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UNIVERSITY OF OULU
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FUTURE MANUFACTURING TECHNOLOGIES
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Design for Metal Additive Manufacturing

24.11.2021 Kari Mäntyjärvi

ARCTIC PLATFORM

▶ PRINT YOUR IDEAS IN METAL

I2P IDEA TO PRINT

PROJECT «FROM IDEA TO PRINTING OF METAL PRODUCTS»

ARCTIC PLATFORM FOR METAL ADDITIVE MANUFACTURING

PROJECT INFORMATION, REPORTS, EVENTS, NETWORK MEMBERS AND SAMPLES OF METAL 3D-PRINTING **CAN BE FOUND ON OUR SITE**: **i2metprint.com**

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From Idea to Printing of Metal Products
I2P – Project

Project ID: KO4012


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Contents:

1. ”No AM method is an island”
2. DFAM – 90 second walkthrough
3. Design for PBF-LB/M 120 second walkthrough
4. Design for metal AM (DED)
5. Conclusions

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”No AM method is an island”

*) A variation on John Donne's famous phrase 'No man is an island'.

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"No AM method is an island"

- AM methods are one group of many manufacturing methods
- AM printed parts are always associated with a work steps includes different manufacturing techniques.
- Very rarely is an AM printed part ready for use straight from the printer.

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The rule of thumb

– If a part can be manufactured cost efficiently using a conventional manufacturing methods, it should probably not be produced using AM.
– Good parts for AM tend to have:
- complex geometries,
- custom geometries,
- low production volumes,
- special combinations of properties or characteristics,
- or some combination of these characteristics.

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The most common and mature metal AM methods

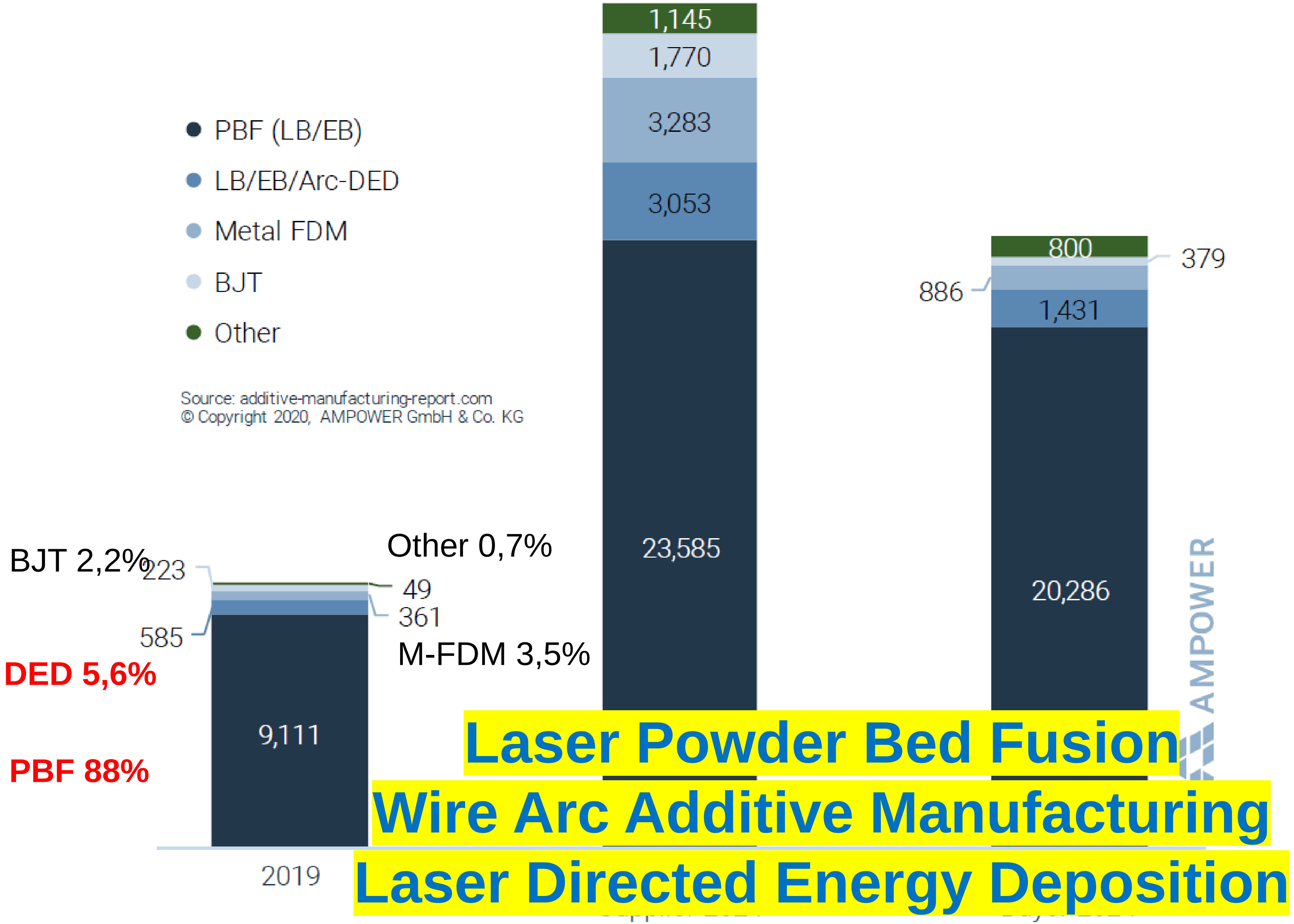

FIGURE 24 INSTALLED BASE BY TECHNOLOGY 2019 AND SUPPLIER VS. BUYER FORECAST 2024 [UNITS]

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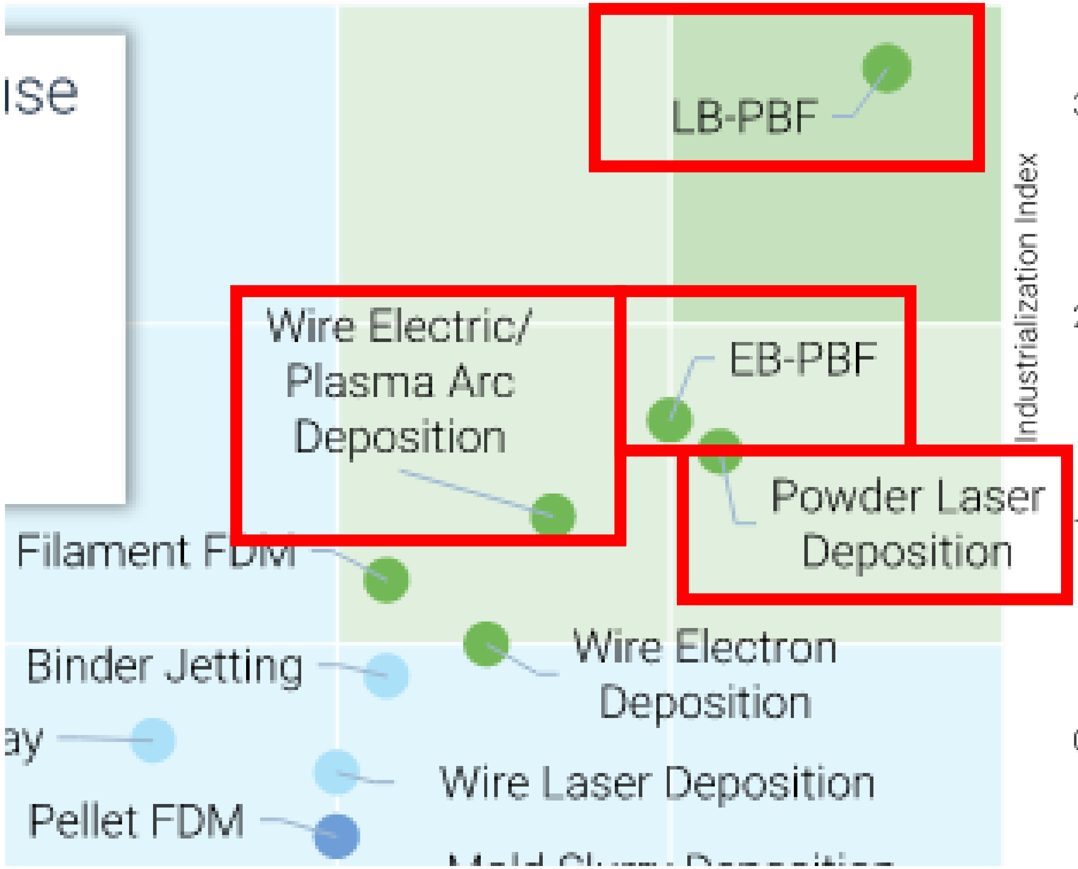
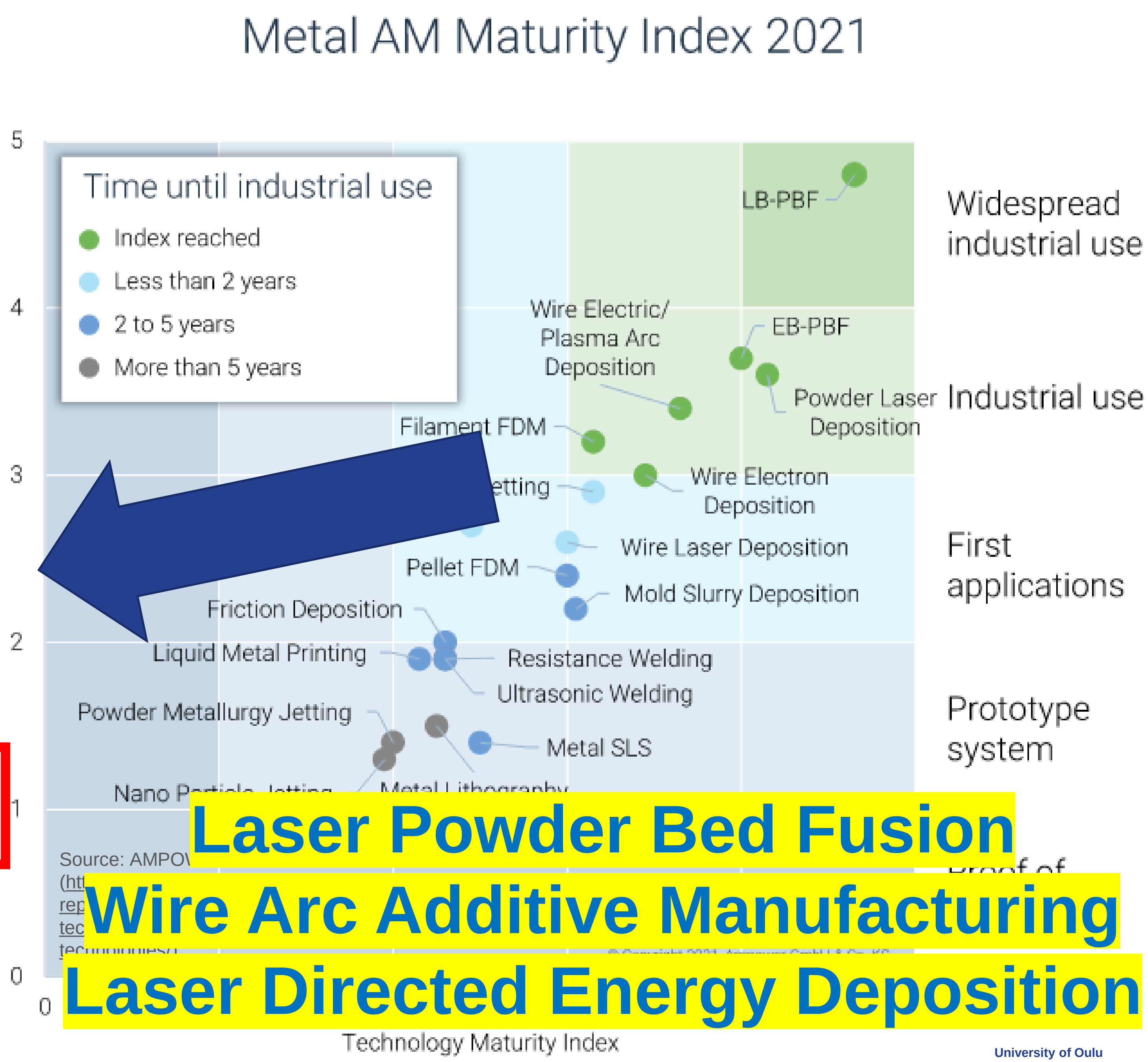
The most common and mature metal AM methods

