amadam additive manufacturing

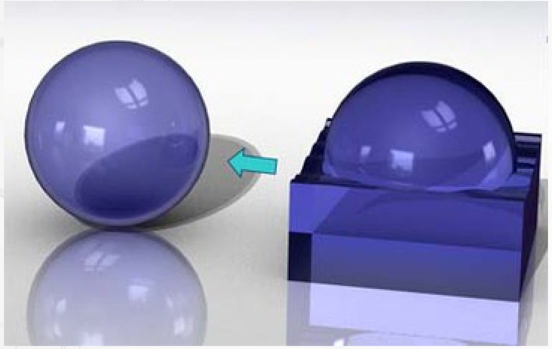
Design for Additive Manufacturing

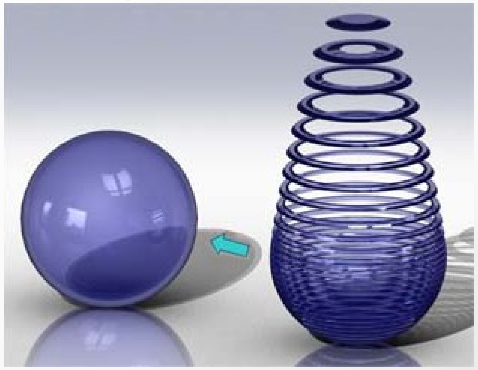
Nebojša Bogojević

PROJECT SUPPORTED BY European Commission

Additive manufacturing

- New – Old approach for part production
  - For humans – new procedure for part production– 40 years
  - In nature – from the beginning of the world
- Parts are produced by adding the material where is the necessary
- Building in the layers

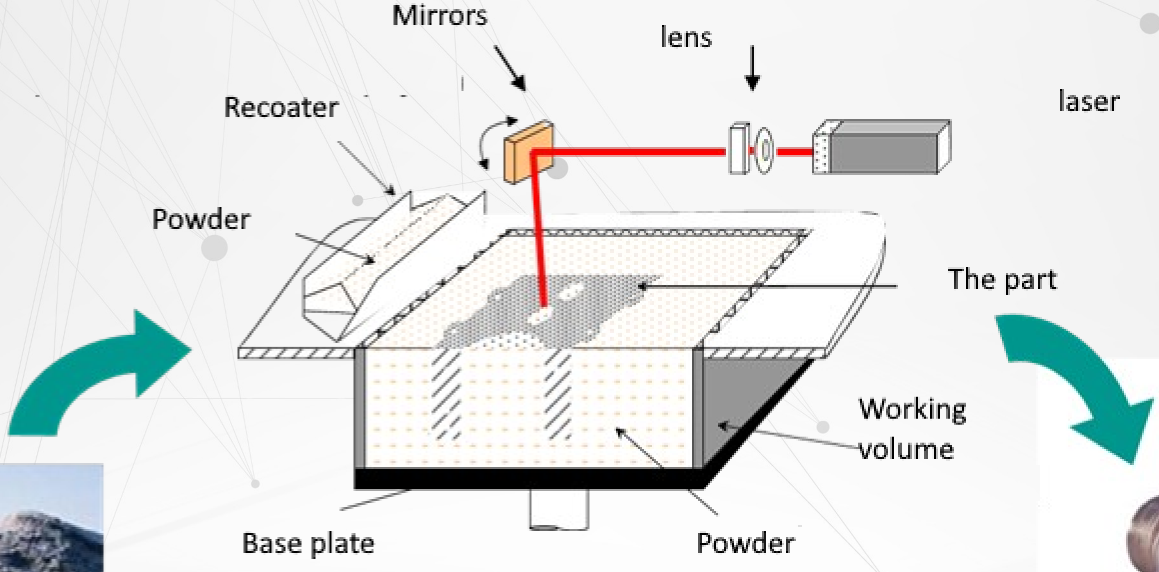




Additive manufacturing

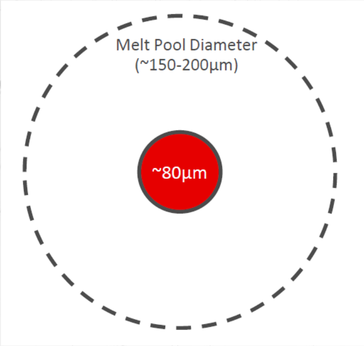
- AM category
- **VAT polymerization –** parts are made by polymerization of liquid. Polymerization is induced by light source**,**
- **Material jetting - MJ** – this technology is very similar to ink-jet printers, the droplets of the liquid are distributed by ink-jet head
- Binder jetting - BJ – the parts are build by adding the droplets of the binder through the ink-jet head in the powder base**,**
- **Material extrusion - ME**- the material is pushed trough heated nozzle, where is melted and then is deposited in the x-y plane**,**
- **Powder Bed Fusion - PBF** – the parts are made by melting the thin layer of powder
- Sheet Lamination - SL – building the parts by stacking and laminating thin sheets of material
  - Direct energy deposition - DED – the part was made by melting the base material (wire or powder) with the laser, electronic beam or electric arc


Additive manufacturing

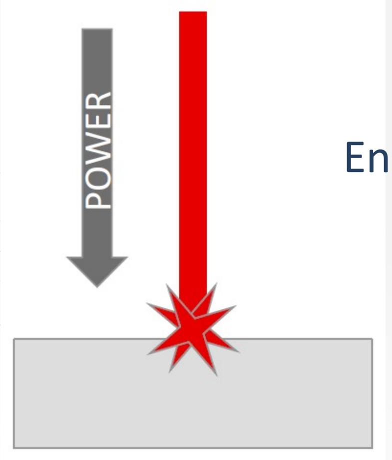


Additive manufacturing

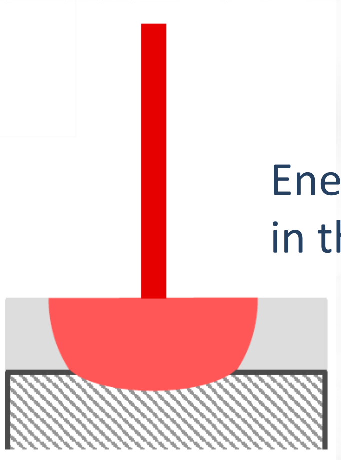
SLS – the process characteristics



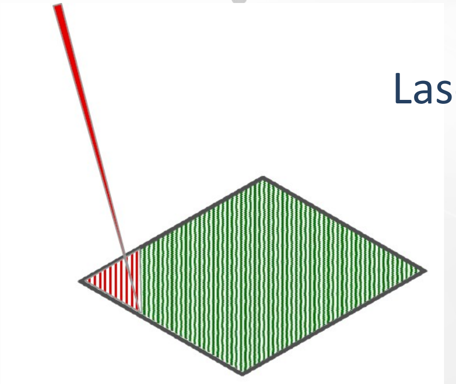
Laser spot and melting pool



Energy transition



Energy deposition in the part



Laser path

Additive manufacturing

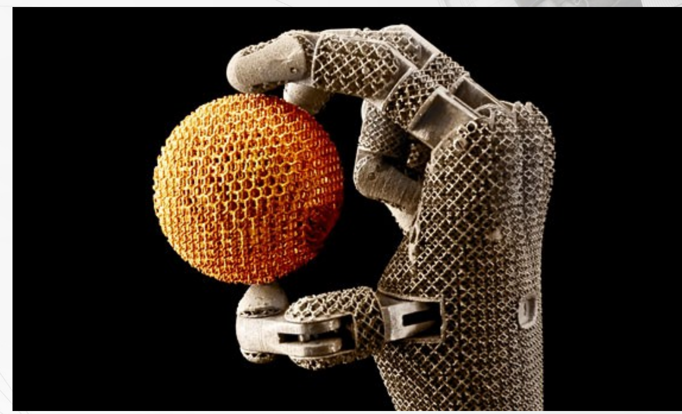
- "Complexity free" - still is myth!
- Complex forms can be produced but the limitations of the AM process must be respected
- It is necessary to know the design process, mechanics, thermodynamics, metallurgy and the specifics of a particular AM process
- Knowledge of additional-accompanying processing procedures

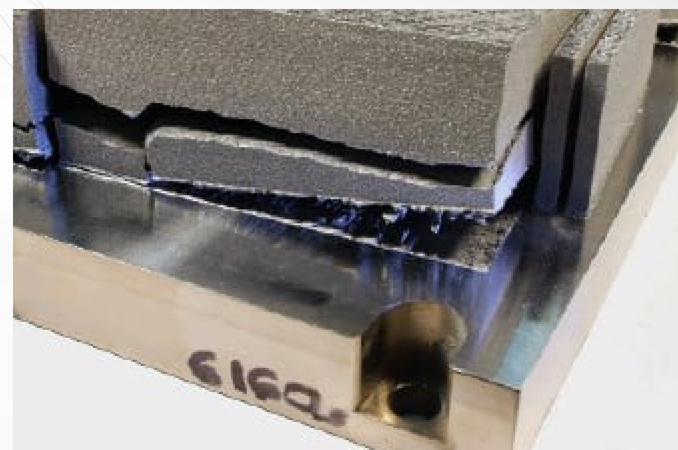
Additive manufacturing

- Mechanics
  - Knowledge of machine properties - AP systems, interdependencies between materials, parts and energy required for making parts
- Thermodynamics
  - the generation and flow of heat during the process of making parts and heat dissipation from the place of melting of the material
- Metallurgy
  - Knowledge of chemical processes, crystal structure, heat treatment, additional processing procedures, ...

Additive manufacturing

- AM gives more design freedom
- AM gives more freedom for production compares to conventional production processes
- Each AM technology has its own characteristics and limitations
- Design and not adhering to basic design rules for AM leads to failure in production



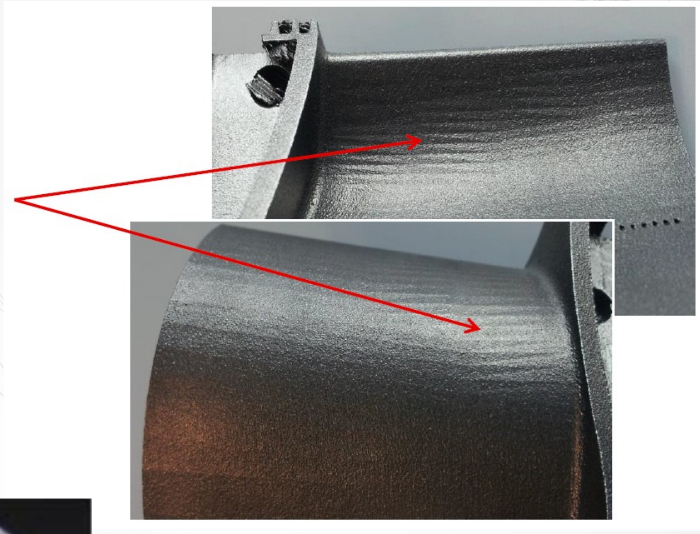


Design rules for AM

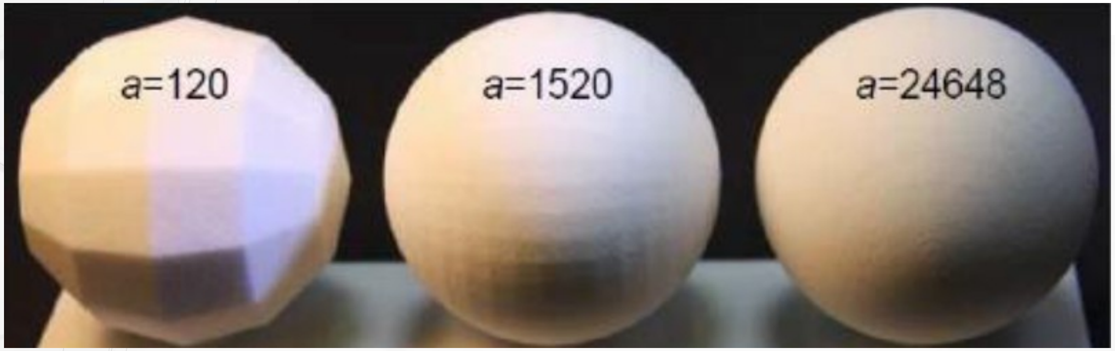
- Product design
- Design for digital production
- Design for additive manufacuting
- Desgin for specific AM technolgy (SLS, FDM, SLA)

