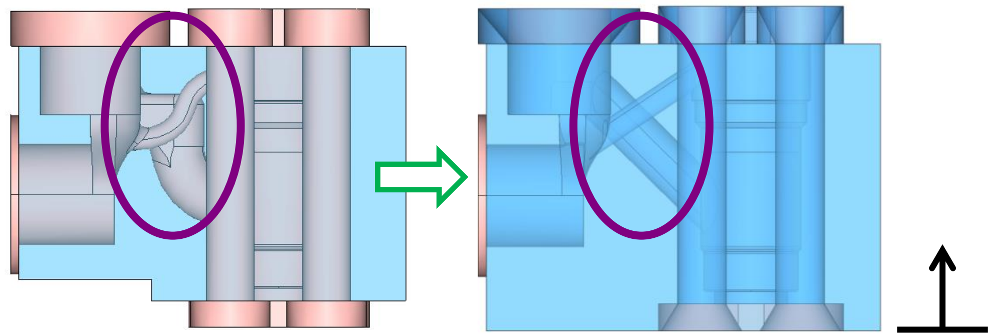
In cooperation with: NURMI®

- Understanding the AM process
- Design approach & tools
- Print preparation

Modify design space for printability

Initial Design Space

Final Design Space



- Original channel design requires supports → difficult or impossible to remove
- Solution: Internal channels are now straight (~45° to base plate) with elliptical cross section