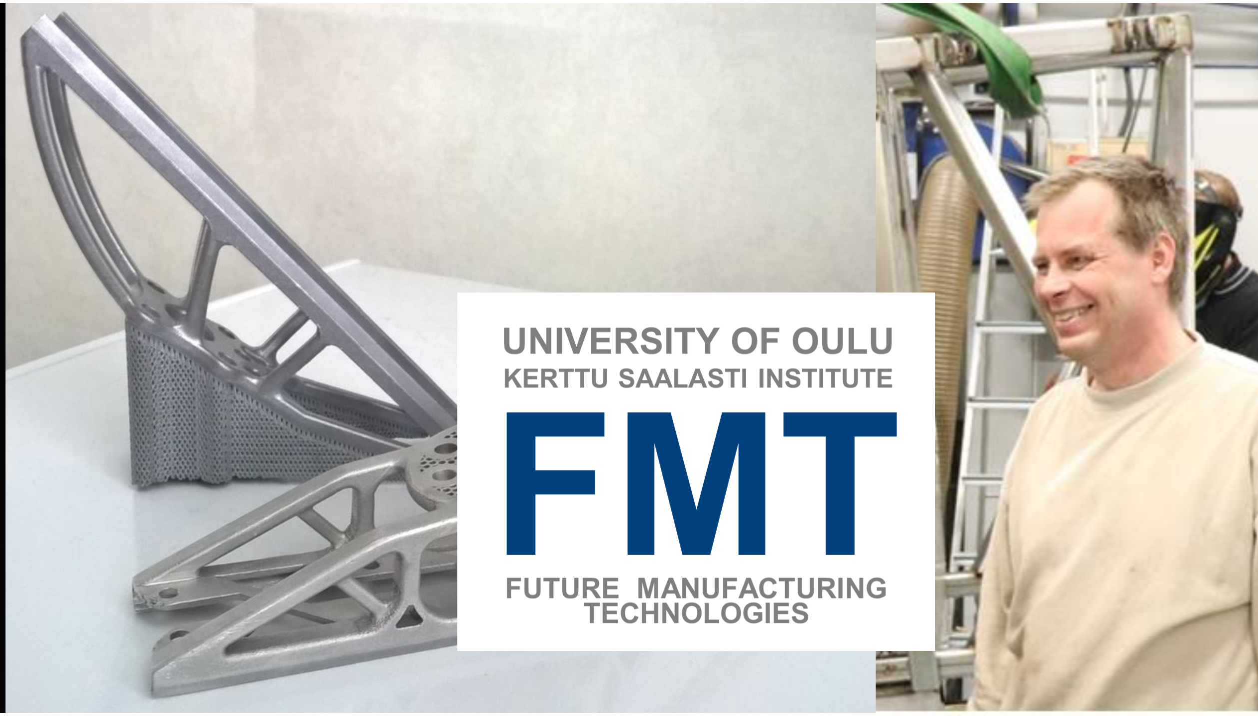




Laser Powder Bed Fusion

Wire Arc Additive Manufacturing

Laser Directed Energy Deposition



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SFS-EN ISO/ASTM 52910:2019

Additive manufacturing. Design. Requirements, guidelines and recommendations (ISO/ASTM 52910:2018)

Focus on the words in ***bold*** and ***italics***!

Design for Additive Manufacturing

90 second walkthrough!

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SFS-EN ISO/ASTM 52910:2019

Additive manufacturing. Design. Requirements, guidelines and recommendations (ISO/ASTM 52910:2018)

Here is a general AM design process that can be used by all AM methods.

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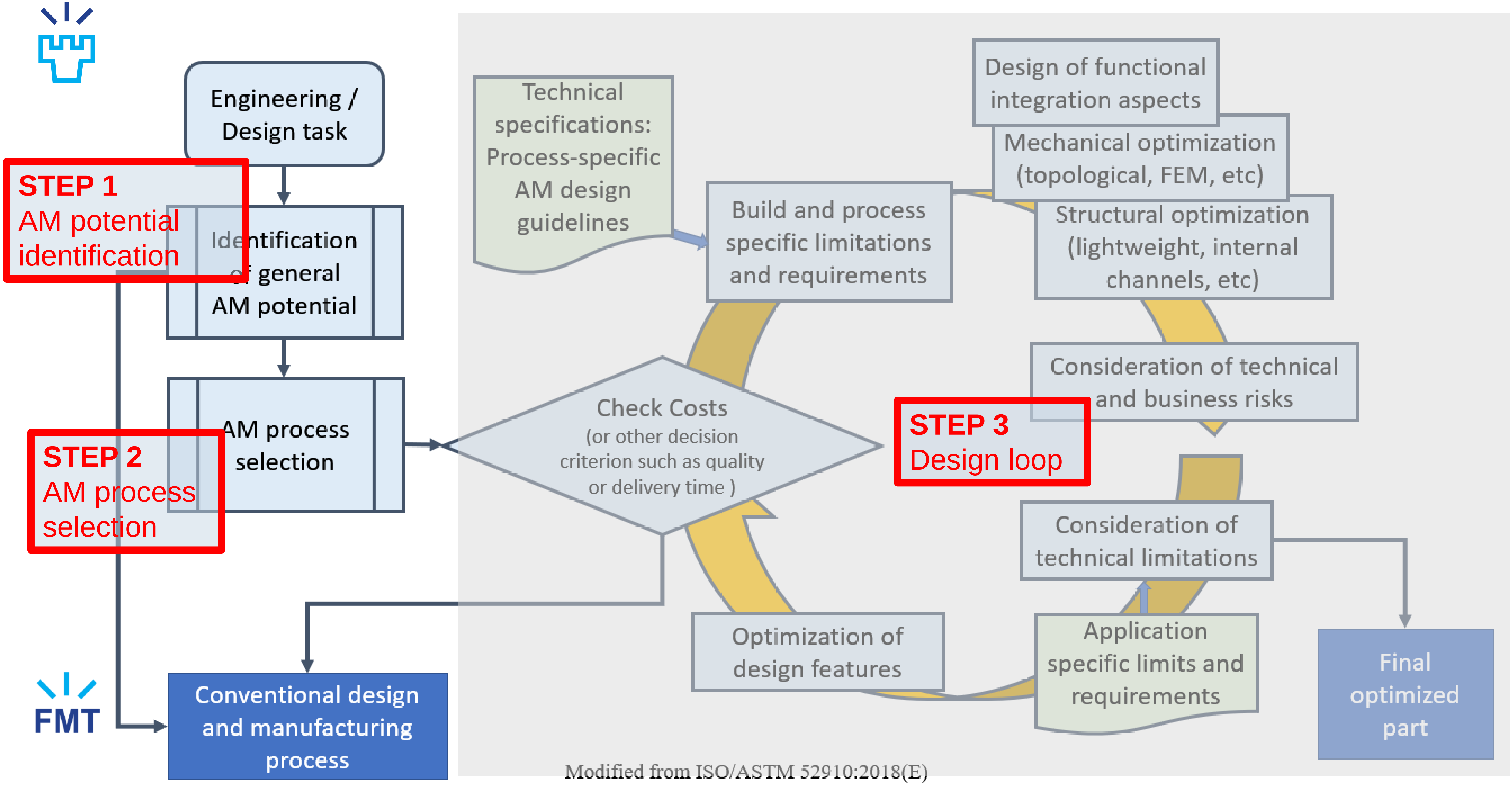
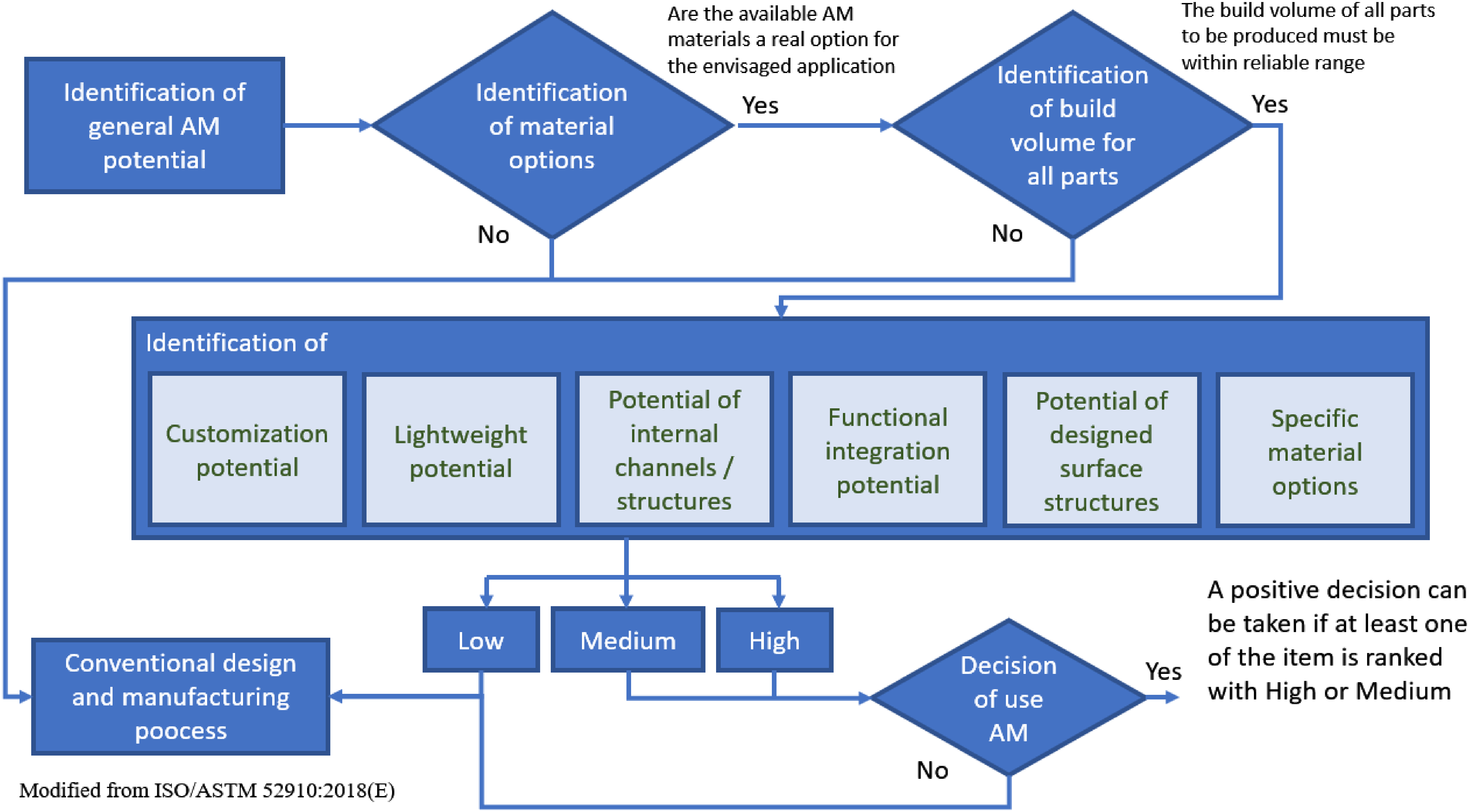


Modified from ISO/ASTM 52910:2018(E)

STEP 1 AM potential identification



Modified from ISO/ASTM 52910:2018(E)

STEP 2 AM process selection

AM Process selection → Material selection + Process selection

AISI 316L
AlSi10Mg
Etc.

PBF-LB
WAAM
DED-LB
Etc.

Technical specifications
System/sub system level
Component level

Application specific limitations

Main technical issues
Surface
- Roughness
- Staircase effect
Geometrical properties
- Geometrical accuracy
Static physical properties
- Porosity
- Tensile strength
- Ductility
Dynamic physical properties
- Life cycle fatigue