Design rules

- This is not a design rule but it can be very important and helpful rule!!!
  - Conversion CAD to STL file format
    - Low resolution – low surface
    - High resolution – big file and better surface quality



File size



Design rules

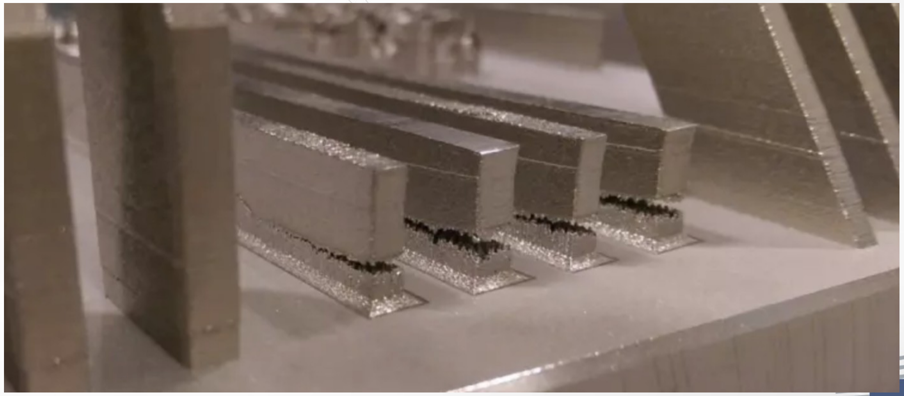
- The generic design rules
  - Material
  - Part dimensions
  - Min/Max feature size on the part
  - Part geometry
  - Parts consolidation
  - Tolerances assigned to part
  - Additional support structure
  - Captured basic material
  - Part orientation

Design rules

- The material -> define the type of the AM technology which will be used.
- It is not possible to use every material in different AM technology In SLA technology as base material is resign, in FDM is thermoplastics and metal, in EBM(Electron Beam Melting) - only metals, SLS and DMLS– thermoplastics and metals
- For certain materials, in some AM technologies exist the large residual stresses which can cause major problems in the production process (SLS and DMLS), while for other processes (EBM) there are no problems with residual stresses

Design rules

The residuals stresses in SLS-DMLS (stainless steel PH1)

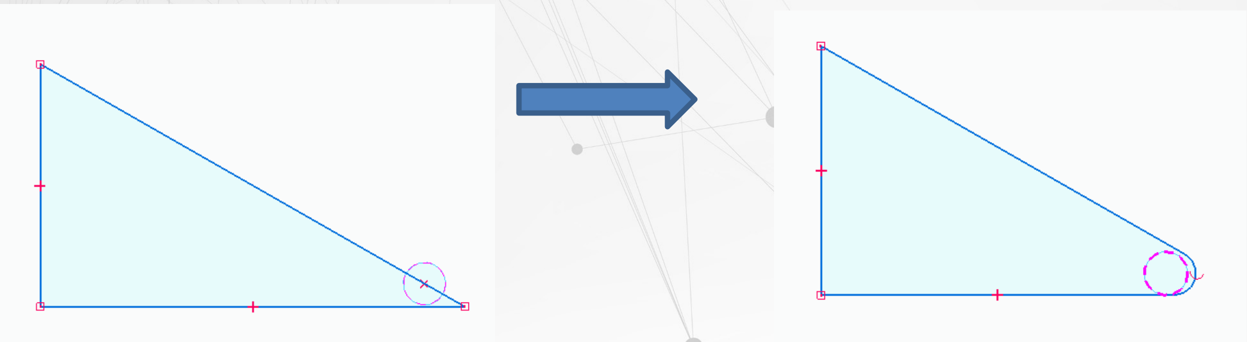


PROJECT SUPPORTED BY European Commission

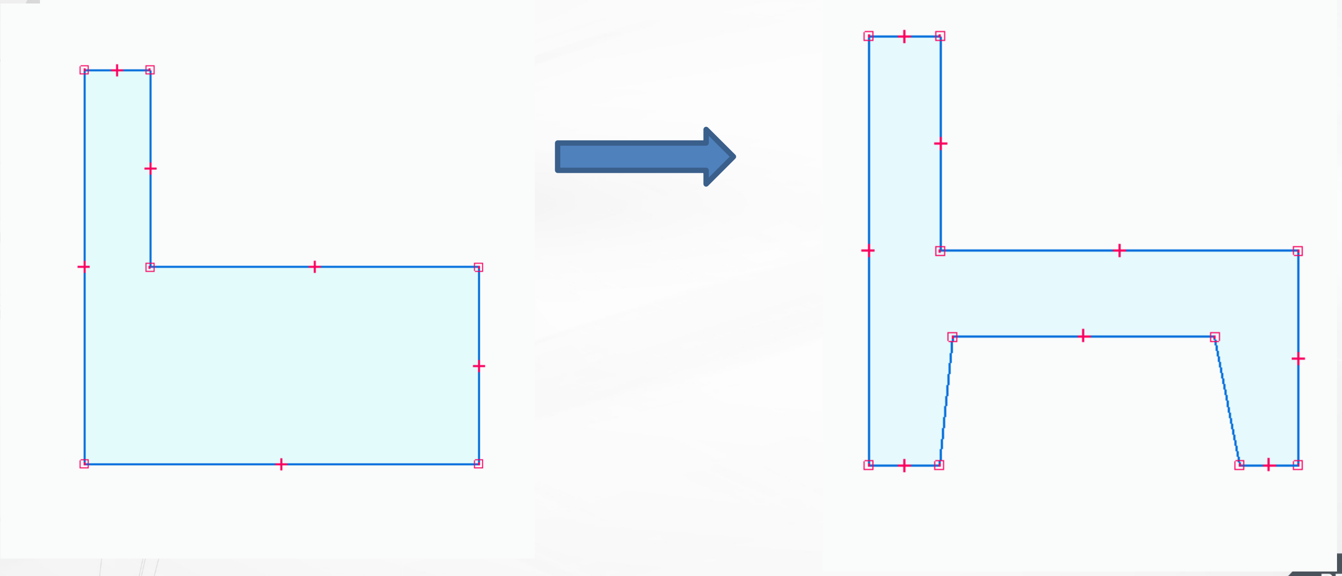
Design rules

- Part dimensions
  - The dimensions of the working volume is the key factor for selection of the appropriate AM technology
  - In some types of the AM technologies is possible to split part and after building process to combine (gluing parts which are produced by SLS)
  - Due to materials or production process in some types it is not possible to split parts and then combine in single part

Design rules



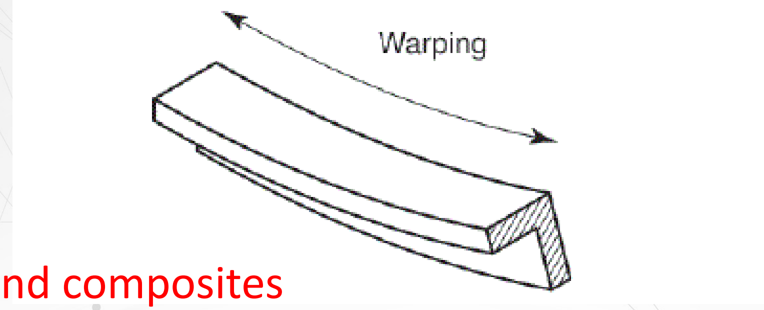
Restrictions related to some technologies



Recommendation for AM

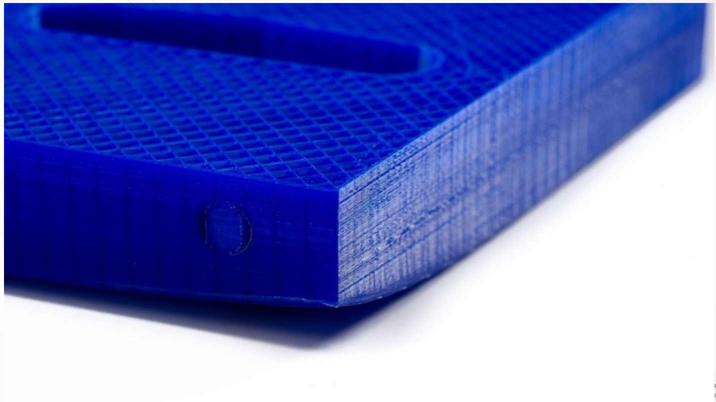
Design rules

- Problems of the materials concentration and thermal stress in the parts during process of the production
  - Warping –



SLS-thermoplastics and composites

FDM



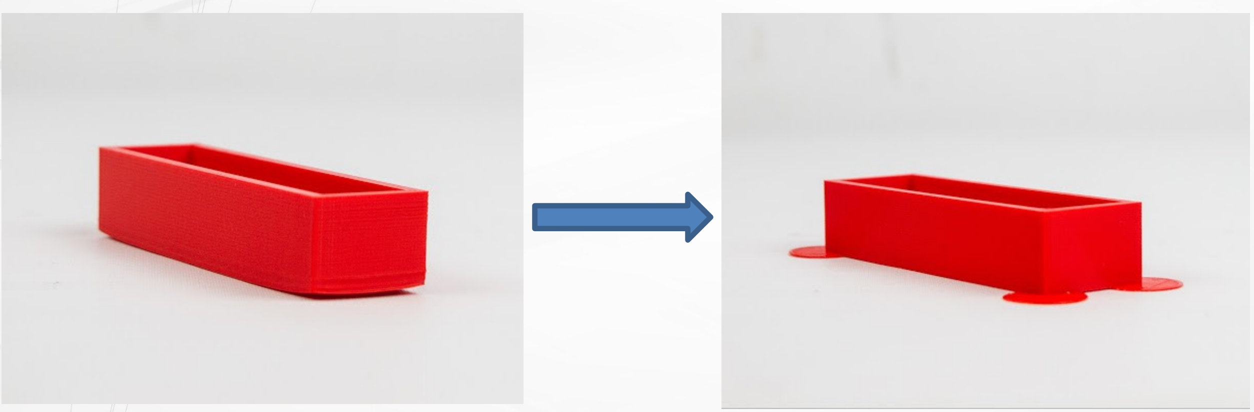
Design rules

- Min/Max feature on the part
  - Minimal feature on the part determines the possible type of the AM technology which can be used for production
    - SLS – DMLS – the laser spot defining the minimal feature dimension on the part, for instance, the laser spot size for plastics and composites in SLS is 0.3mm and for DMLS and metals is 0.2 mm
    - FDM – the nozzle diameter and step size defining the minimal feature size
    - SLA – the screen resolution or laser spot size defining the minimal feature size
  - Besides the mechanical characteristics of the different systems, the minimal feature siye also defining and materials characteristics
    - In SLS or FDM it is possible do build the axle of 0.8mm, but it is very likely that will not be able to withstand the load
  - The maximal feature size on the part are determined by characteristics of the process and material. For instance, if we have very tine and long parts then it is possible to have problems with residual stress and with warping