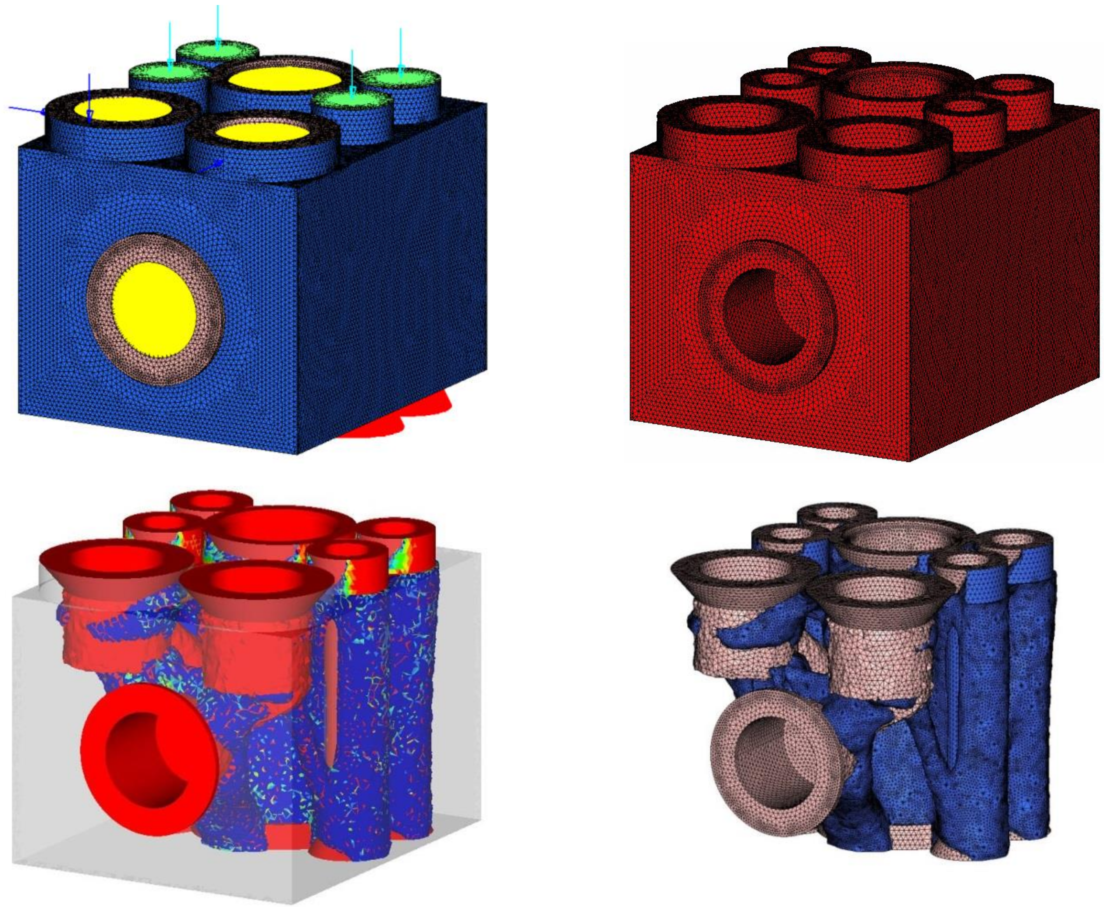
SOLUTION

In cooperation with: NURMI®

Understanding the AM process

Design approach & tools

Print preparation



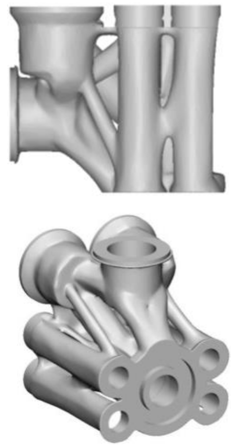
SOLUTION

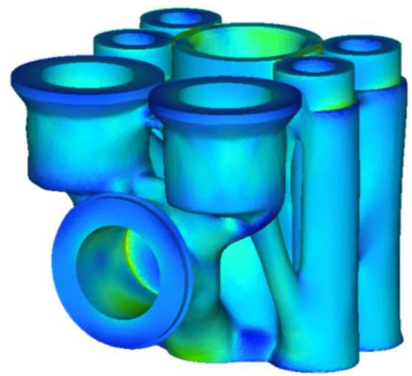
In cooperation with:

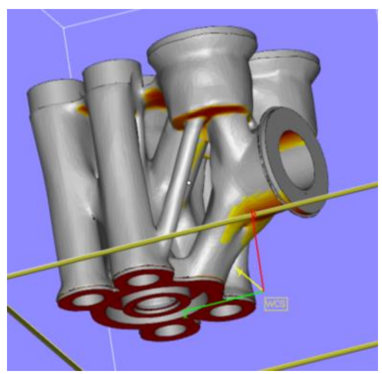
Understanding the AM process

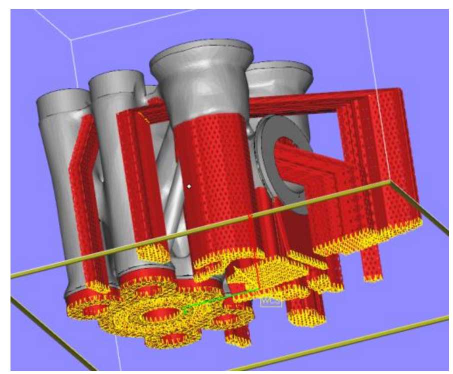
Design approach & tools

Print preparation









RESULT

In cooperation with:

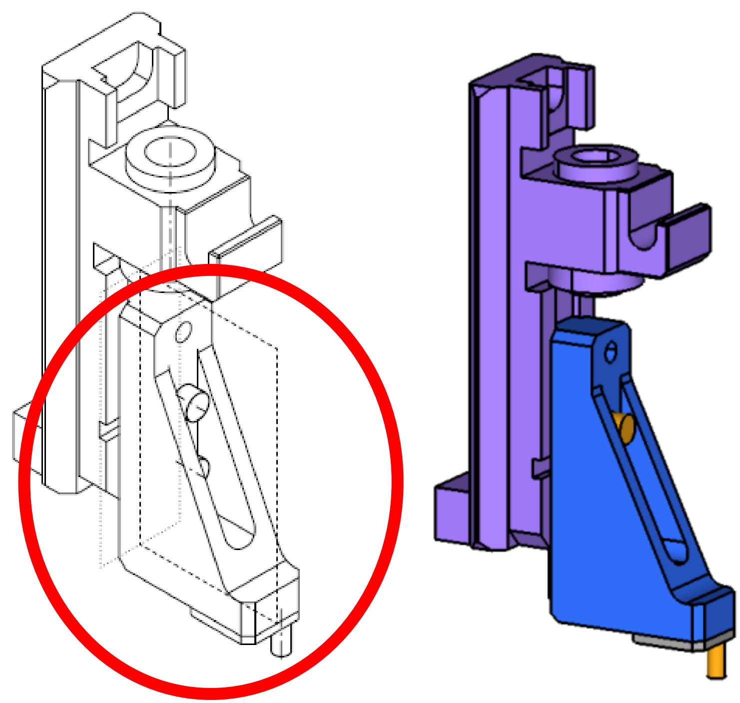
- **76% reduction in mass** → money saved by reduction in necessary metal powder and print time
- No need for auxiliary drillings → **less chance of leaks**
- **Improved flow** due to smooth transitions between internal channels