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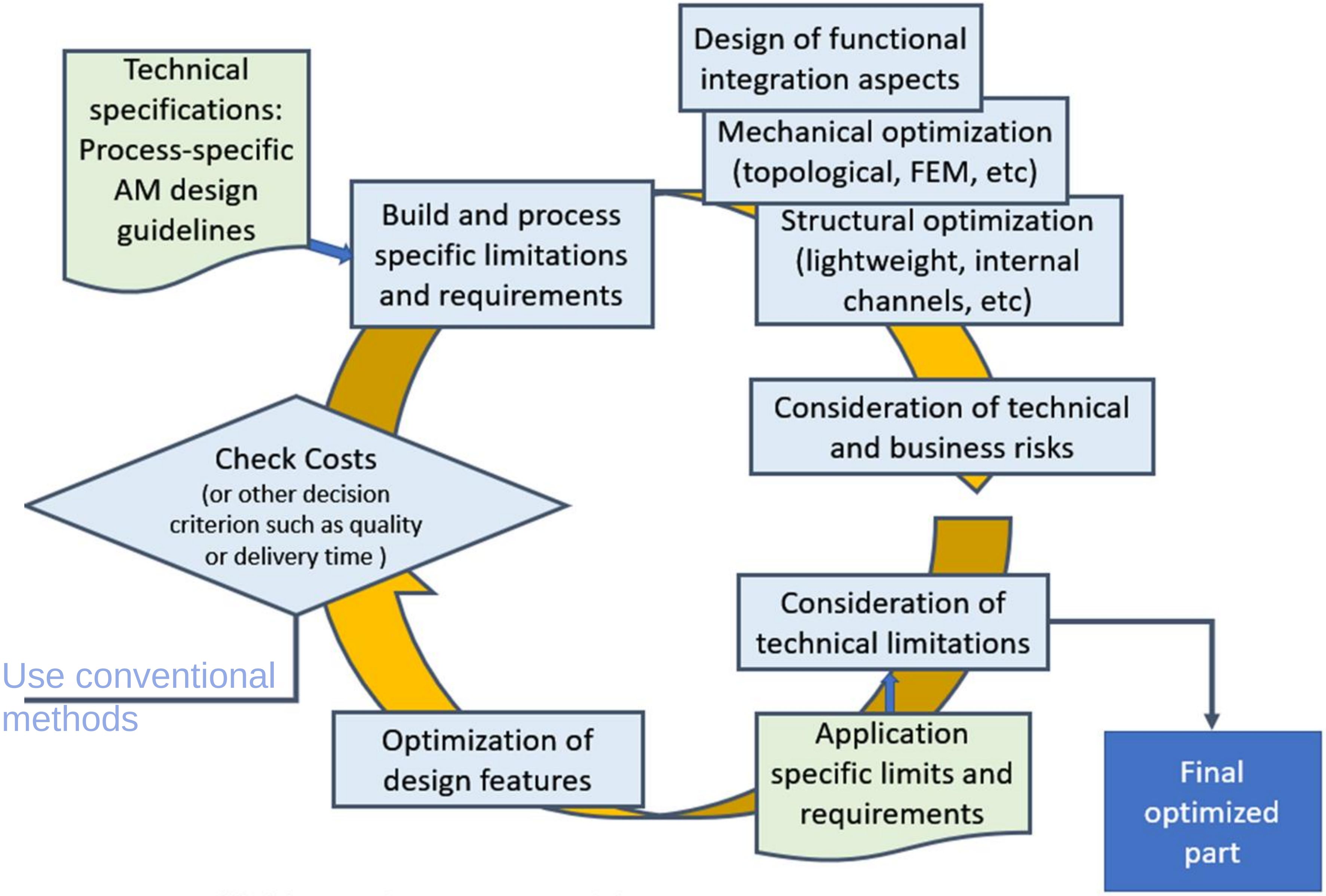
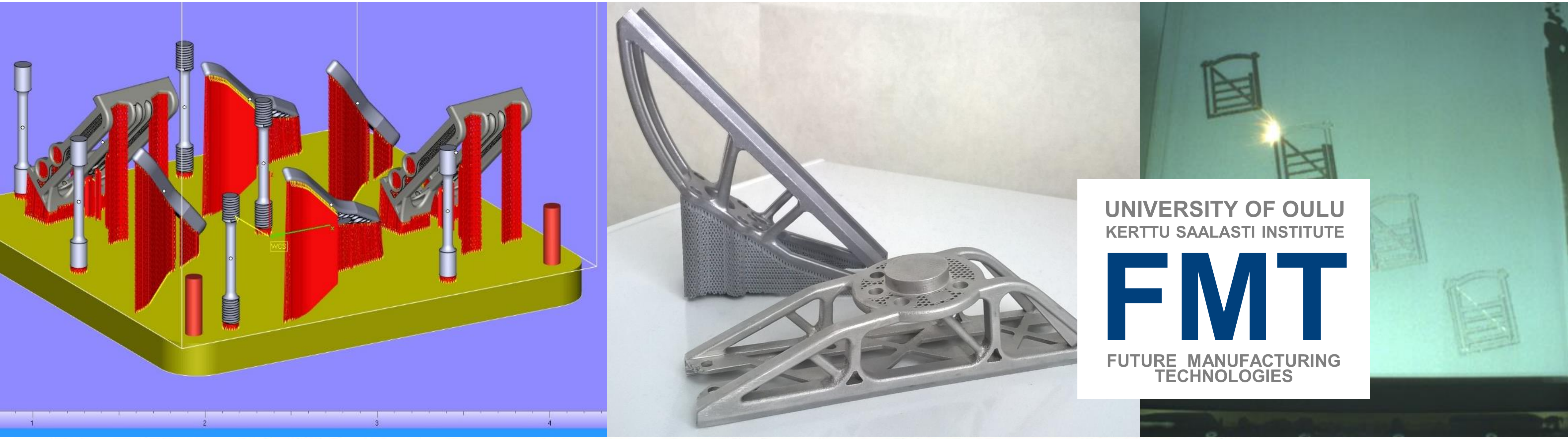
STEP 3 Design loop



Use conventional methods

Modified from ISO/ASTM 52910:2018(E)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120 second walkthrough!

Focus on the words in **bold** and ***italics!***

SFS-EN ISO/ASTM 52911-1:2019:en

Additive manufacturing. Design. Part 1: Laser-based powder bed fusion of metals (ISO/ASTM 52911-1:2019)

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PBF-LB Characteristics

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Characteristics of laser powder bed fusion (PBF-LB) processes

- ***General***
- ***Size*** of the parts
- ***Benefits*** to be considered in regard to the PBF process
- ***Limitations*** to be considered in regard to the PBF process
- Economic and time ***efficiency***
- Feature ***constraints*** (stair-step effect, islands, overhang)

General

- Laser power from **200W to 1 KW** and more
- One or more simultaneous laser beams in use
- Printing is done on a platform and the supporting structures are made of the same material as the printed part

Size of the parts

- Main limitation is the working area of the PBF-LB printer
  - ***Most common*** size category ca. ***280x280x350 mm³***
  - Larger chamber sizes are on the way

- The size and volume of the part have a direct relation to cost of production

Benefits

- Near-net shape method
- High degree of ***design freedom***
- ***Complex geometries*** can be produced

Benefits

- Multiple functions in the same part
- “***Complexity for free***.” Complex geometry does not increase the cost of the part
- “***Consolidation***.” Assembly or multiple parts in the same part

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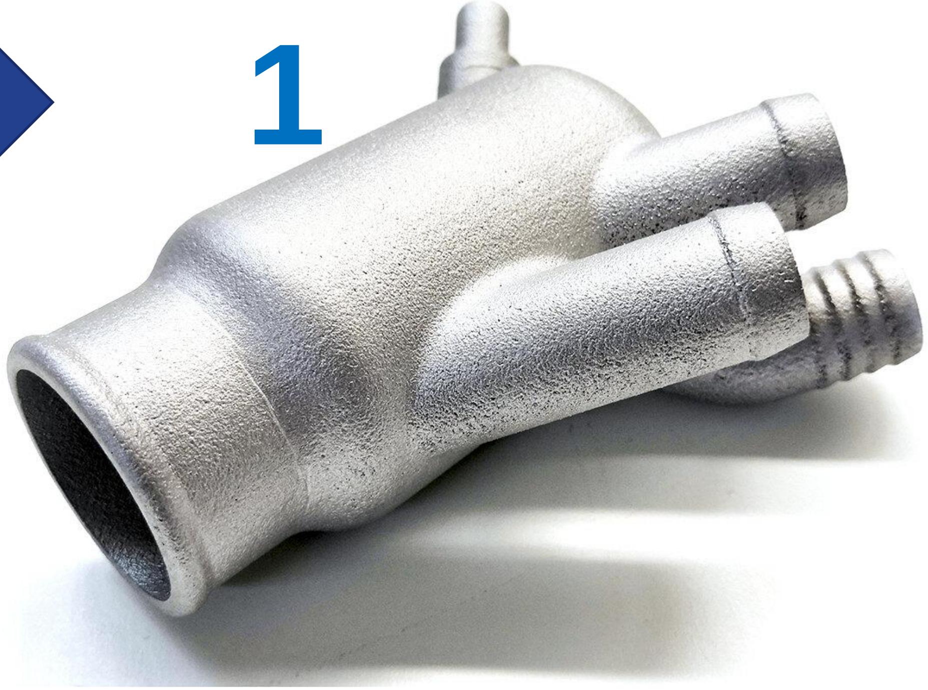
Example – Hydraulic manifold from Avant and 3DStep



Original assembly, 33 parts.

New AM part.
Combined and functionally developed.

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Source: 3DStep https://www.3dstep.fi/asiakastarinoita/hydrauliblokin-optimointi-avant-tecno
Picture left: https://images.squarespace-cdn.com/content/v1/60ac8c718fa9774e3688baa4/1623919552821-HWSO1NWSSM3D5X55LCY4/IMG_20190909_092220-768x576.jpeg
Picture right: https://images.squarespace-cdn.com/content/v1/60ac8c718fa9774e3688baa4/1623919529108-17146F5TS6TQGFL1B6K4/IMG_20190909_092244.jpeg

Limitations

- ***Anisotropy***
- ***Deviations or inaccuracy*** in form, dimensions and positional tolerances of parts
- Possibilities for shrinkage, residual stress and deformation

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Economic and time efficiency

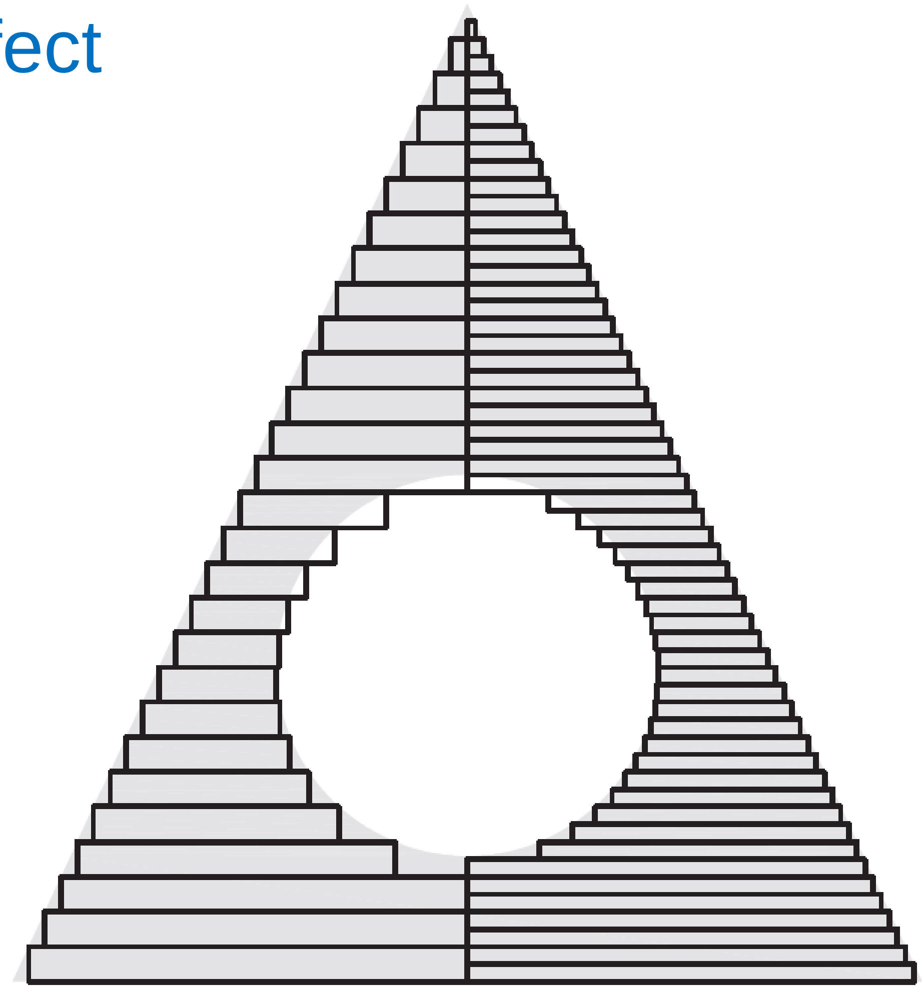
- ***Height*** (Z-direction) has the greatest ***impact*** on building ***time*** and build ***costs***

Economic and time efficiency

- ***Minimising weight*** reduces printing time and costs
- ***Tight nesting.*** To minimize costs, build space should be used as efficiently as possible

Feature constraints - stair-step effect

- Geometric inaccuracy
- Depends on layer thickness



Source: SFS-EN ISO/ASTM 52911-1:2019
(Original source VDI 3405-3:2015)

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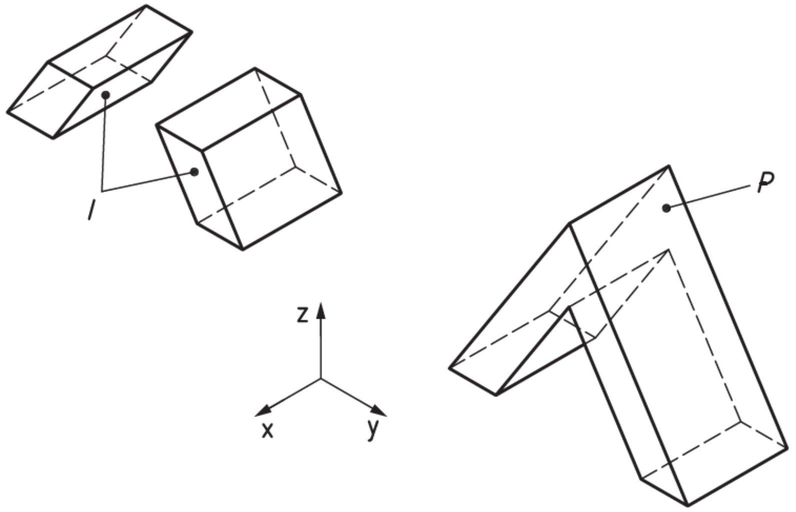
Feature constraints - Islands