Design rules

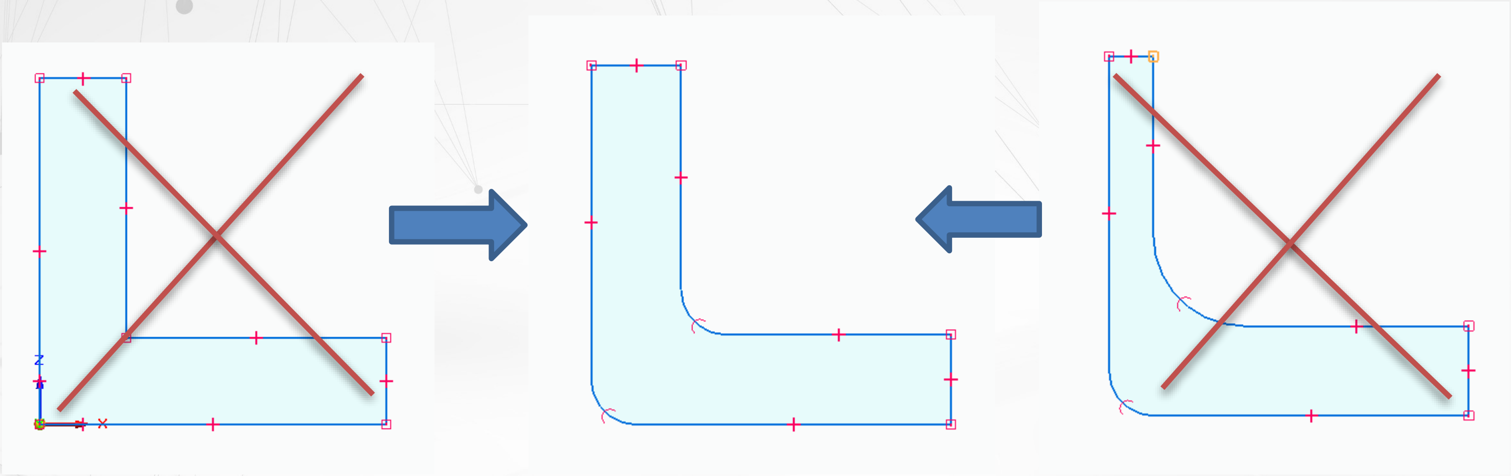
- In different types of AM technologies a different approaches to solve same problem (warping)
- SLS – part reorientation

- FDM – add the additional structures



Design rules

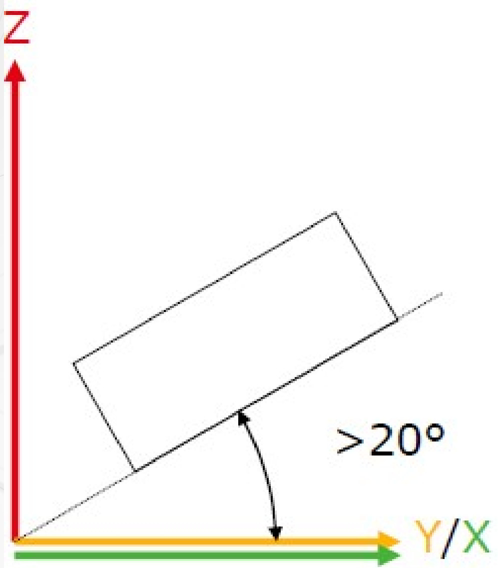
- SLS- plastic and metal parts
  - Avoid the sharp corners

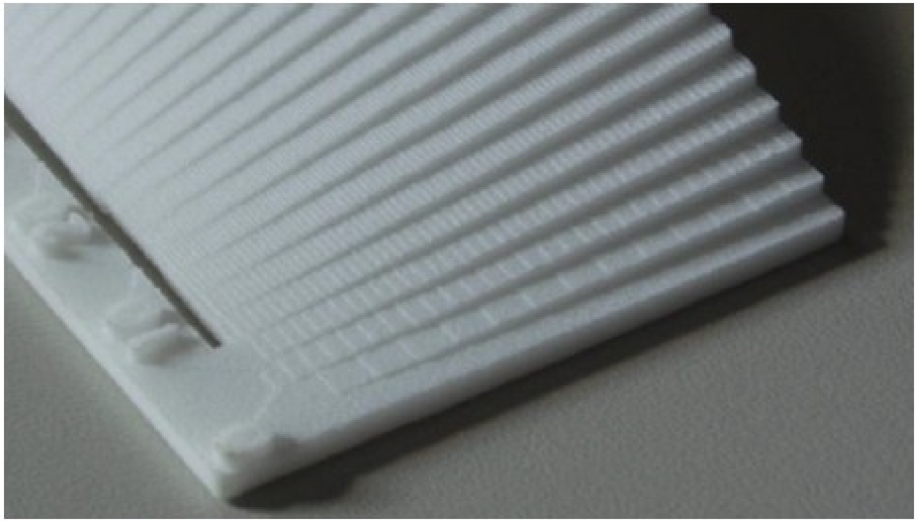


Design rules

- The part production in layers have also and some disadvantiges.

The stair-stepping effect is usualy shown on surfaces with low slope angle to the base





Design rules

- **The gaps (SLS):**
- x and y direction – 0,3 do 0,5 mm
- z direction – 0,5 do 0,6 mm

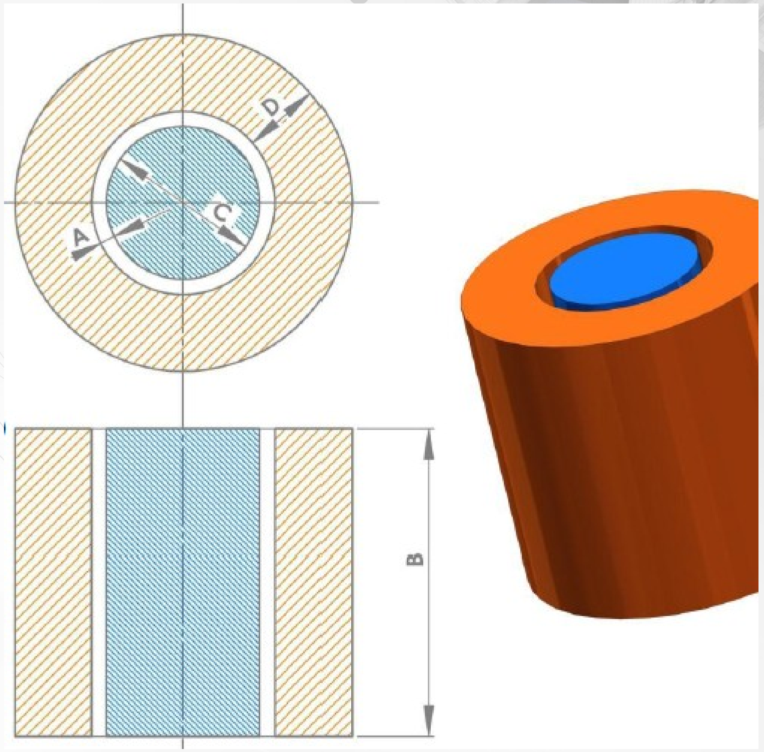
Variable:

The gap dimension A

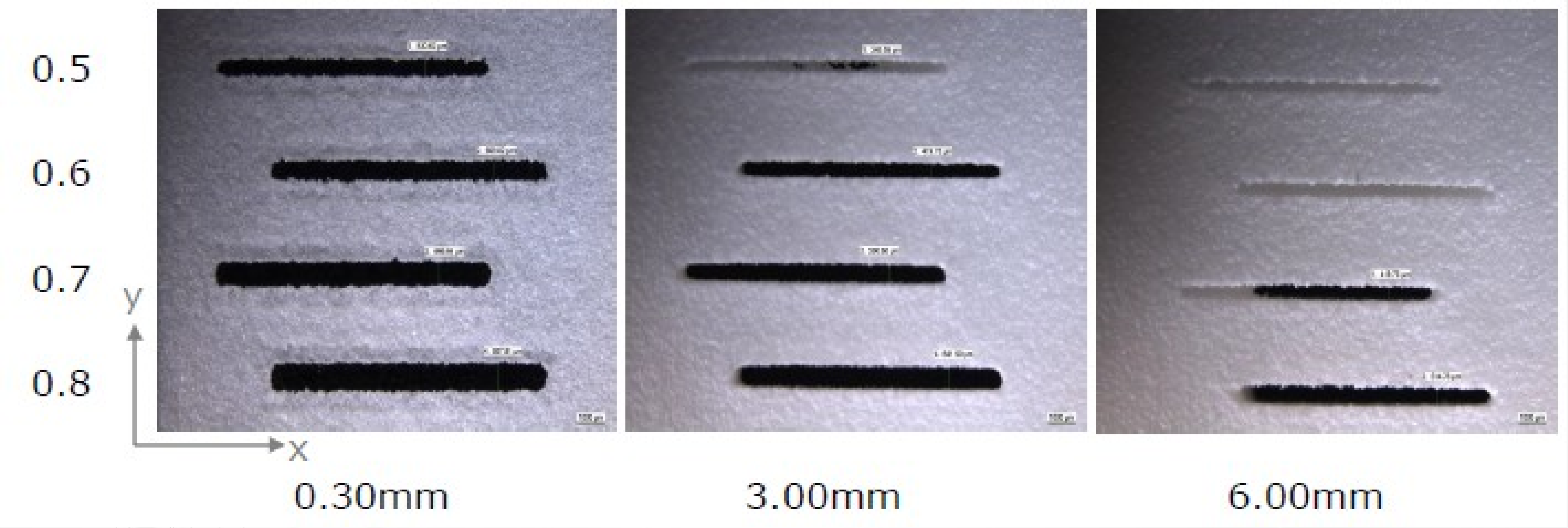
Shaft dimension C

Thickness of the part D

Hinge height B

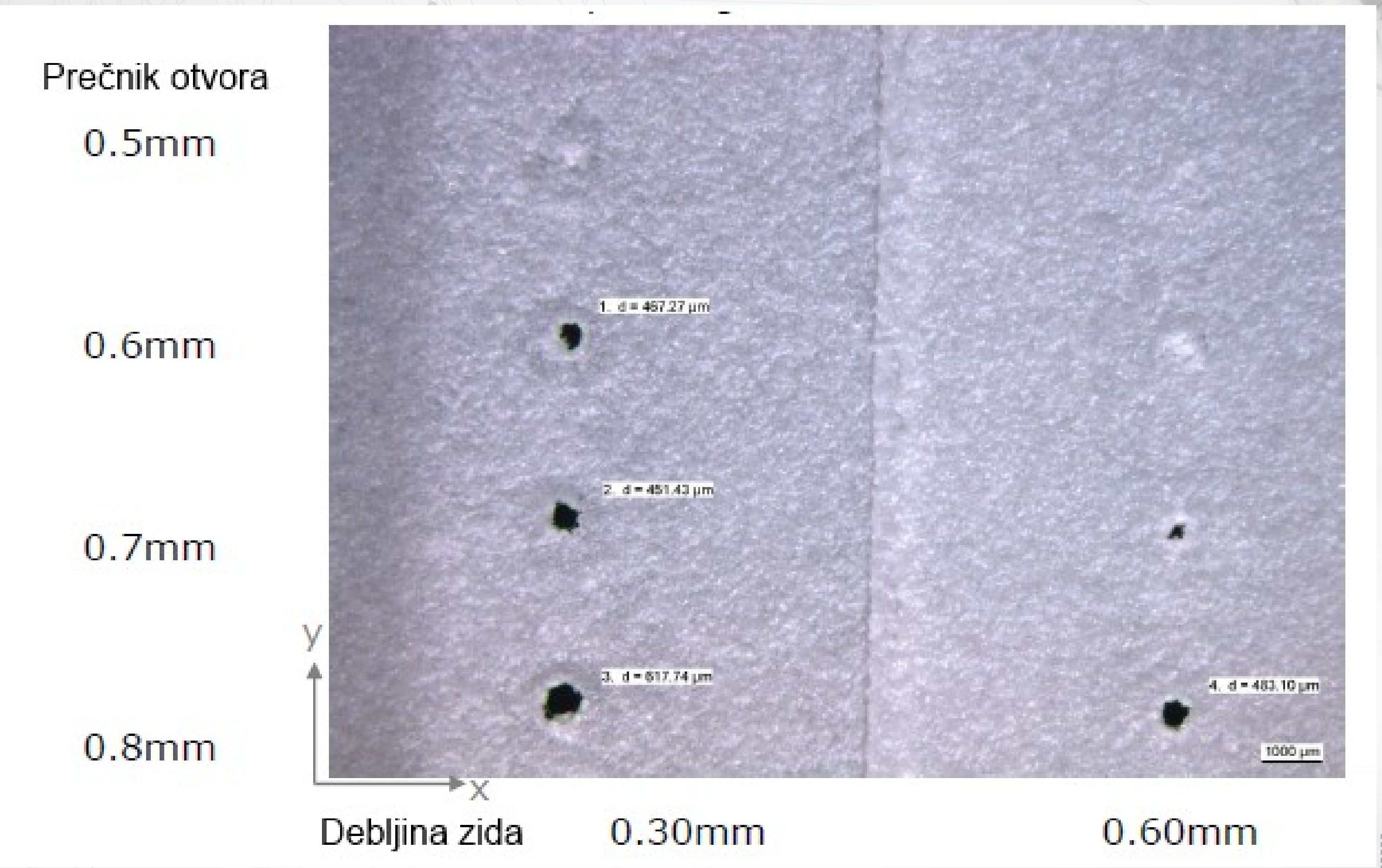


- Openings and holes



Wall thickness

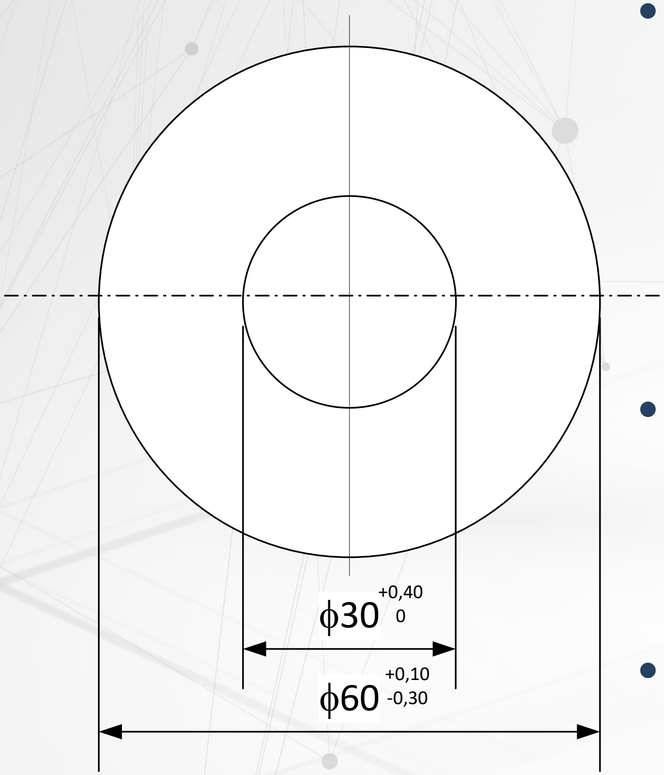
Design rules



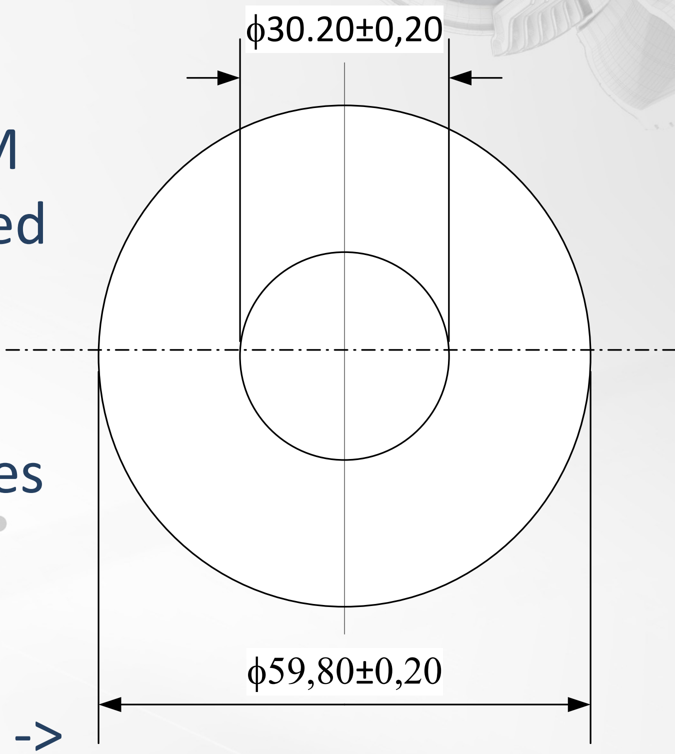
PROJECT SUPPORTED BY European Commission

Design rules

- **The tolerances**

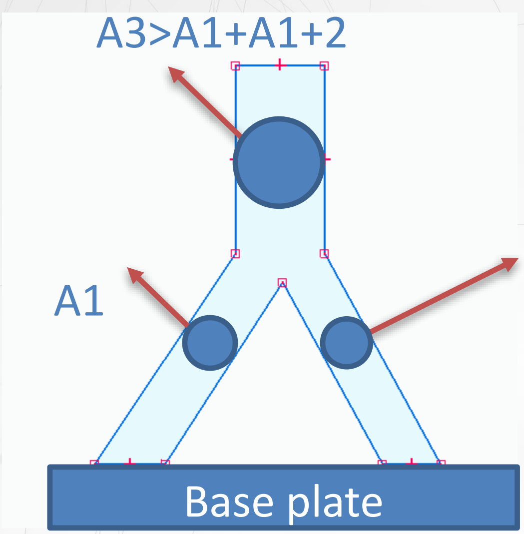


- The deviation of the nominal values for AM parts should be defined as symmetric
- < - Asimetric tolerances
- Symmetric tolerances ->

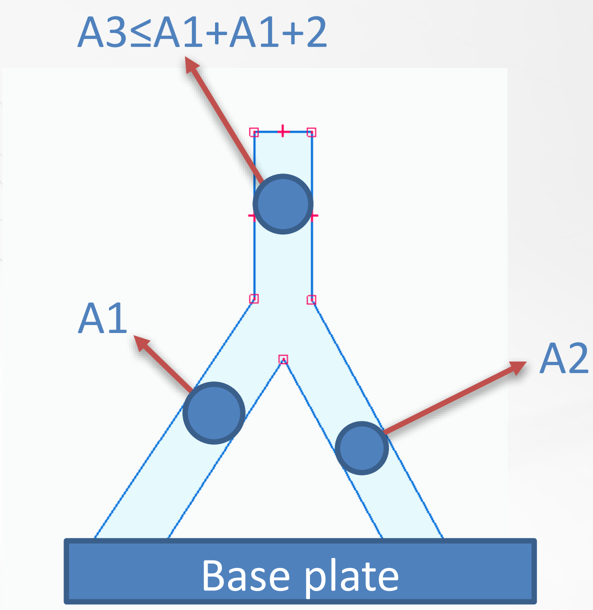


Design rules

- DMLS – Metal laser sintering
- Shape transition



Undesirable

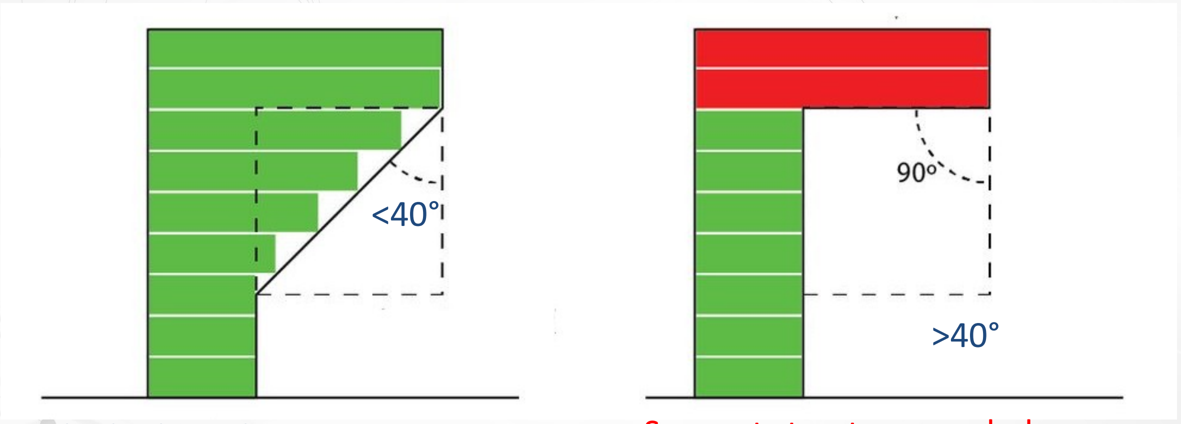


Desirable

This shape transition is very important for metal parts building due to transition of the generated heat from melting pool to the base plate

Design rules

- Overhange
  - For each surface with the slope less than 40 deg from the x-y plane it is necessary to build the support structure