Welding Head Bracket

In cooperation with:
meconet

CHALLENGE

- Redesign welding head bracket on a multi-center machine for manufacture by SLM
- Goal – minimize component mass



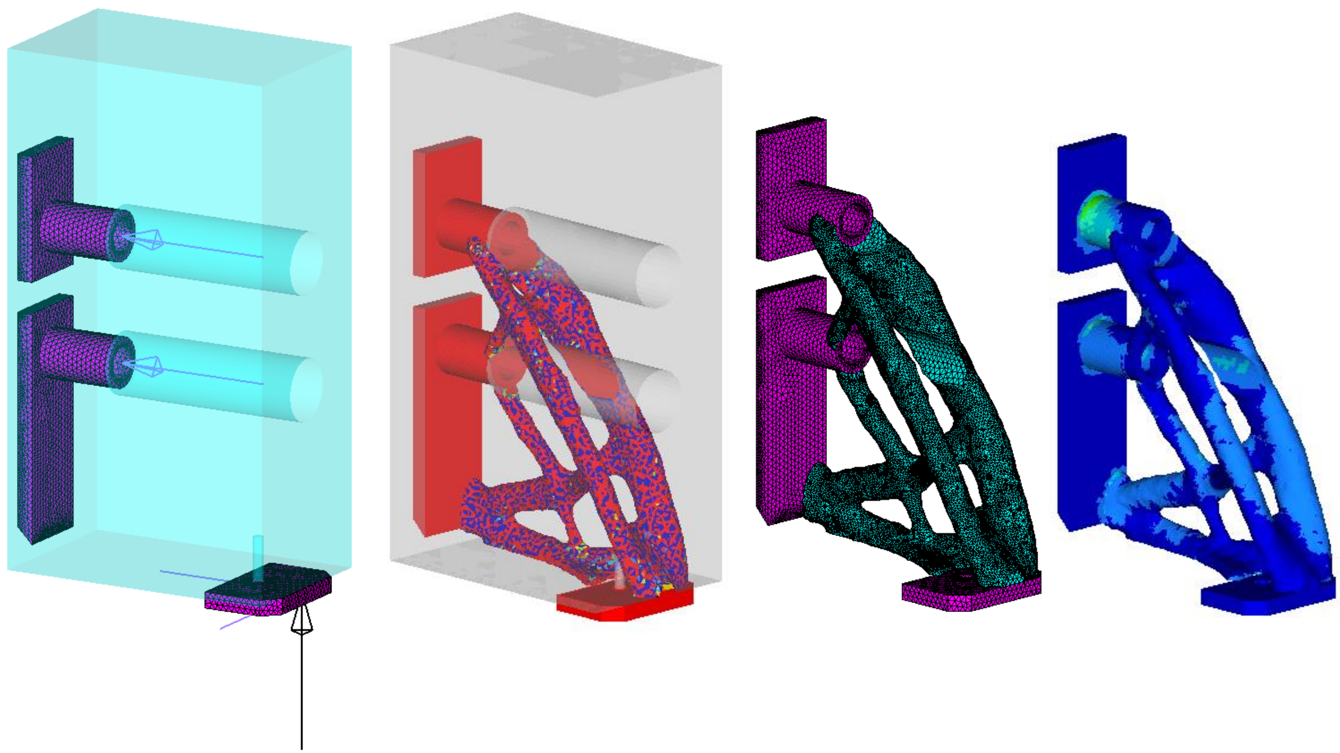
SOLUTION

In cooperation with:
meconet

Understanding the AM process

Design approach & tools

Print preparation



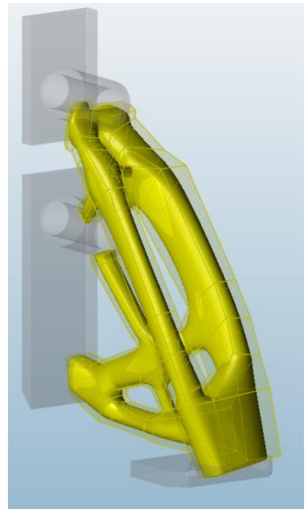
SOLUTION

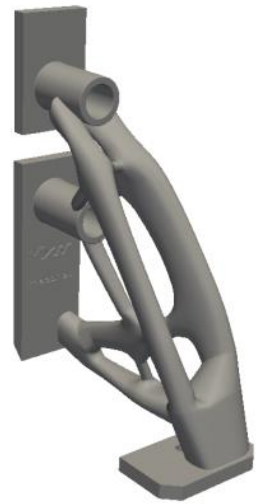
In cooperation with: meconet

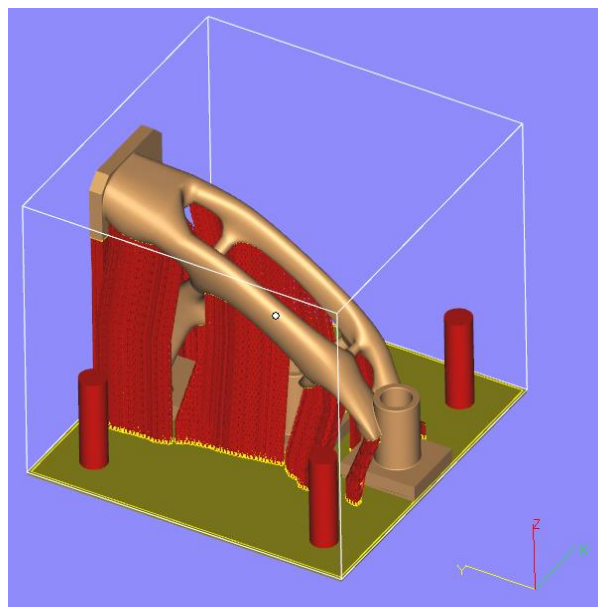
Understanding the AM process

Design approach & tools

Print preparation







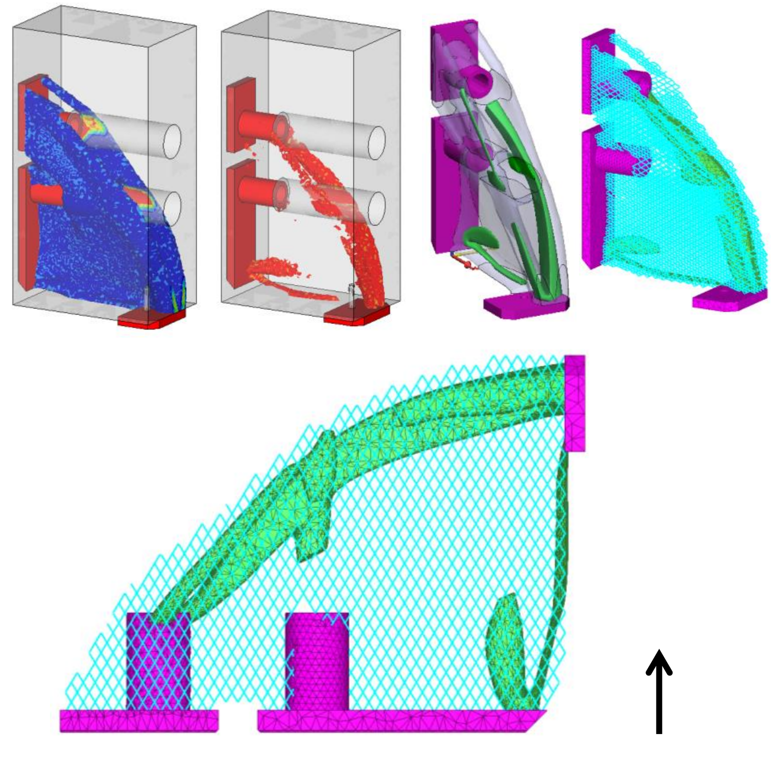
RESULT

In cooperation with:

86% reduction in mass = energy and money savings during operation

Ongoing Work at VTT

- Investigation of ways to simplify and reduce costs of post-processing procedures

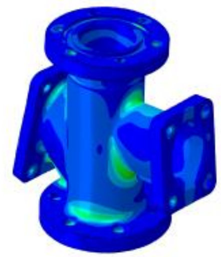


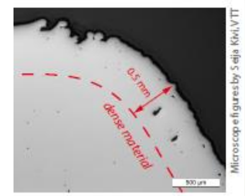
In cooperation with:

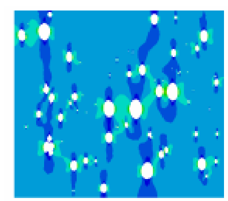
meconet Materialise innovators you can count on

Ongoing Work at VTT

- Investigation of ways to simplify and reduce costs of post-processing procedures
- Prediction and identification of defects → defect tolerant design concept







In cooperation with:

geonX


TECHNOLOGY FOR BUSINESS