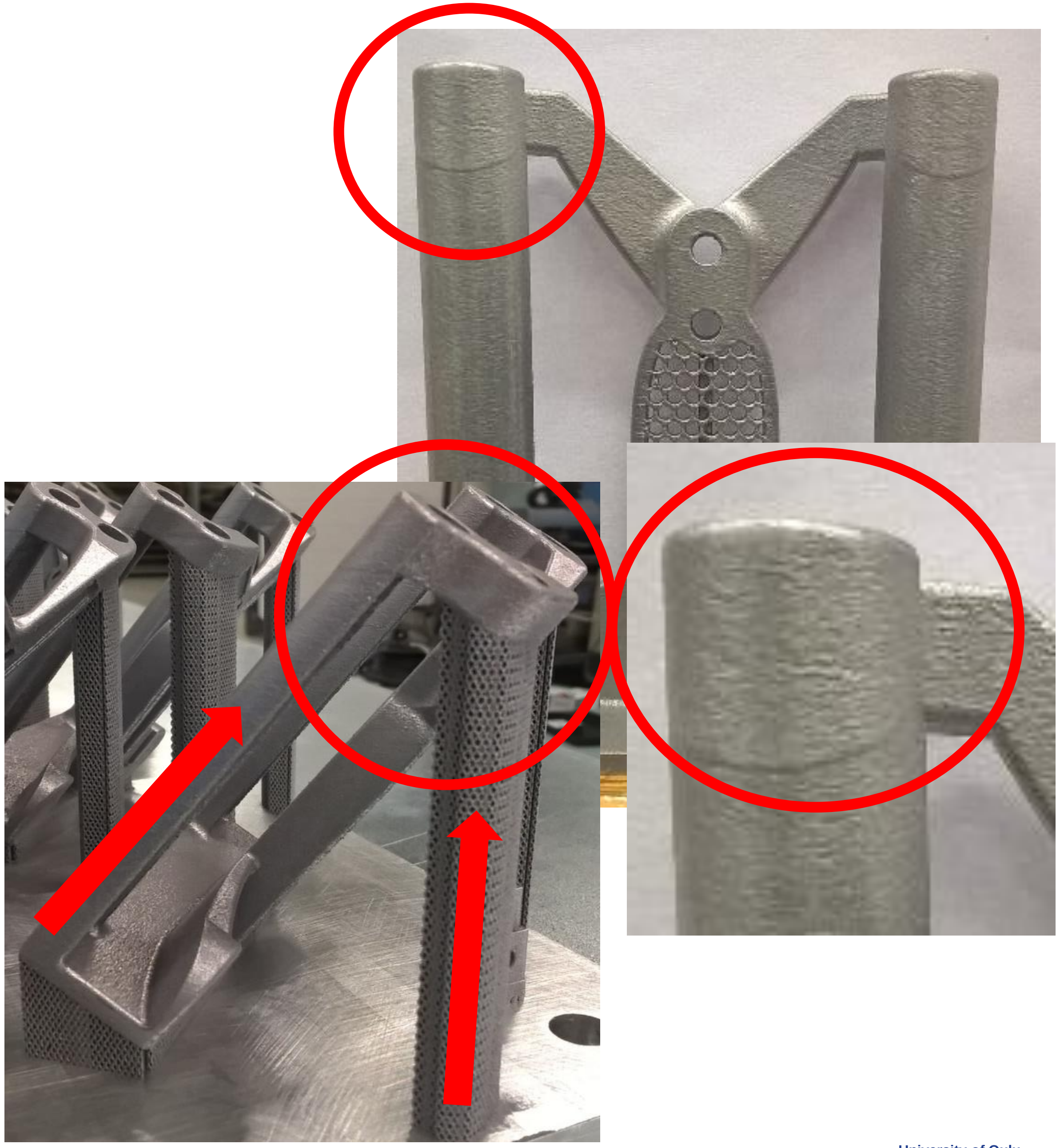


Key

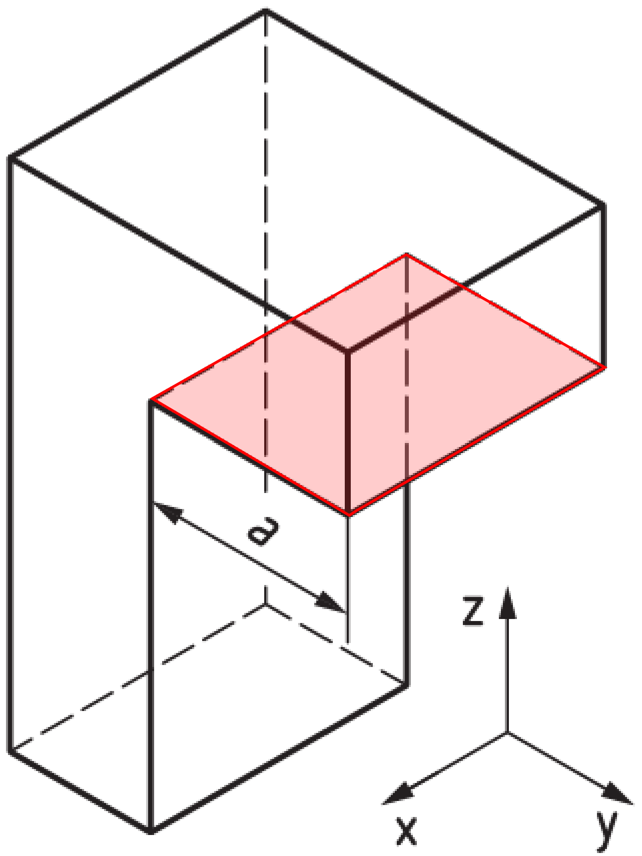
I islands

P part

Source: SFS-EN ISO/ASTM 52911-1:2019
(Original source VDI 3405-3:2015)



Feature constraints - Overhang



Source: SFS-EN ISO/ASTM 52911-1:2019
(Original source VDI 3405-3:2015)

- ***Support is needed***
- Small (a<2mm) overhangs do not need support
- ***Poor surface quality*** in the overhang area

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PBF-LB/M
Design guidelines

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Design guidelines for laser-based powder bed fusion of metals (PBF-LB/M)

- Materials
- Support structures
- Build orientation, positioning and arrangement
- Design considerations

Materials

- Most commonly used materials:
  - Stainless steel ***AISI 316L***
  - Aluminium ***AlSi10Mg***
  - Tool steel 1.2083
  - Titanium TiAl6V4
  - Nickel-based IN625
  - Cobalt-based CoCr

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Materials - microstructure

- Heavily dependent on the processing environment
- May ***contain porous*** and defects
- Post ***heat treatments*** can be used for ***release of residual stresses*** and tuning material properties

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Support structures – WHY?

- ***Fixing*** the part to the build platform
- ***Heat transfer***
- As a provisional ***support for a part*** under construction
- ***Compensating for warping*** caused by residual stress

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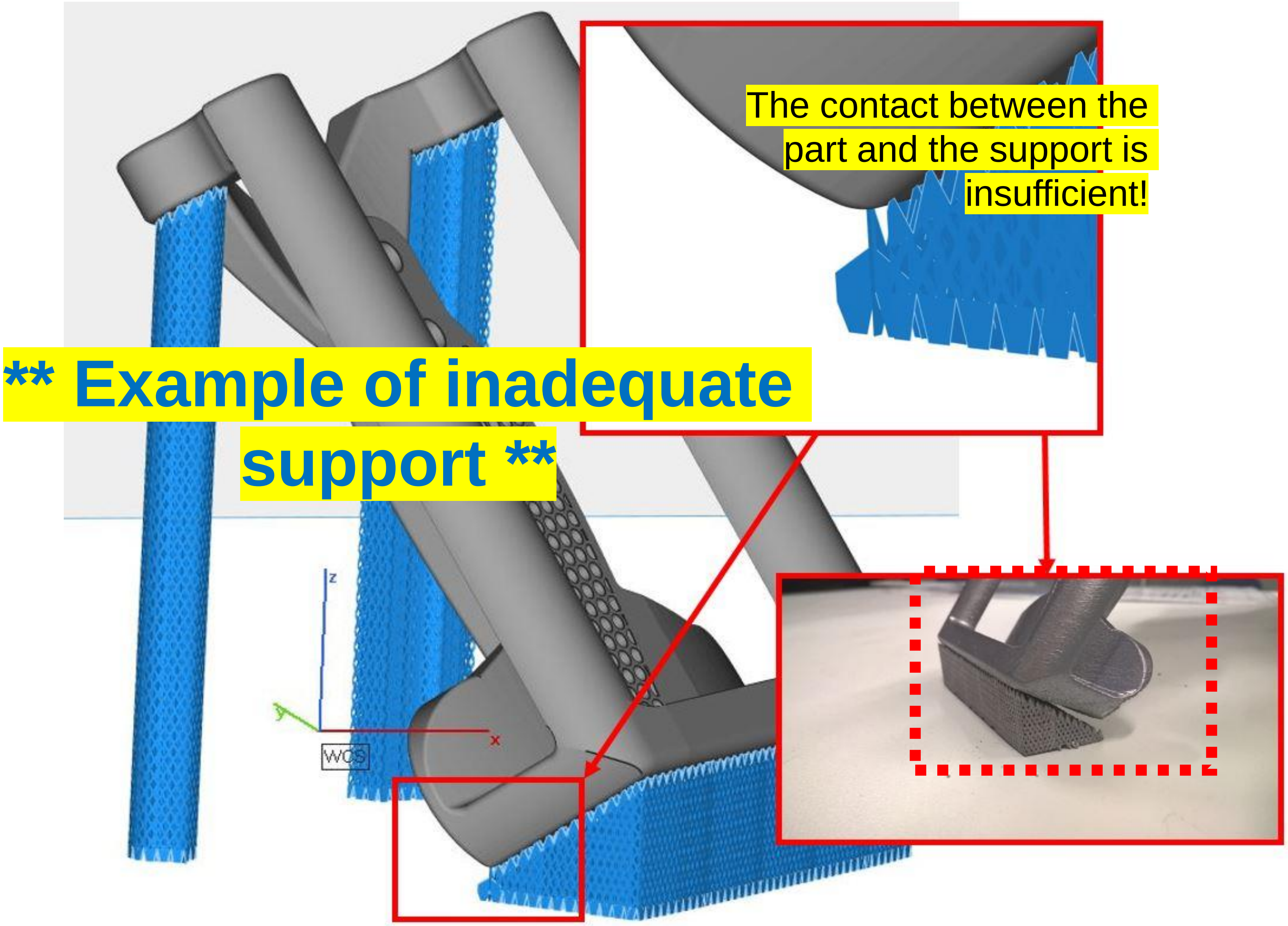
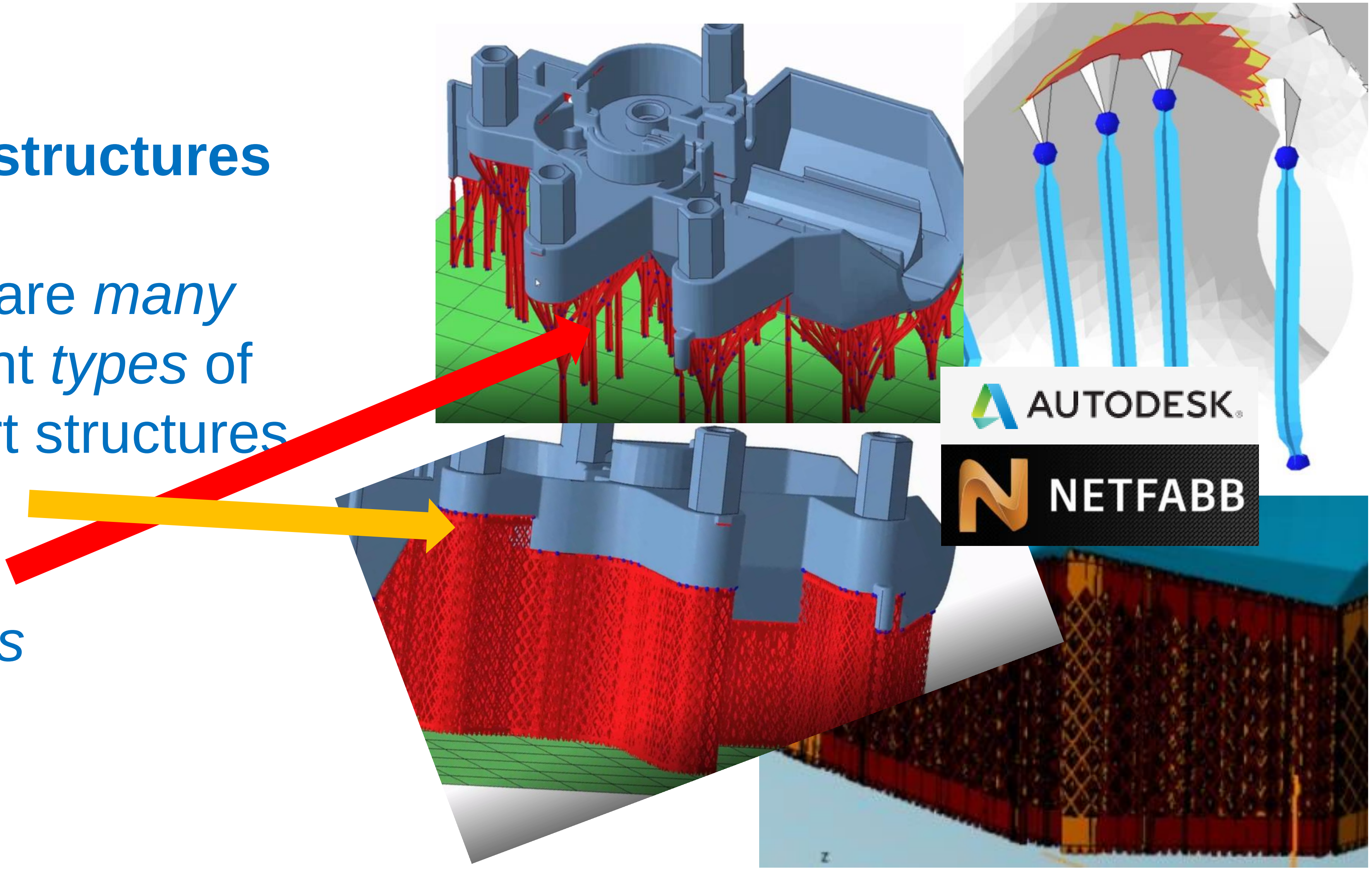