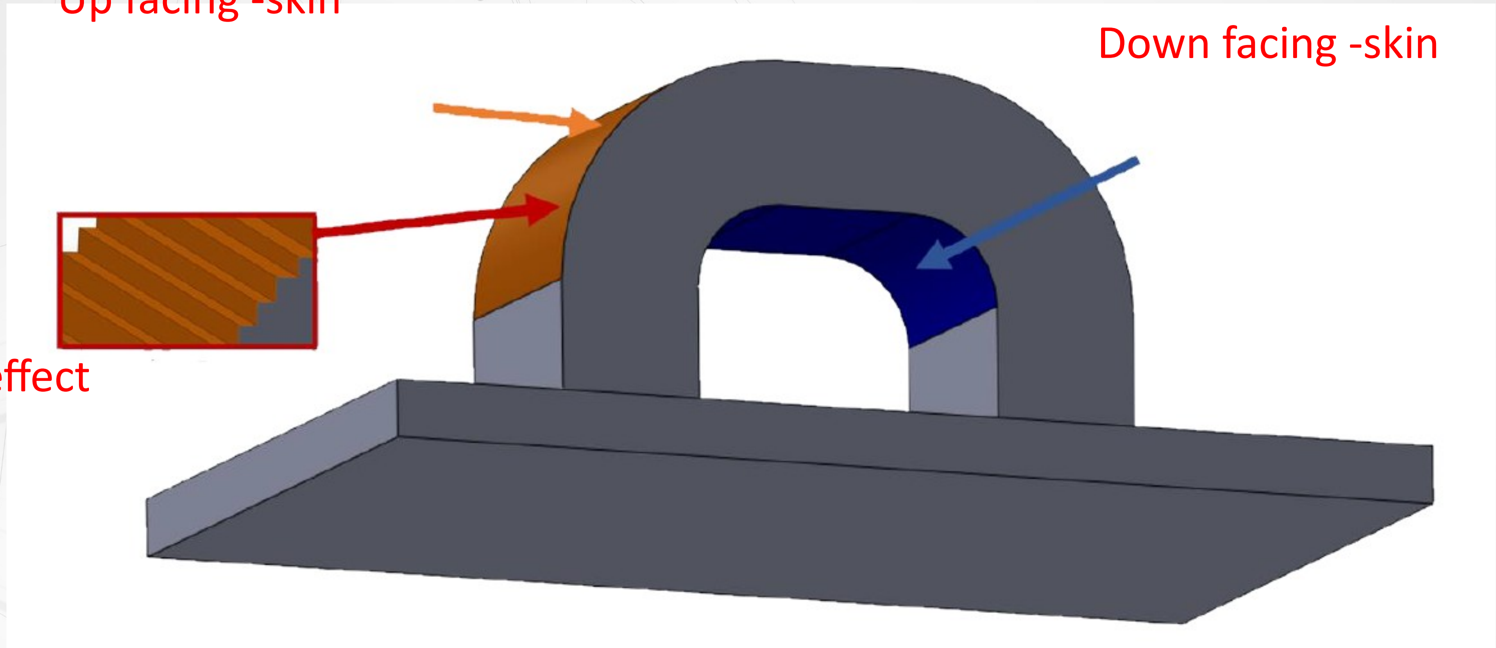


It can be build without support structure

Support structure needed

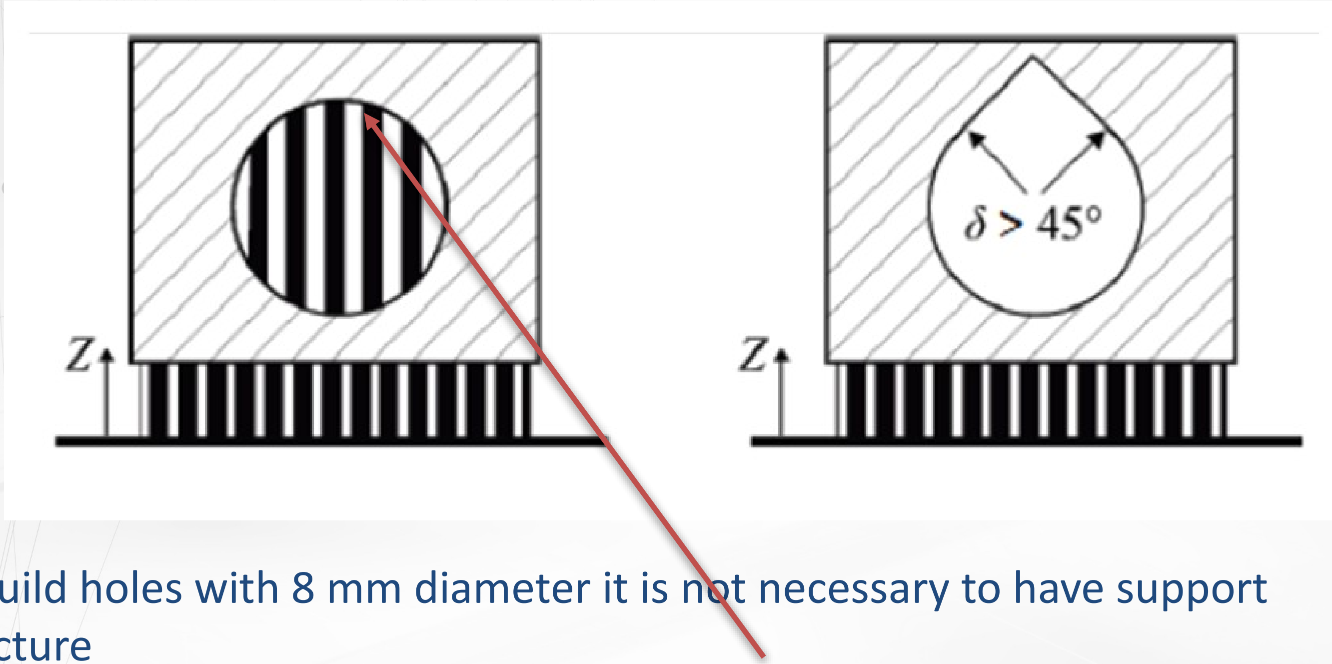
Design rules

- Surface definition



Design rules

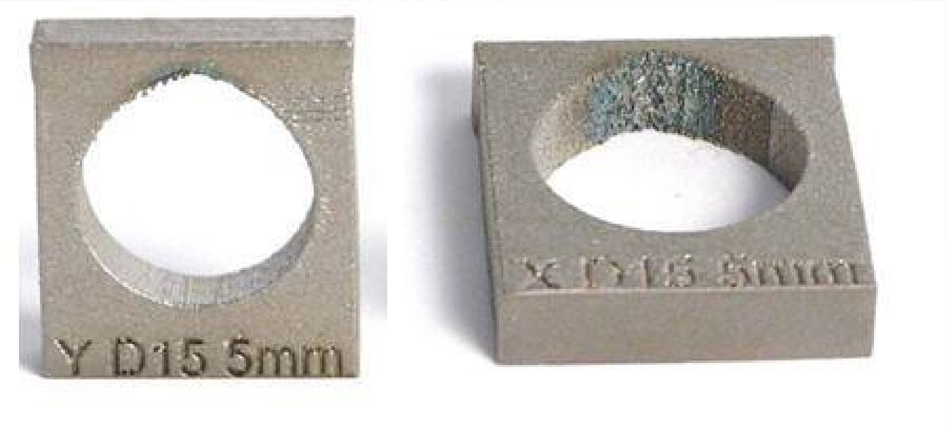
- Self-supported structures



- To build holes with 8 mm diameter it is not necessary to have support structure
- For holes the down skin surface has very low quality

Desig rules

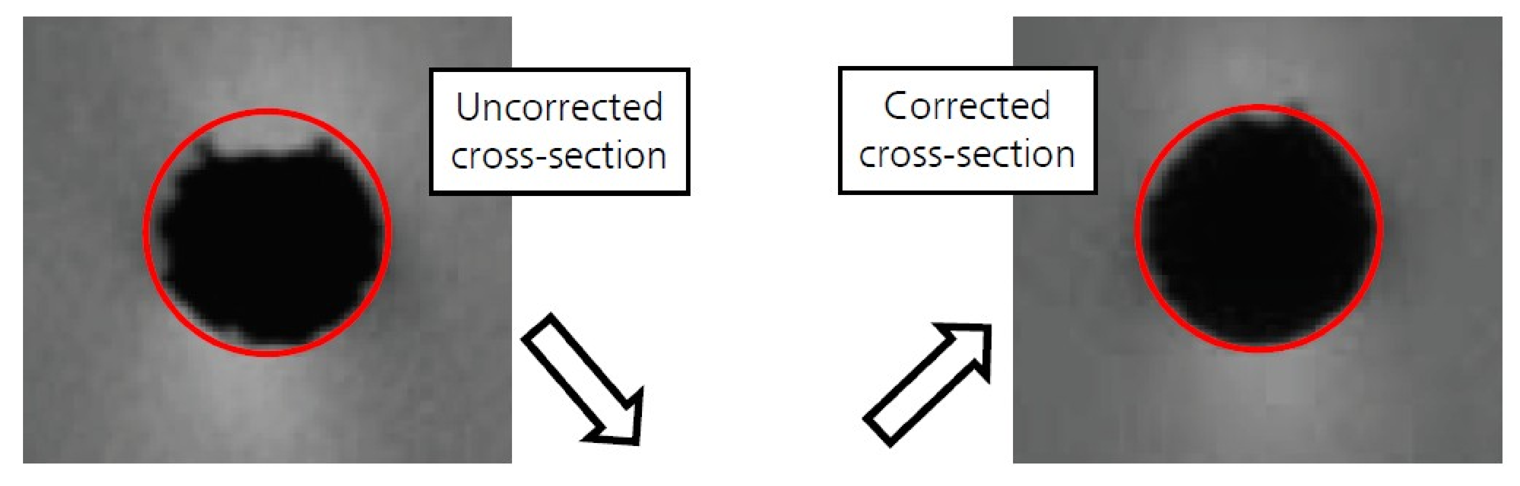
- Self-supported structure

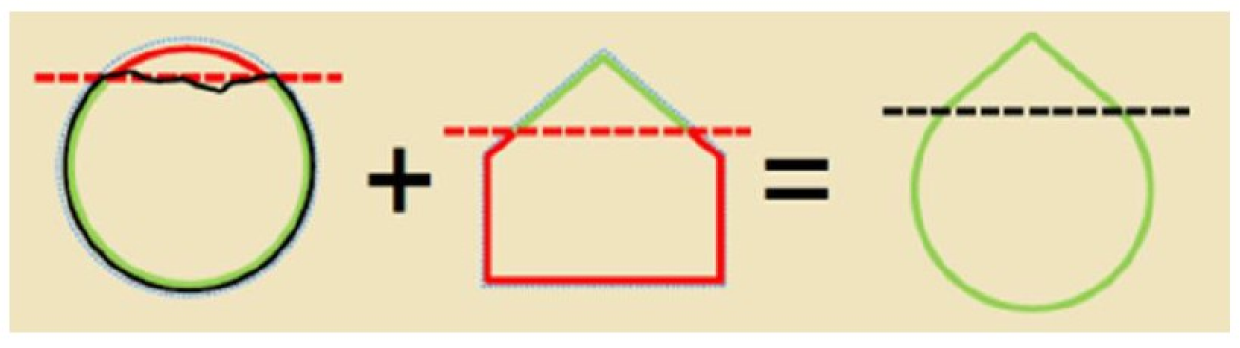


Example of building the hole of 15mm diameter without support structure
On the right picture it is shown the surface quality on the down skin inside the hole