The contact between the part and the support is insufficient!
** Example of inadequate support **
z
x
WCS

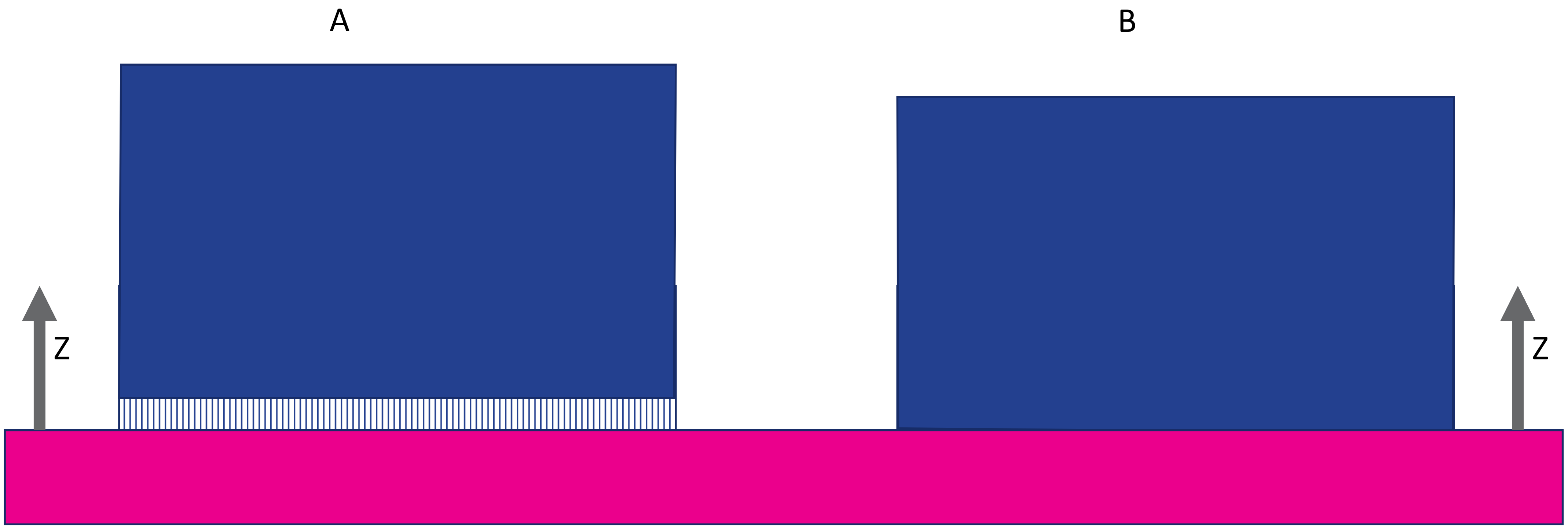
Support structures

- There are *many* different *types* of support structures
- ***Fence***
- ***Tree***
- *Lattices*
- Etc.



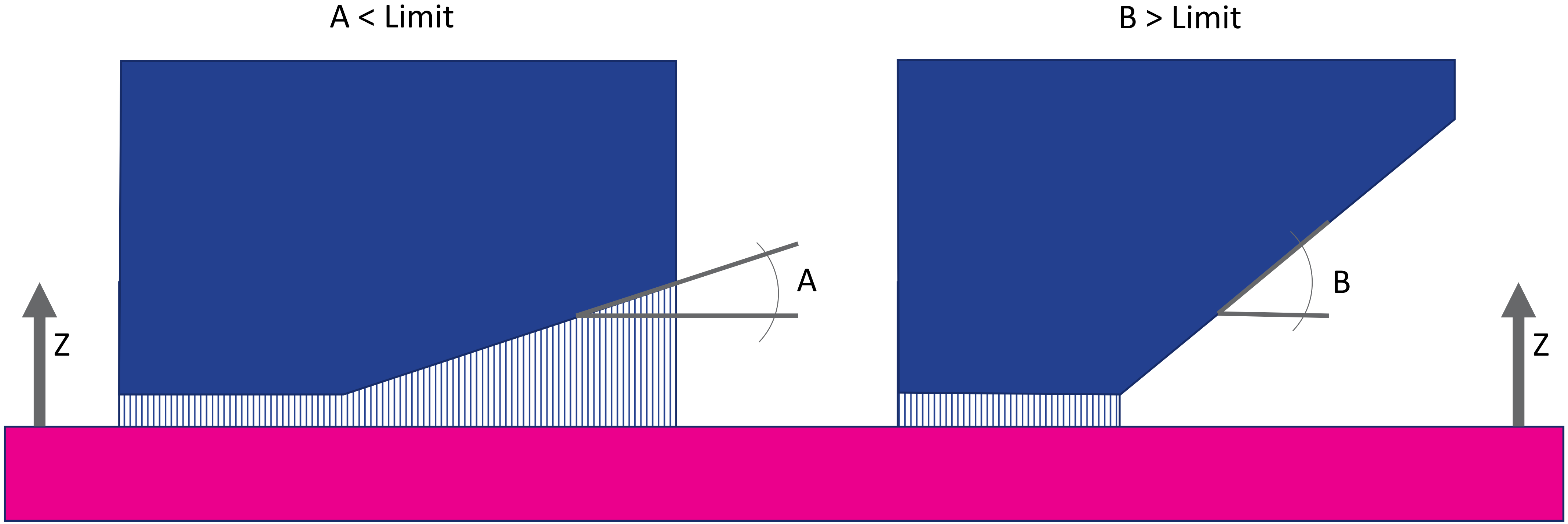
Source: https://www.autodesk.com/products/netfabb

Support structures - Fixing the part to the build platform

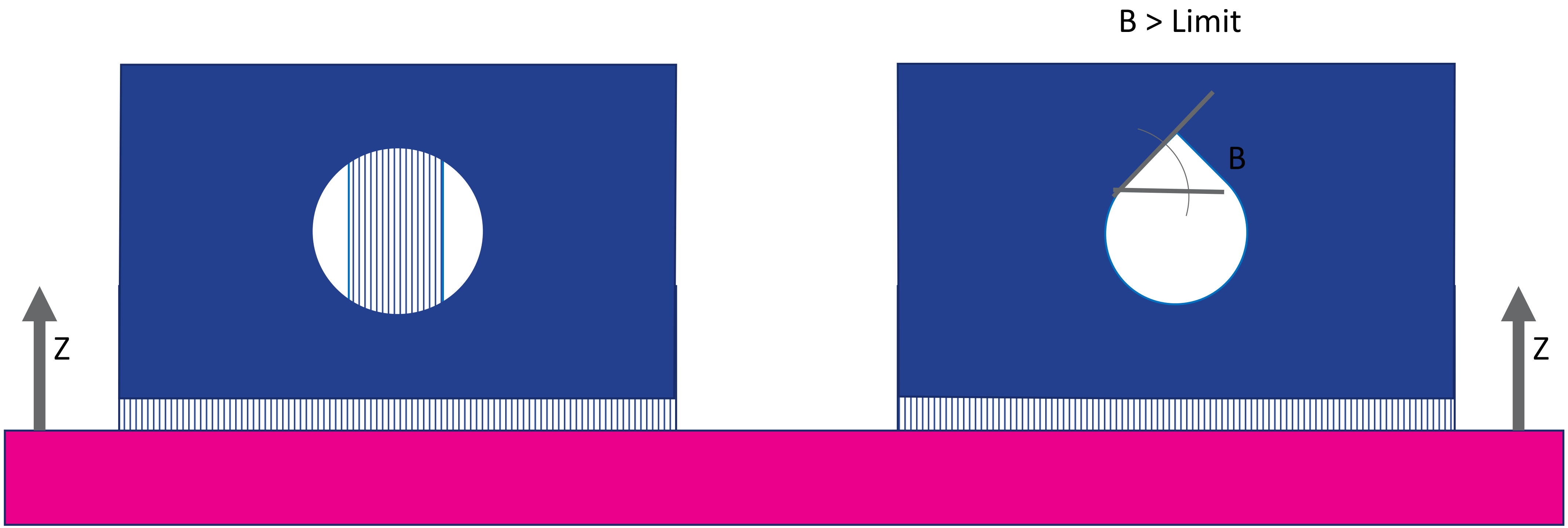


Support structures – Overhang angle

In PBF-LB limit from 30 to 45 degrees



Support structures – vertical hole



Build orientation, positioning and arrangement

Source: SFS-EN ISO/ASTM 52911-1:2019
(Original source VDI 3405-3:2015)

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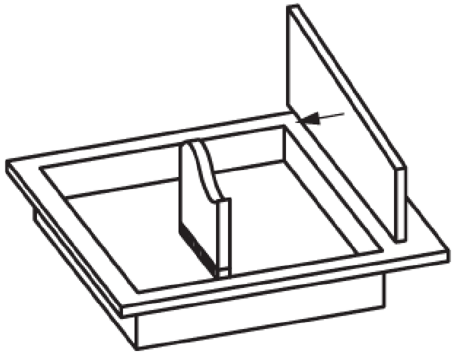
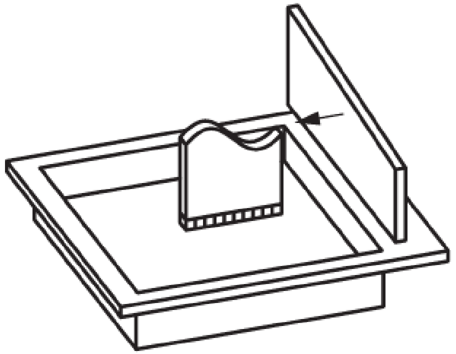
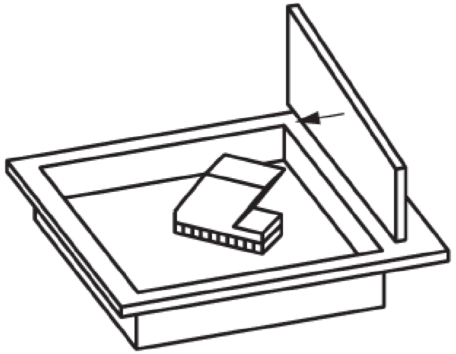
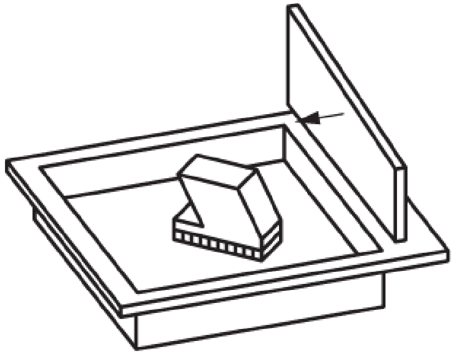
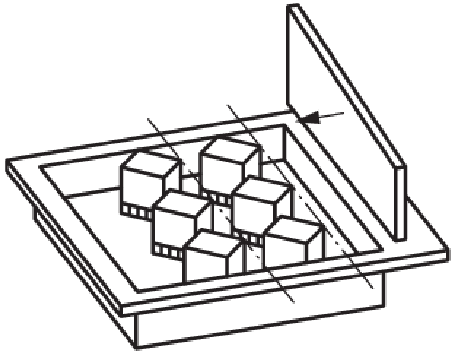
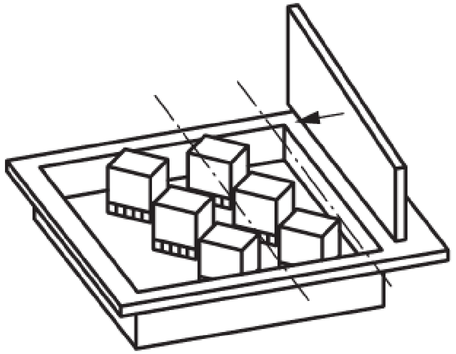
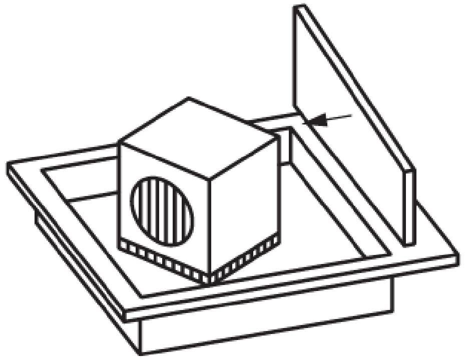
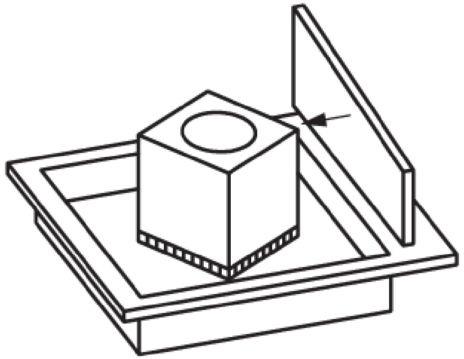
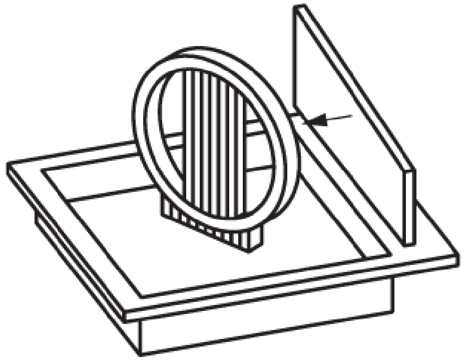
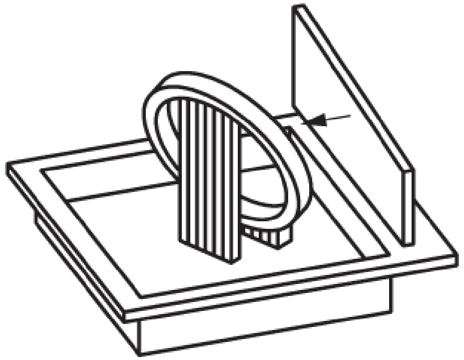
Table 3 Arrangement of critical elements in the build space of the machine

Description	Poor	Good
Longitudinal geometries should be oriented in a way that the contact length with the spreading system is minimized.		
Critical geometries should be oriented in a way that avoids parts being bent-up if there is a contact between spreading system and part. A suitable angle is often 10°.		
Multiple parts should be positioned in a way that the contact length with the spreading system is minimized (arranged with an offset).		

SOURCE: VDI 3405-3:2015.

Support structures design

Table 4 Examples of support structures

Description	Poor	Good
Avoiding support structures through part orientation that leads to least need for support structures.		
Avoiding post-processing effort through support structure design that considers the desired post process for its removal.		

SOURCE: VDI 3405-3:2015.

Source: SFS-EN ISO/ASTM 52911-1:2019
(Original source VDI 3405-3:2015)

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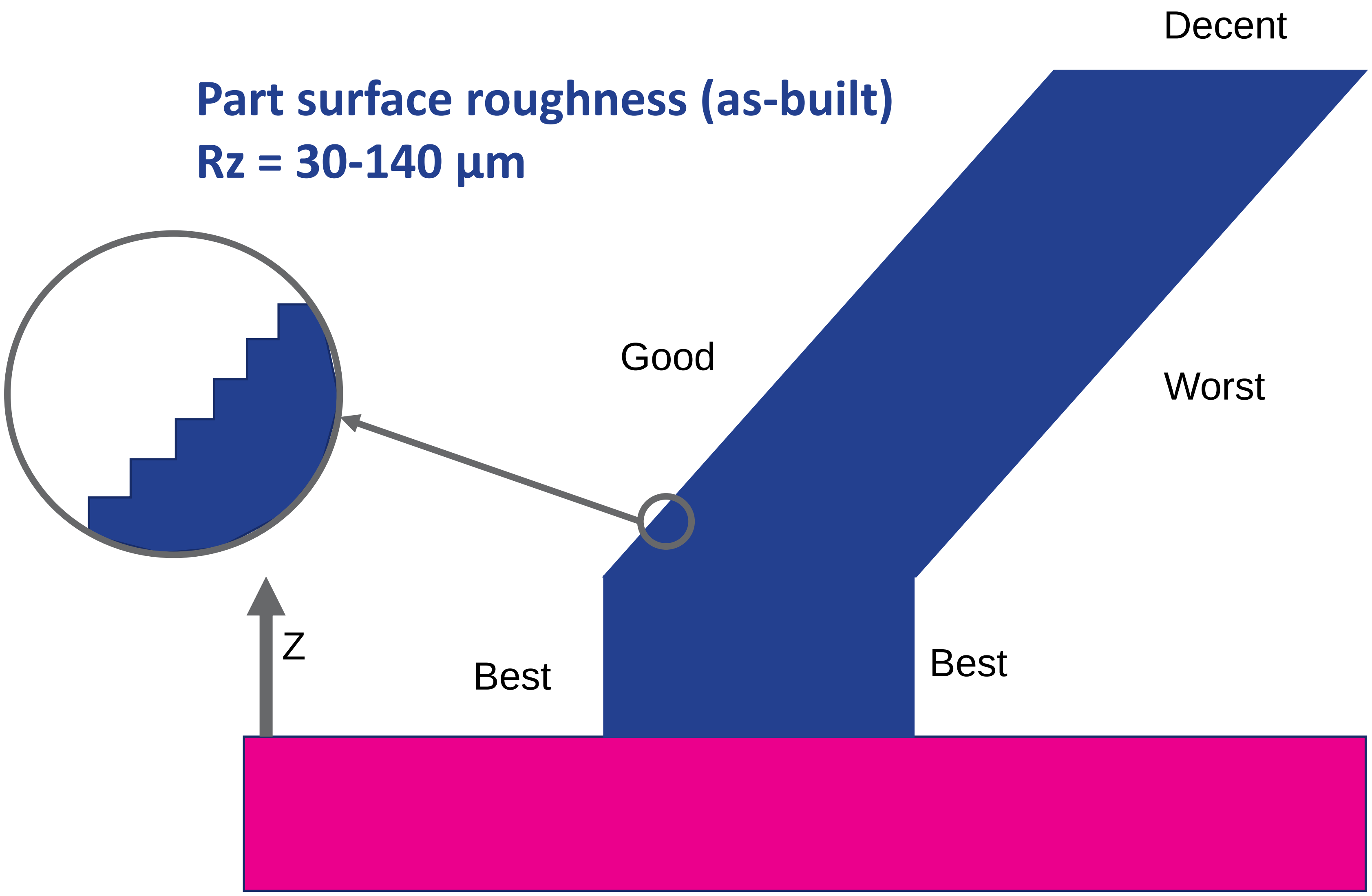
PBF-LB/M design considerations

Surface roughness

Part surface roughness (as-built)
Rz = 30-140 µm



Cavities

- Design with loading in mind
- Reduce mass and build time
- Hollow, powder inside or filled with mesh or bionic structures

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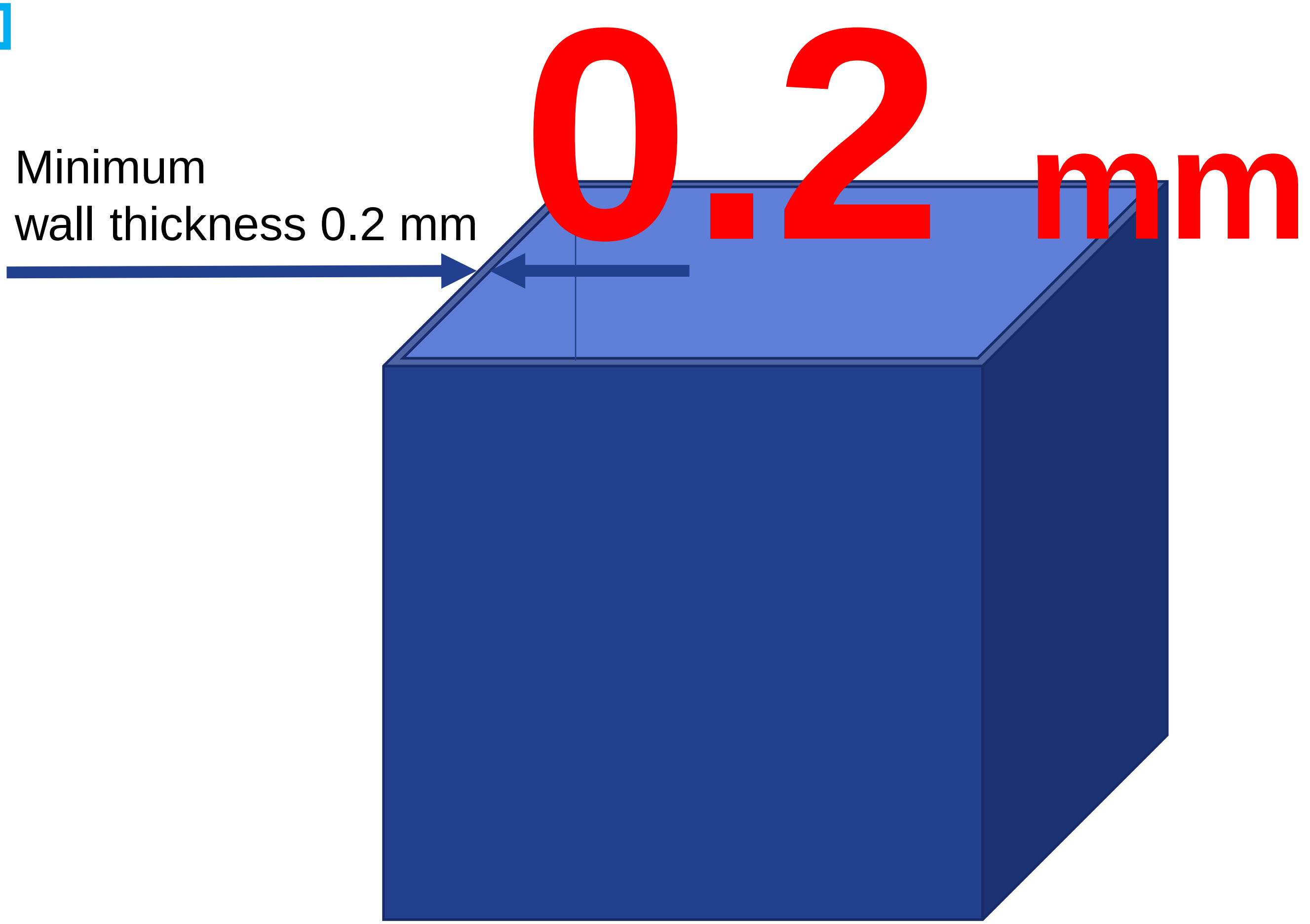

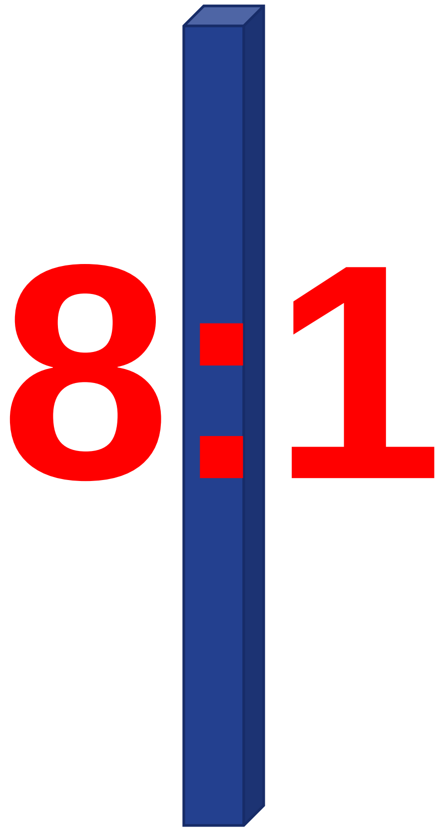

Maximum length-to-height ratio 8:1

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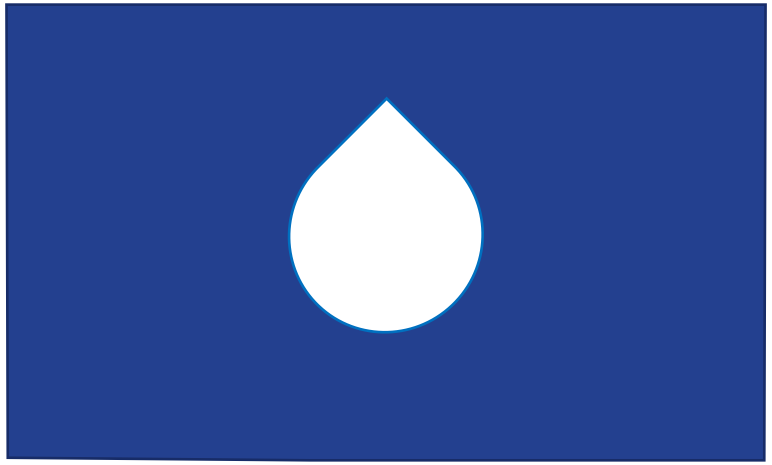
Holes