Design rules

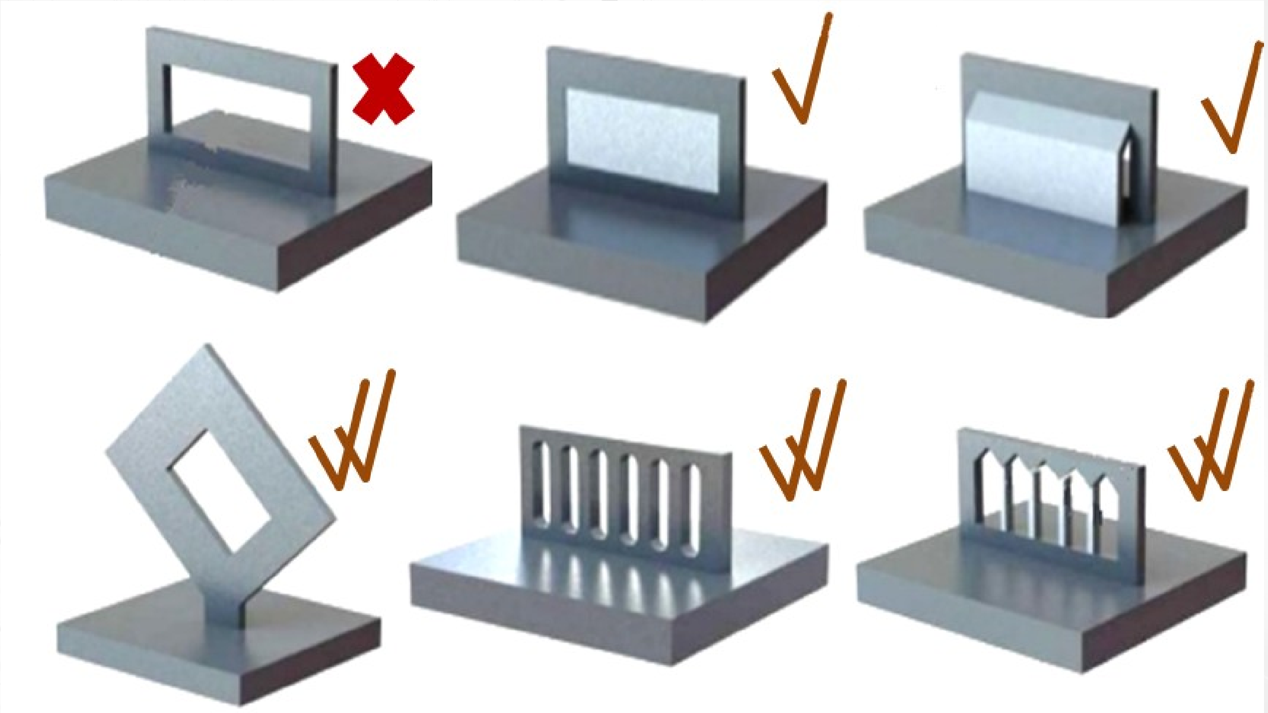
- Self-supported structure





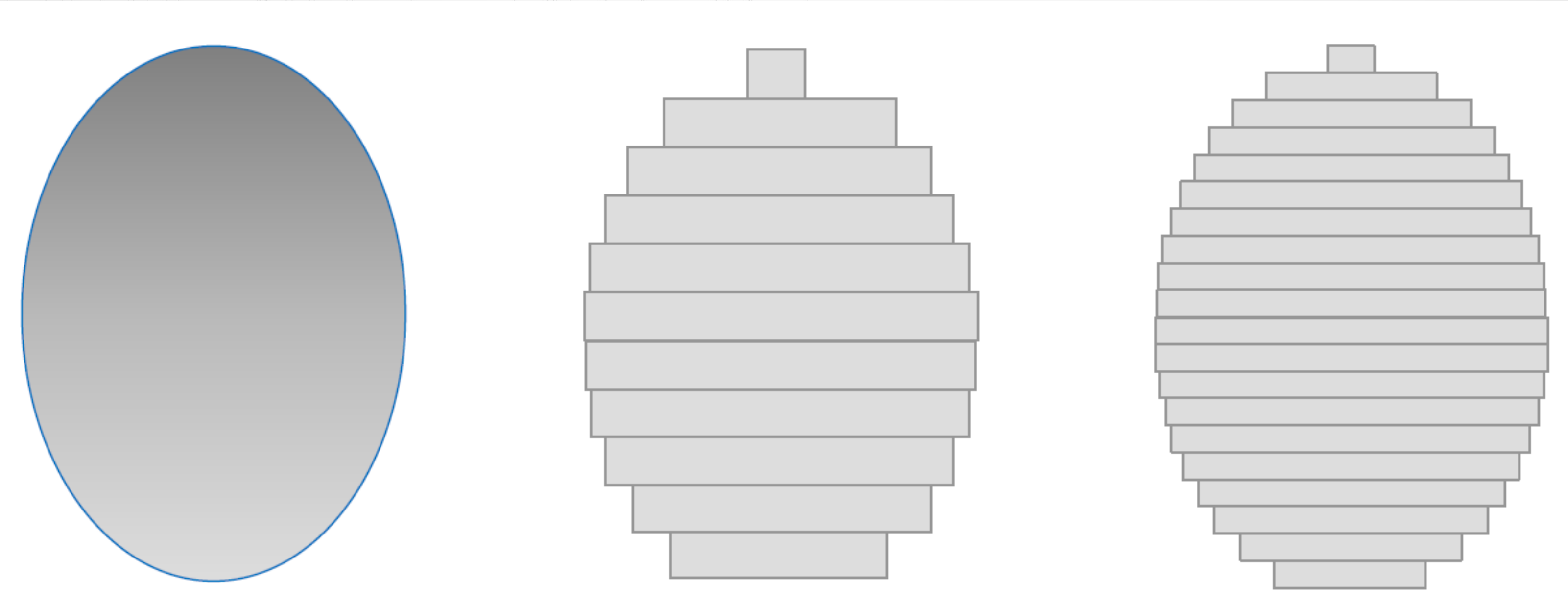
Design rules

- A few solution how to build the self-supported structure



Design rules

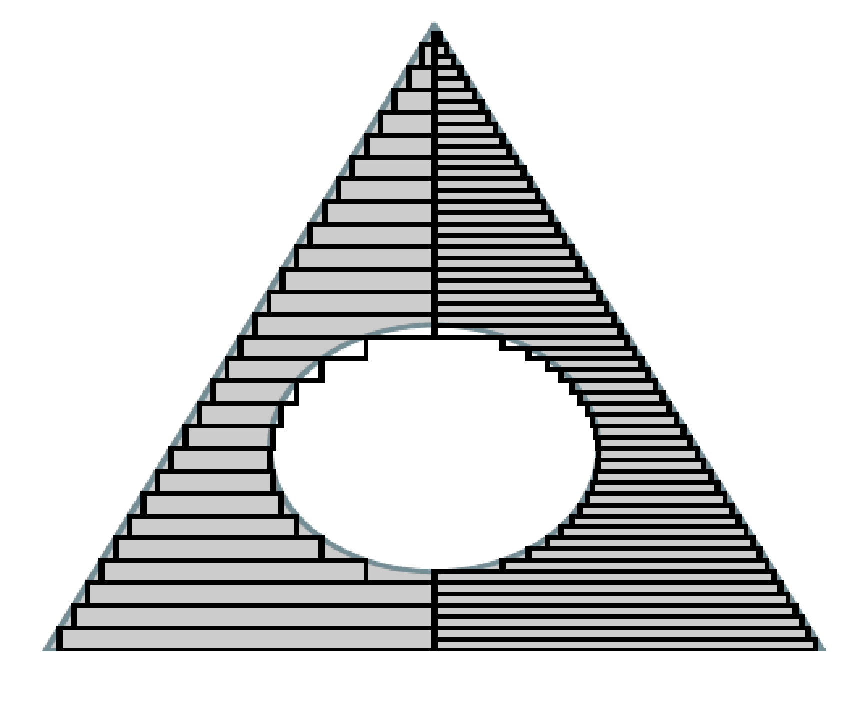
- Production parts in layers



More layer – better representation of the surface curvature
The build process is last longer
The size of the file is bigger

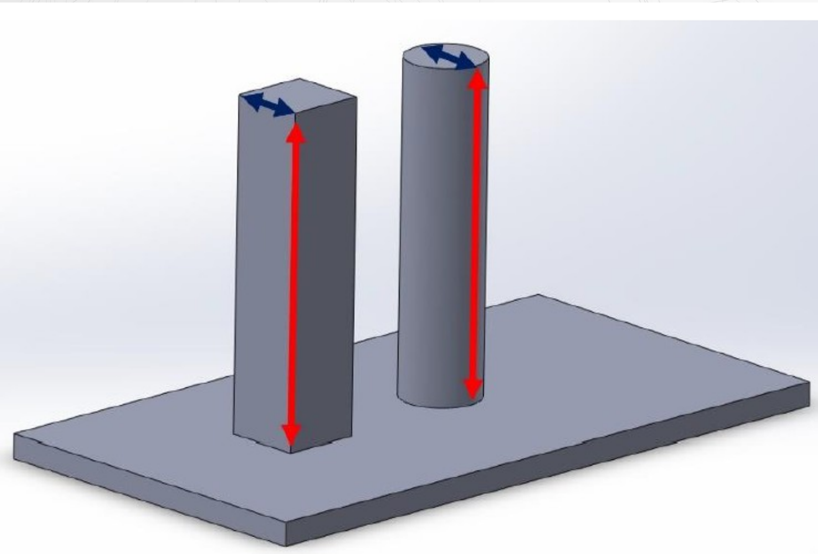
Design rules

- The resolution in x-y plane define the laser spot movement
- The resolution in z direction defining the layer thickness and, in general, have a big influence on:
  - Building speed
  - Process stability
  - The part acuracy
  - Surface quality
  - Mechanical characteristics of the parts
  - etc...



Design rules

- Height-Width ratio



	Height [mm]					
	<1	1	10	20	30	>30
Width <1						
1						
2						
3						
5						
>5						

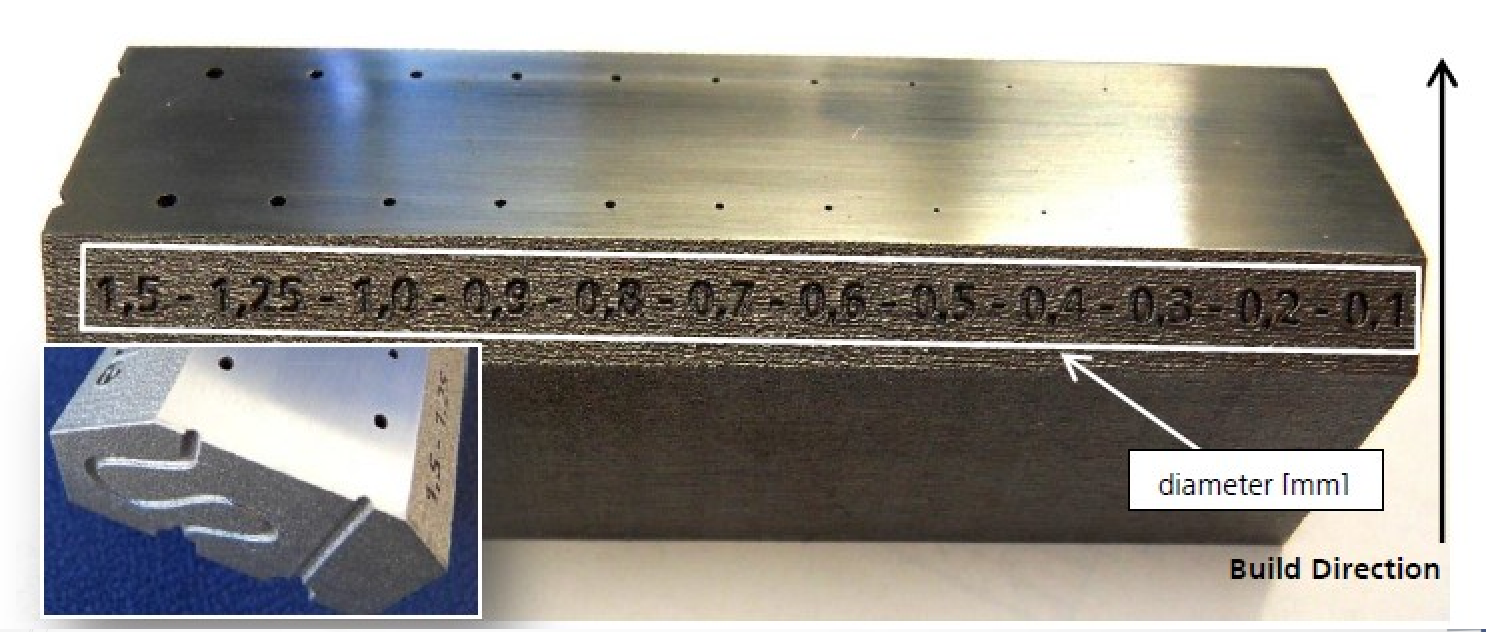
	Height [mm]					
	<1	1	2	5	10	>10
Side length / <1						
Diameter 1						
2						
3						
5						
>5						

If the parts have big ratuio of heiht/width than during of the process of recoating it is most likely to have the vibrations of that parts and they can be deformed

If it if possible it should be in the limits H/B(D)< 8

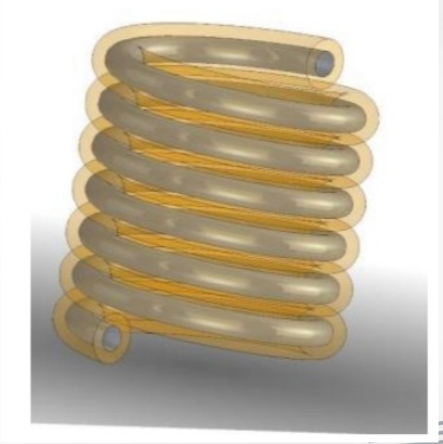
Design rules

- Minimal hole diameter
  - Recommendation 1 mm
  - If we have straight holes than air can pass thru holes with diametar of 0.4mm
  - In the case that holes are not straight than the air can pass thru holes of diametere of 0.6mm



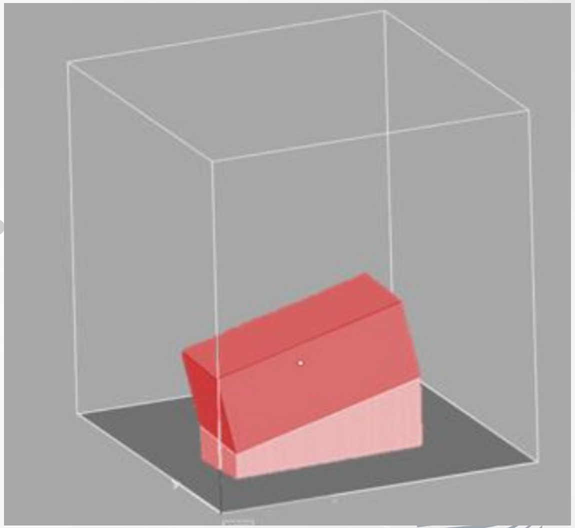
Design rules

- Captured base material
- Removing powder form channels (SLS)
    - It can be a problem remove the powder from long channels with small diameter
  - Complex structures



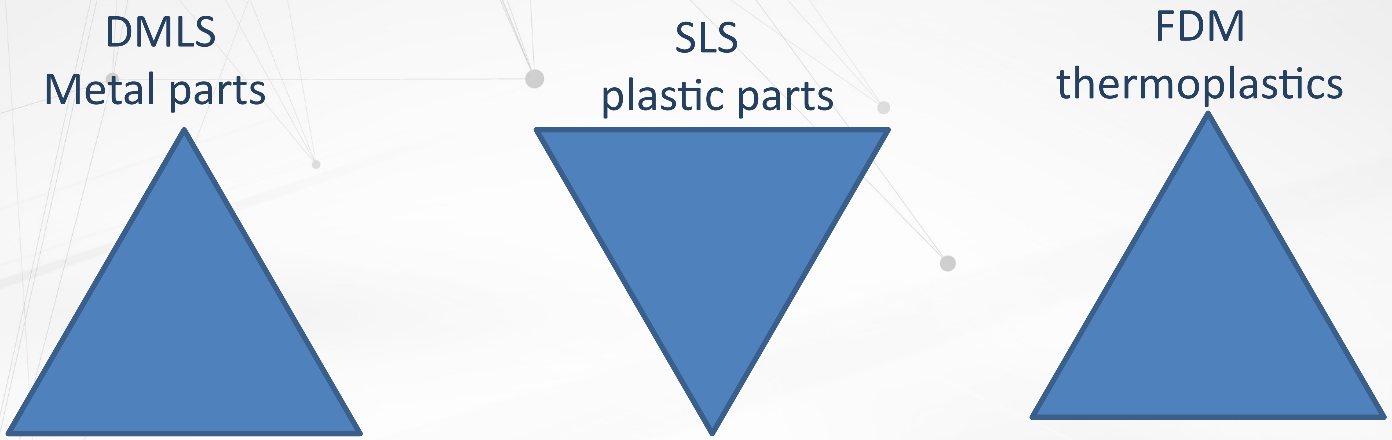
Design rules

- Part orientation
  - It is necessary to take into account the part orientation during building in the phase of part design
  - The part is acceptable for AM and if we need to create the additional support structure.
  - Orientation has big influence on:
    - Quality
    - Possibility to build parts
    - Part mechanical characteristics
    - Price
    - Post-processing



Design rules

- Each type of AM technology has its own rules



Design rules

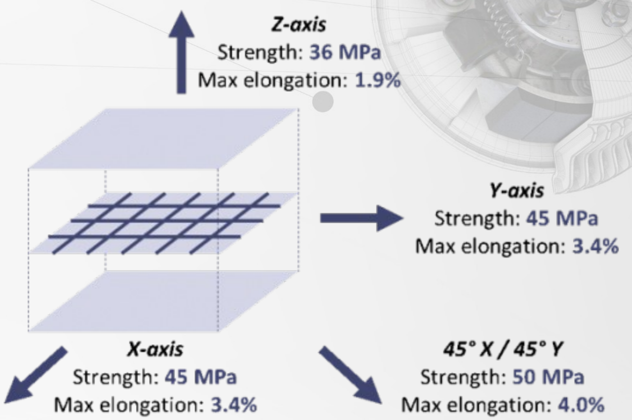
- Part orientation:
  - Part-surface quality
  - Possibility of building
  - Mechanical characteristics
  - Price
  - post-processing

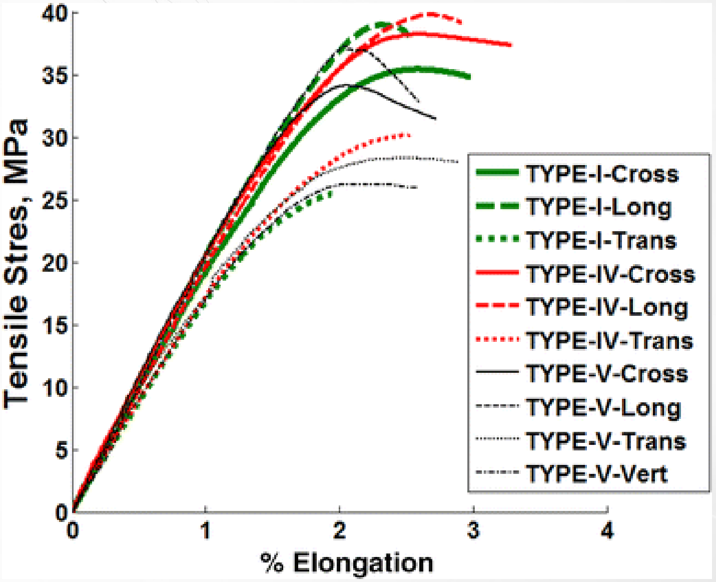
Design rules

- Part orientation:
  - Part-surface quality
  - Possibility of building
  - Mechanical characteristics
  - Price
  - post-processing

Design rules

- Part orientation:
  - Quality
  - Possibility of building
  - Mechanical sharacteristics
  - Price
  - Post-processing

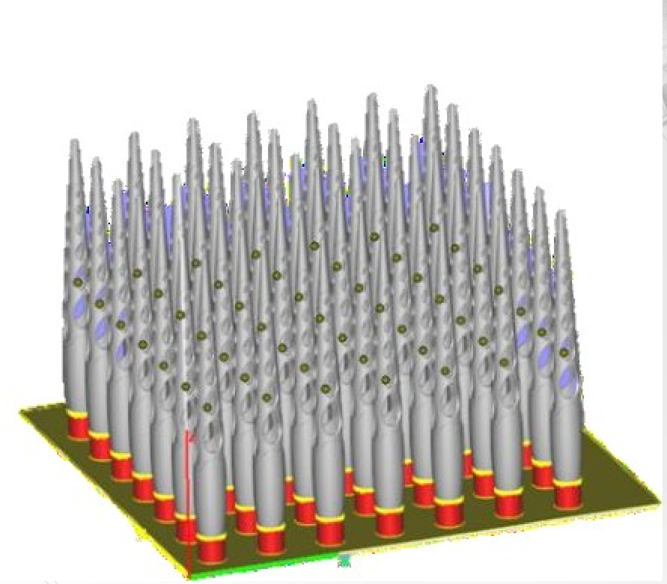




PROJECT SUPPORTED BY European Commission

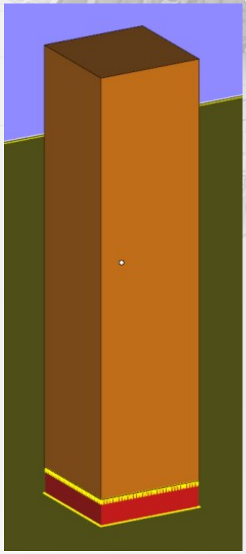
Design rules

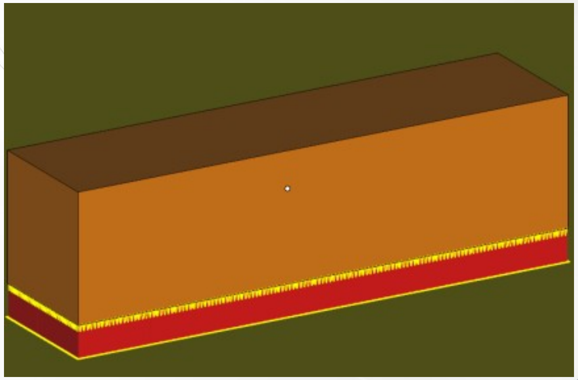
- Part orientation:
  - Quality
  - Possibility to build
  - Mechanical characteristics
  - Price
  - Post-processing



Design rules

- Orientation:
  - Quality
  - Possibility to build
  - Mechanical characteristics
  - Price
  - Post-processing





PROJECT SUPPORTED BY European Commission

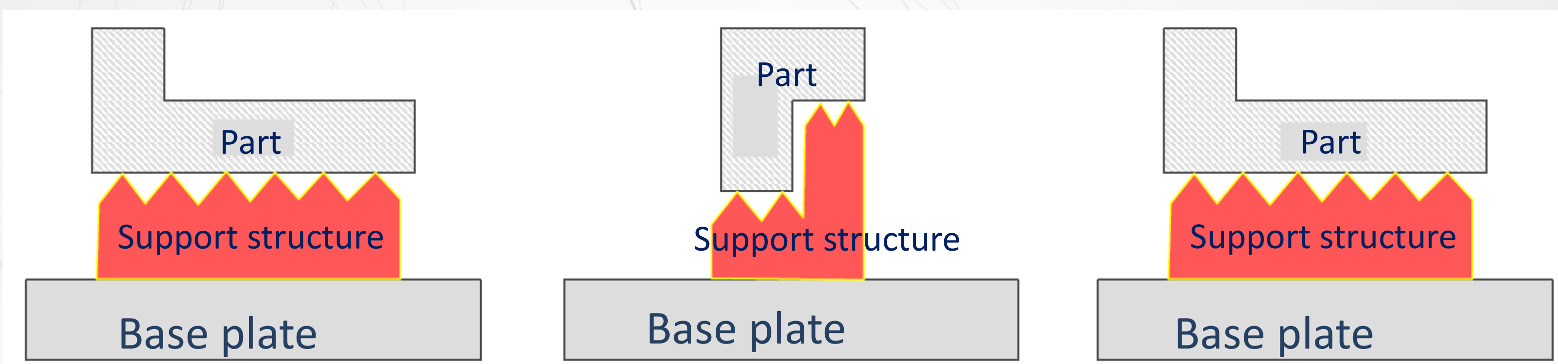
Design rules

- Support structures – role in AM

Secure part in one position in working volume

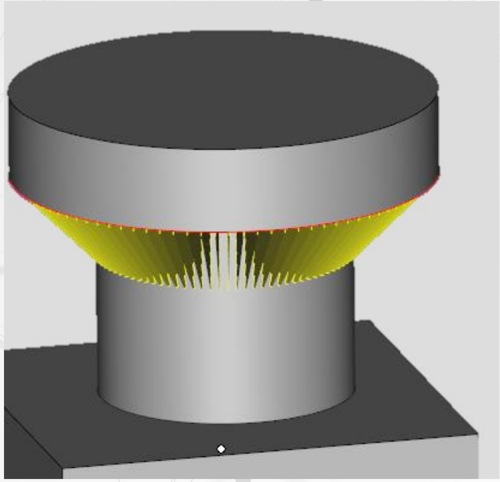
Provide the the possibility to build part overhangs

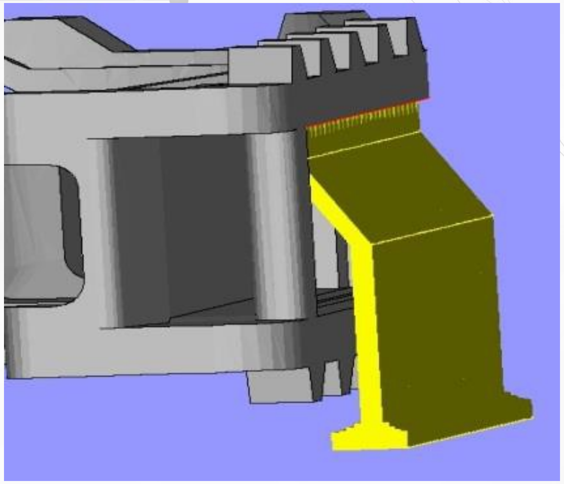
Provide the transfer of heat from melting pool to the base plate

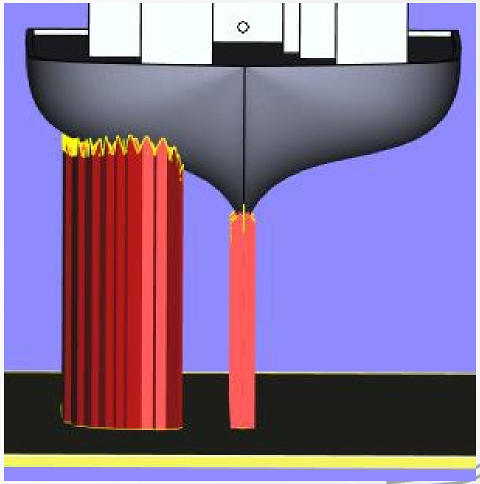


Design rules

- Support structures significantly complicates the process of making parts
- It does not add any new value to the part being built
- Increase the price of the part
- Therefore, it is desirable to introduce support structures only in places where it is necessary
- The surface on which the support structure is placed, after removing it, has a very high roughness and it is necessary to provide a larger allowance for processing