- Minimum diameter 0.4 mm
- Maximum diameter with no support 10 mm
- “Fear no tears”



Also

- Design for functionality
- Lightweight
- Design parts to be multifunctional
- Topological optimization
- Design for ease of fabrication

SFS-EN ISO/ASTM 52911-1:2019:en Examples

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Source: SFS-EN ISO/ASTM 52911-1:2019
(provided by CETIM — Technical Centre for Mechanical Industry)

Integral design example

- From welded construction to AM construction
- Part reduction from 6 to 1
- Mass reduction 40%

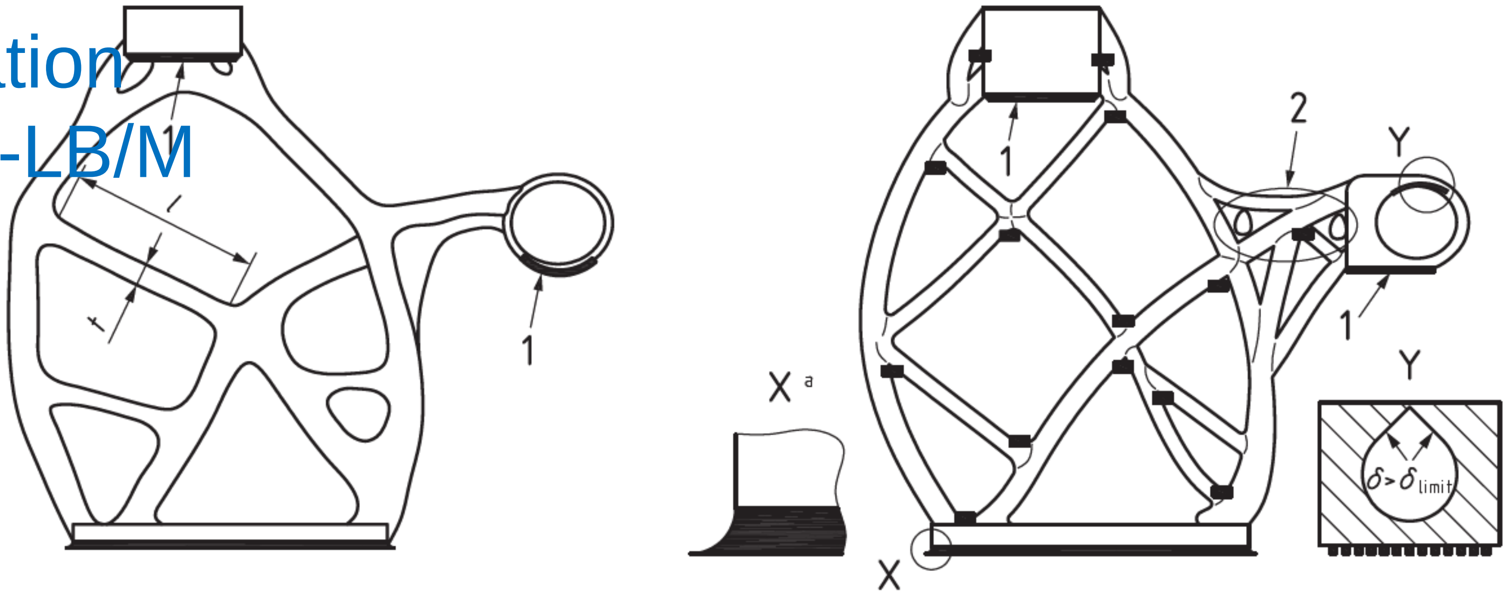
a) Original welded assembly

b) Modified result design by topological optimization and produced by PBF-LB/M

Source: SFS-EN ISO/ASTM 52911-1:2019

Topological optimization example

- Initial parameters
- Topology optimization
- Redesign for PBF-LB/M



a) Initial shape, after topological optimization

b) New shape for LBM process

Key

1	supports required	*t*	thickness
2	thin wall	*l*	length
a	Fillet radius.		

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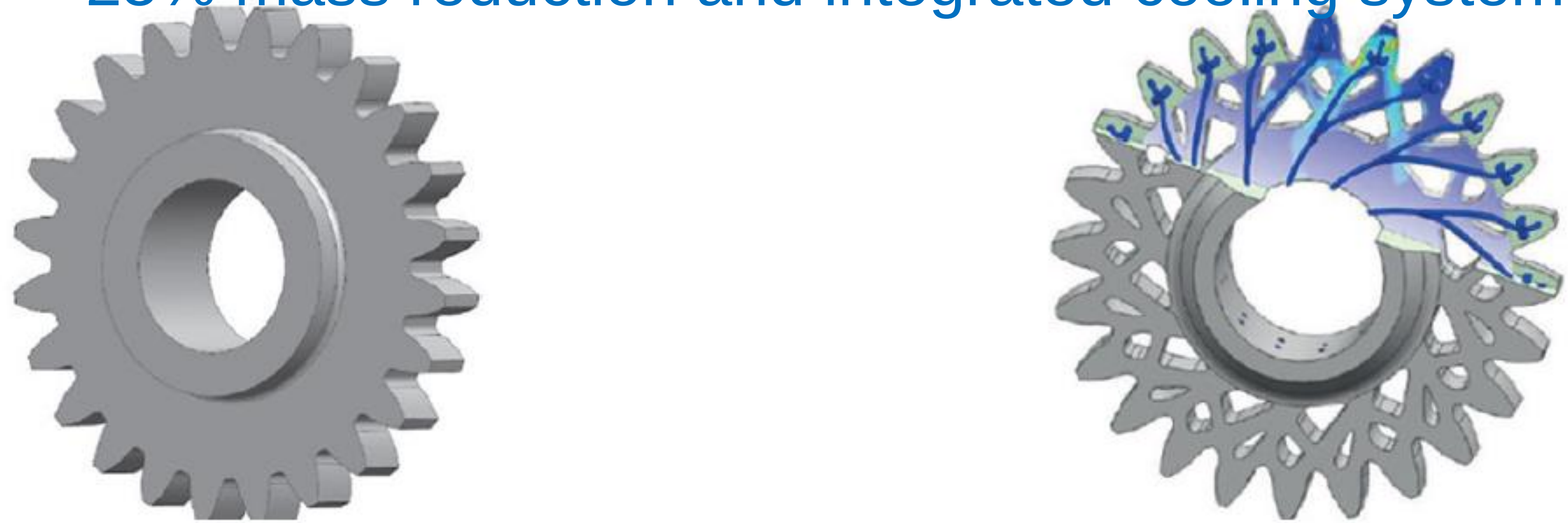
Source: SFS-EN ISO/ASTM 52911-1:2019
(provided by Fraunhofer IGCV)

Gear wheel design example

- 25% mass reduction and integrated cooling system



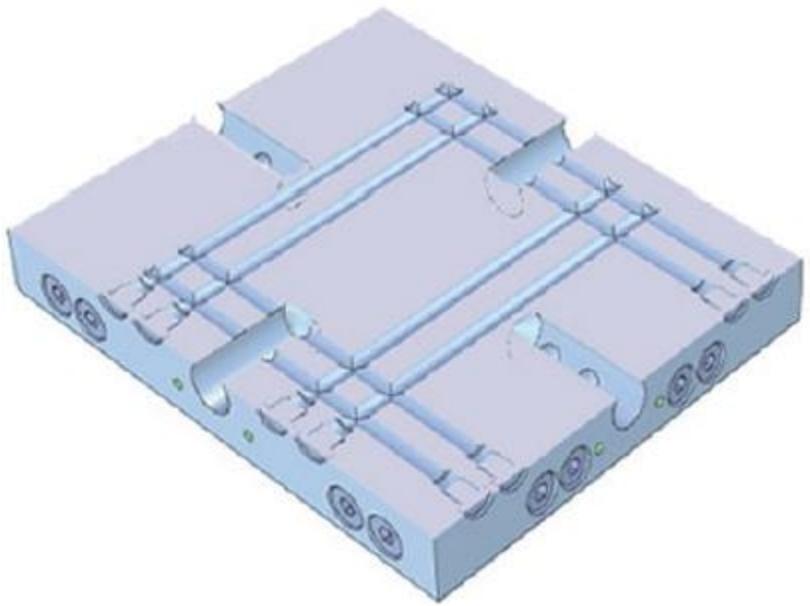
a) Reference gear (FZG type PT-C)

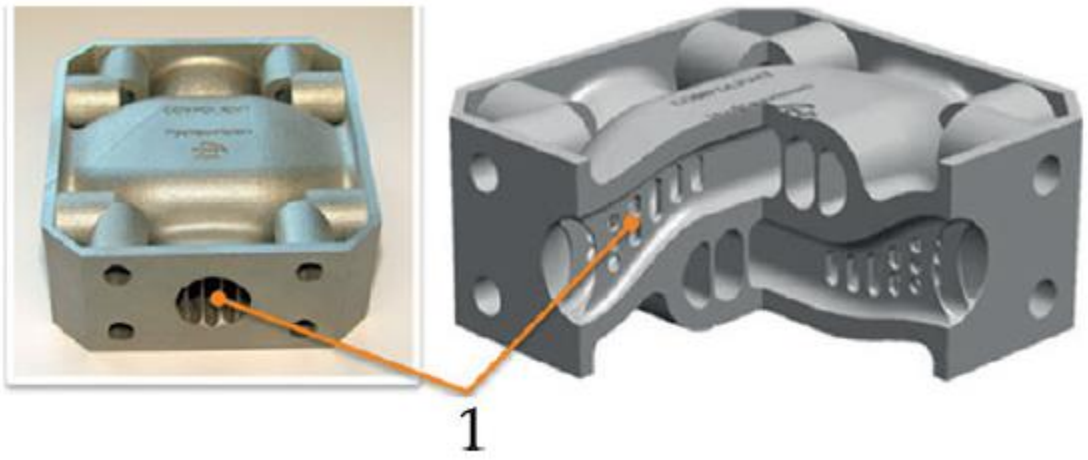
b) Lightweight design including functional integration of conformal cooling system resulting in a mass reduction by 25 %, produced by PBF-LB/M

Source: SFS-EN ISO/ASTM 52911-1:2019
(provided by TNO — The Netherlands Organisation for applied scientific research)

Hydraulic manifold example

- Ca. 70 % reduction of pressure loss
- Weight reduction from 20 kg to 1 kg





a) Reference hydraulic manifold

b) Fluid flow and lightweight optimized design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Design for metal AM

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From general to details

Many functions in one part

- Body structure
- Connecting structures
- Cooling
- Lubrication
- Heat insulation
- Vibration damping
- Heat exchanger
- RF features
- Mixer
- Nozzle
- etc

Assembly into a single part

- Assembly work reduction
- Simplification of functions
- Weight reduction
- Function optimisation
- Optimisation and minimisation of interfaces
- Complex internal structures
- etc

– Look at the product and its functions as a whole

- Try to combine functions into a single part
- Try to compact the assembly or sub-assembly into a single part

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Examining known challenges and problems

Technical challenges

- Durability problems
- Manufacturing problems
- Material problems
- Problems related to the small size of the production series
- Customers' technical wishes and requirements

Commercial or administrative challenges

- Part manufacturing costs
- Assembly costs
- Time or timing problems
- Problems related to product management

– Examining whether the use of AM methods could have a positive impact on

– On the other hand, looking at the supply chain of the product/parts and considering whether the use of AM methods could bring added value.

Part design – “Pre-design” phase

– Technical requirements
- Forces, interfaces, operational requirements, etc.

– Economical realities and sustainability considerations

– Dimensions → metal AM method

– Materials selection → metal AM method

– Brainstorming
- Preliminary solutions

→ Preliminary solutions and appropriate AM methods

Part design –
Metal AM Method Capability

– Part requirements vs. AM method possibilities and limitations

Feature	PBF-LB/M	DED-LB- Metal bowder	WAAM
Max. part dimensions	280x280x360	1000x1000x1000	1200x1200x1200
Geometrical accuracy	0.1 mm	0.5 mm	1 mm
Surface roughness	Ra 5-18 um	Ra 15-60 um	Ra 40-200+ um
Min. wall thickness	0.2 mm	3 mm	6 mm
Min. hole diameter	0.4 mm	10 mm	30 mm
Maximum length-to-height ratio	1:8	??	??
Overhang angle/dist,	30…45 / 2 mm	45 **	45 **
Minimum feature size	~ 0.2 mm	2…5 mm**	5…10 mm **

Notice: All values are machine and material depend and can vary widely between equipment from different manufacturers.

** PBF-LB/M – 3 axis ↔ DED – 3 or 5 axis mechanics

Part design –
Geometry optimization

- For
  - Optimal function
  - Weight optimization
  - Manufacturing quality and costs
  - Minimizing post-processing needs
- Topology optimization – FEM based manual geometry optimization - Generative design
- Many times also heat flow, flow path, electrical or RF/antenna geometry optimisation

Design for DED

- SFS-EN ISO/ASTM 52910:2019 Additive manufacturing. Design. Requirements, guidelines and recommendations (ISO/ASTM 52910:2018) ***is good starting point!***

Design for DED (DED-LB and WAAM)

– Usually DED + machining
- Clamping of the workpiece for machining to be taken into account
- With the right fixing solution, intermediate machining is also possible

– 5 axis mechanics:
  - Build overhanging structures without supports
  - Hollow fully enclosed structures possible

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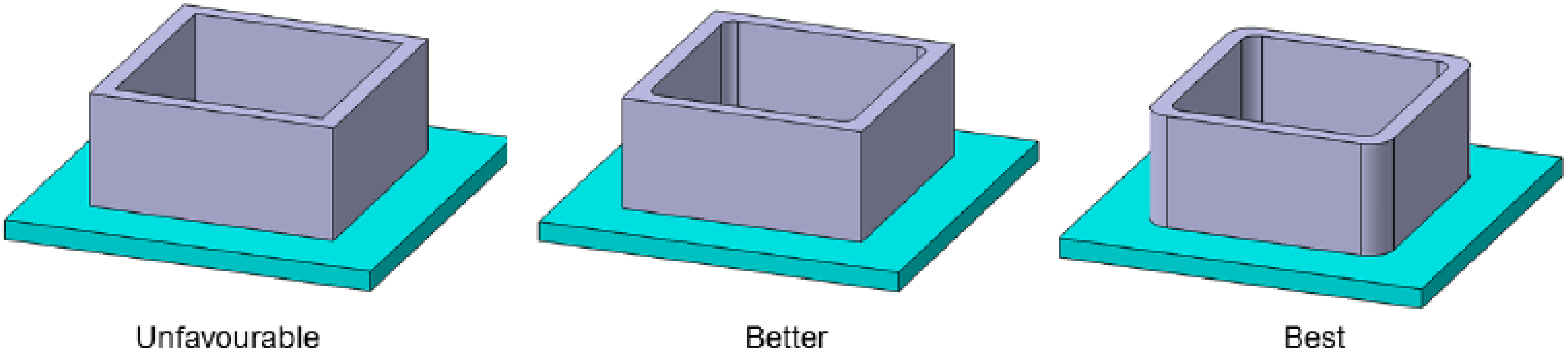
Design for DED

– Use rounded corners



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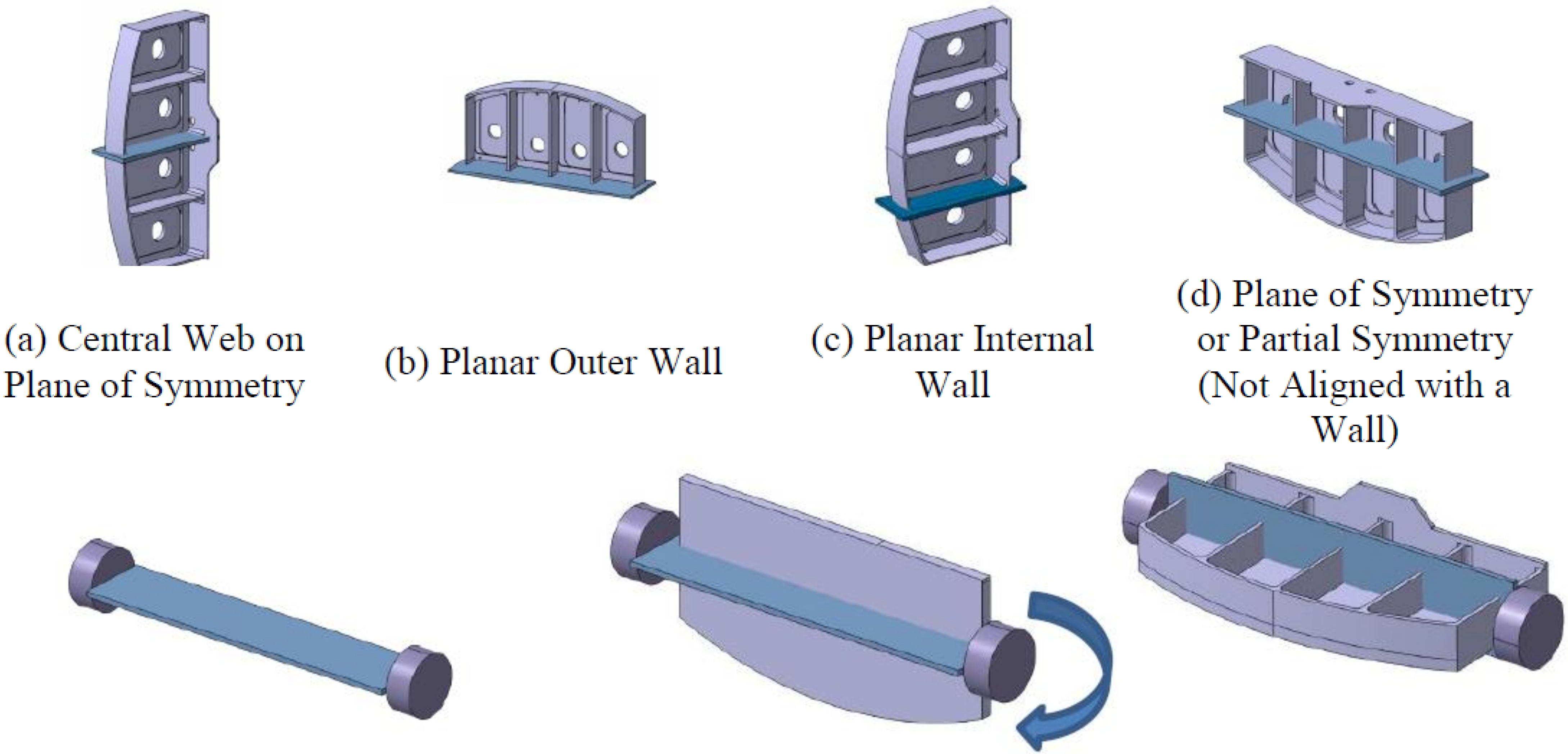
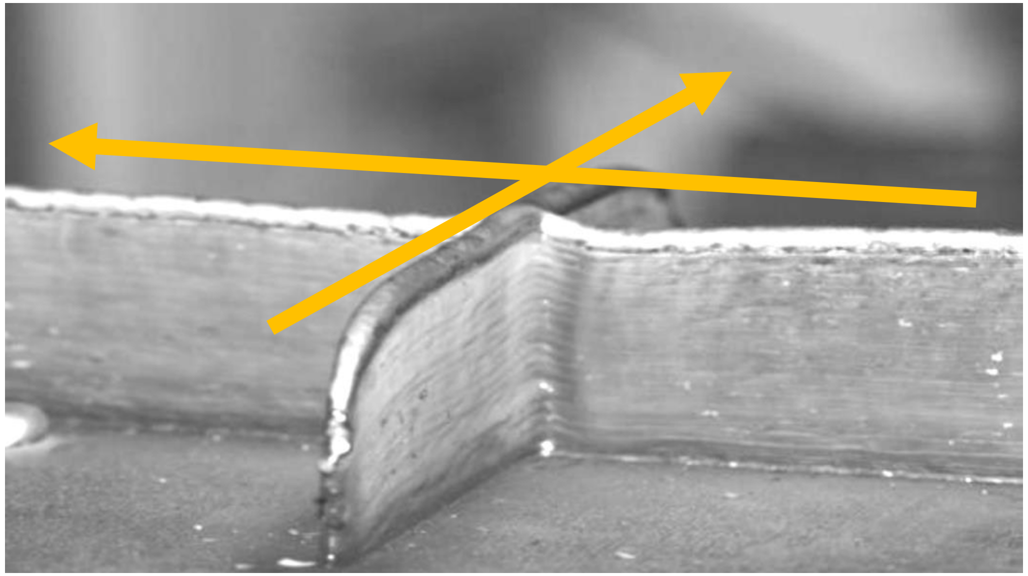
Source: Helen Lockett, Jialuo Ding, Stewart Williams, Filomeno Martina+, **Design for Wire + Arc Additive Manufacture: Design Rules and Build Orientation Selection,** Journal of Engineering Design, Volume 28, 2017 - Issue 7-9, https://doi.org/10.1080/09544828.2017.1365826

DED - Use substrate as part of the part!

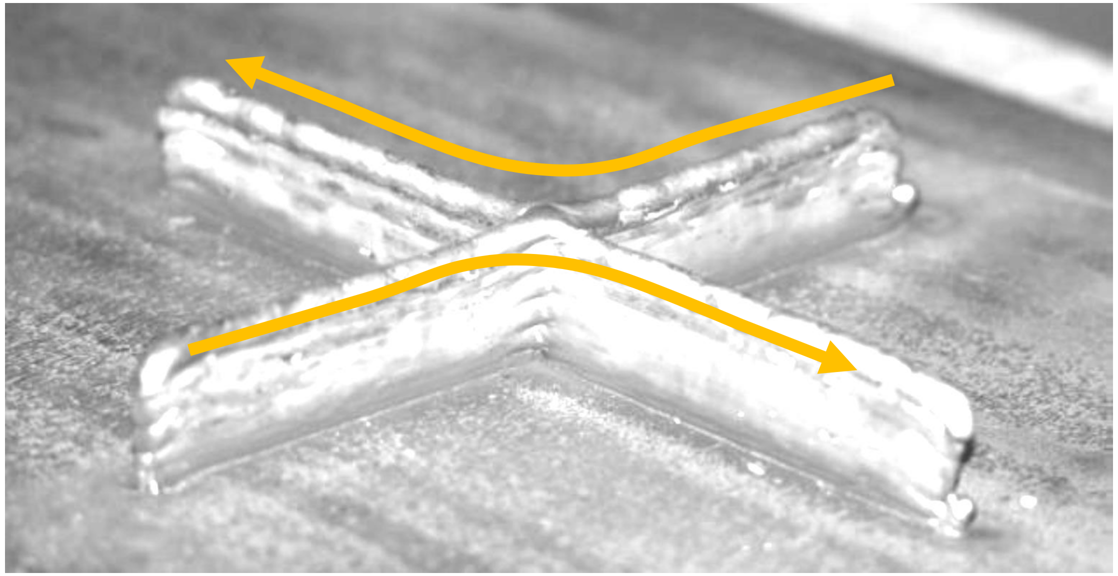


Source: Helen Lockett, Jialuo Ding, Stewart Williams, Filomeno Martina+, **Design for Wire + Arc Additive Manufacture: Design Rules and Build Orientation Selection,** Journal of Engineering Design, Volume 28, 2017 - Issue 7-9, https://doi.org/10.1080/09544828.2017.1365826

DED - Cross Structures



Peak



No peak

Source; J. Mehnen, J. Ding, H. Lockett, P. Kazanas, **Design for Wire and Arc Additive Layer Manufacture,** *CIRP Design Conference 2010*

DED materials

- DED-LB-Metal powder:
- Laser cladding materials
- Corrosion resistant, High stength, Abrasion resistant, Heat resistan etc.
- Prices from 60 €/kg
- WAAM:
- All MIG/MAG low slag welding consumables
- Also mild steel! Price ca 2 €/kg
- Stainless steel AISI136L ca. 6 €/kg

FMT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FUTURE MANUFACTURING TECHNOLOGIES

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Conclusions

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Conclusions

EN ISO/ASTM 52910:2019

Additive manufacturing. Design. Requirements, guidelines and recommendations (ISO/ASTM 52910:2018)

It's worth checking out!

EN ISO/ASTM 52911-1:2019:en

Additive manufacturing. Design. Part 1: Laser-based powder bed fusion of metals (ISO/ASTM 52911-1:2019)

PBF-LB/M - lot of design guidelines

DED – methods (WAAM and DED-LB)

- Coarser than the PBF method
- Possibilities of 5 axis mechanics
- Substrate as part of the part
- Reasonable price of materials

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Thank you for your kind attention!

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