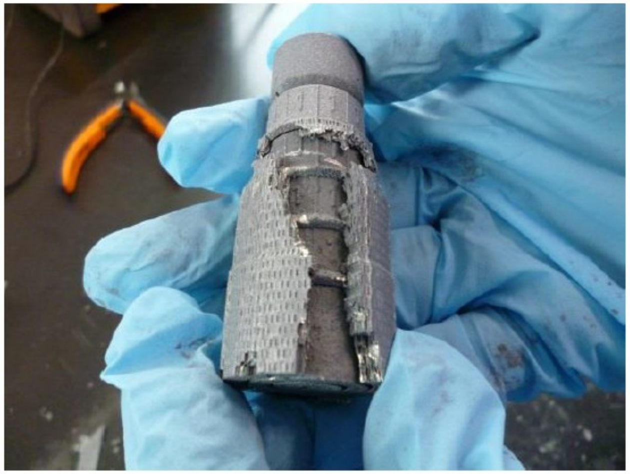






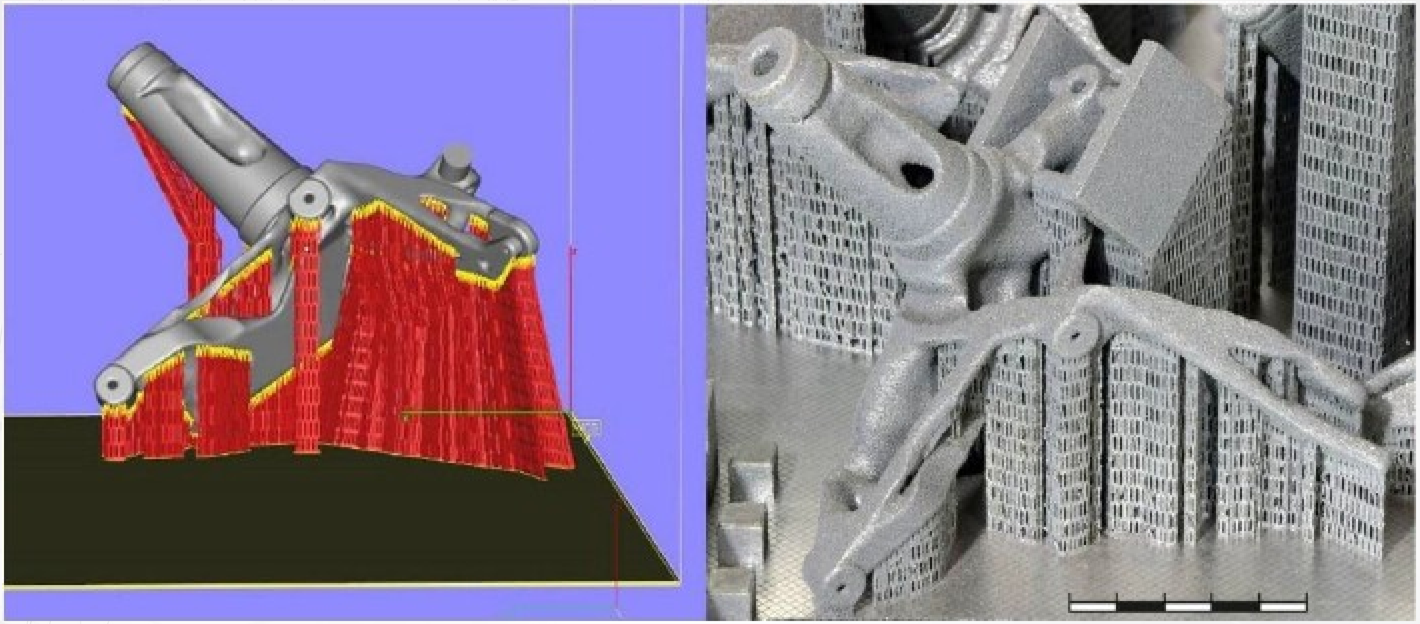
Post-processing

- Removing the support structure



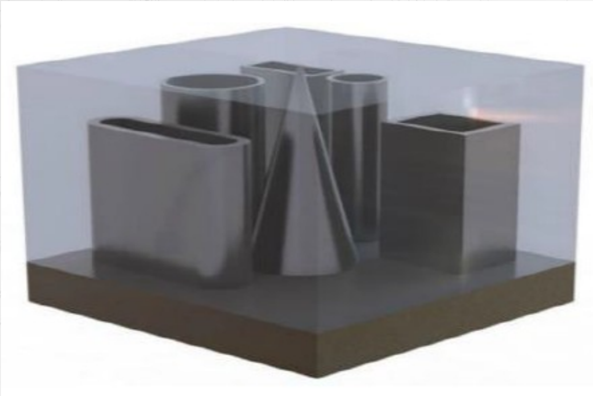
Part preparation

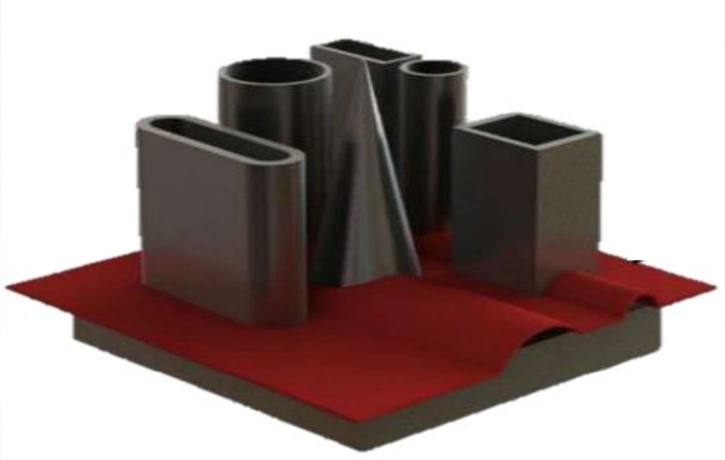
- Support structure and part preparation for production



Post-processing

- Removin parts from base plate



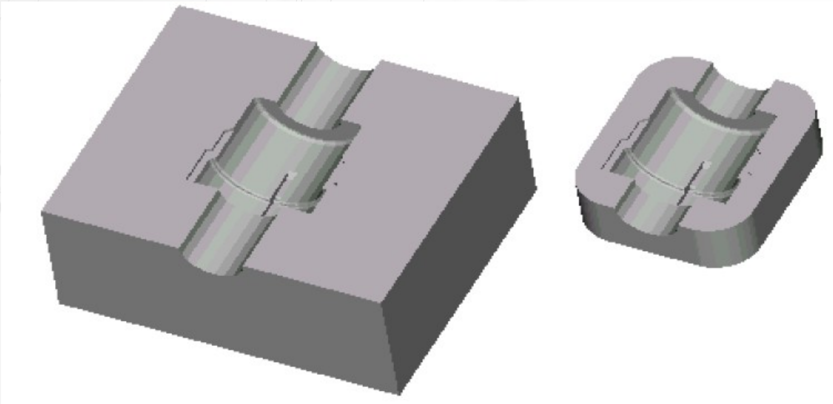


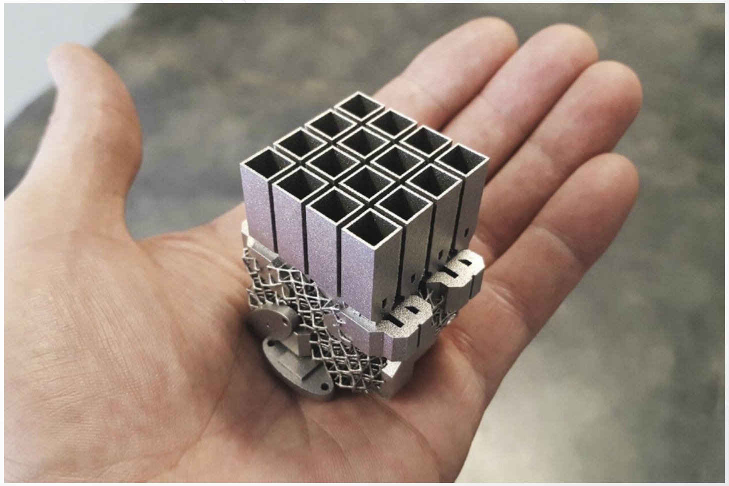
Post-processing

- If it is necessary to achieve a certain surface roughness or appropriate dimensional accuracy, it is recommended that this be achieved by conventional processing procedures.
- The allowance for fine machining should be 0.2-0.5 mm depending on the dimension and the given tolerance field.

Optimization

- Optimize the part that is being built AP in order to reduce production costs
- Instead of making one massive part, separate the part with complex geometry and make the rest in a conventional way.
- Consolidation of several parts into one part



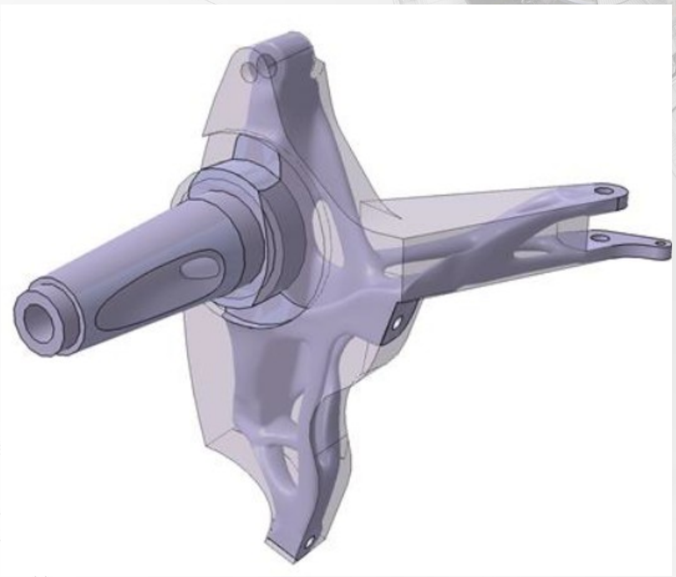


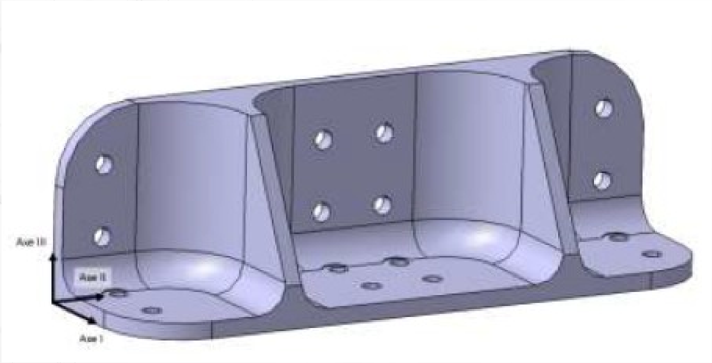
Optimization

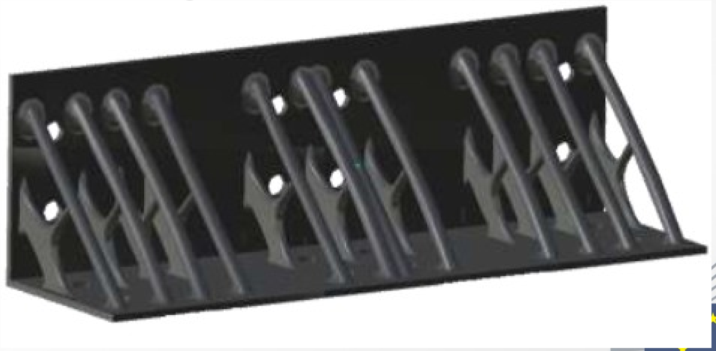
- Perform optimization of the parts produced by AM to reduce the costs
- Reduce the number of the compopnets

Optimization

- Topological optimization vs conventional modeling
- Topological optimization - minimization of the mass of the part while ensuring the appropriate function and load capacity of the part
- Most of the existing design systems have started the implementation of topological optimization

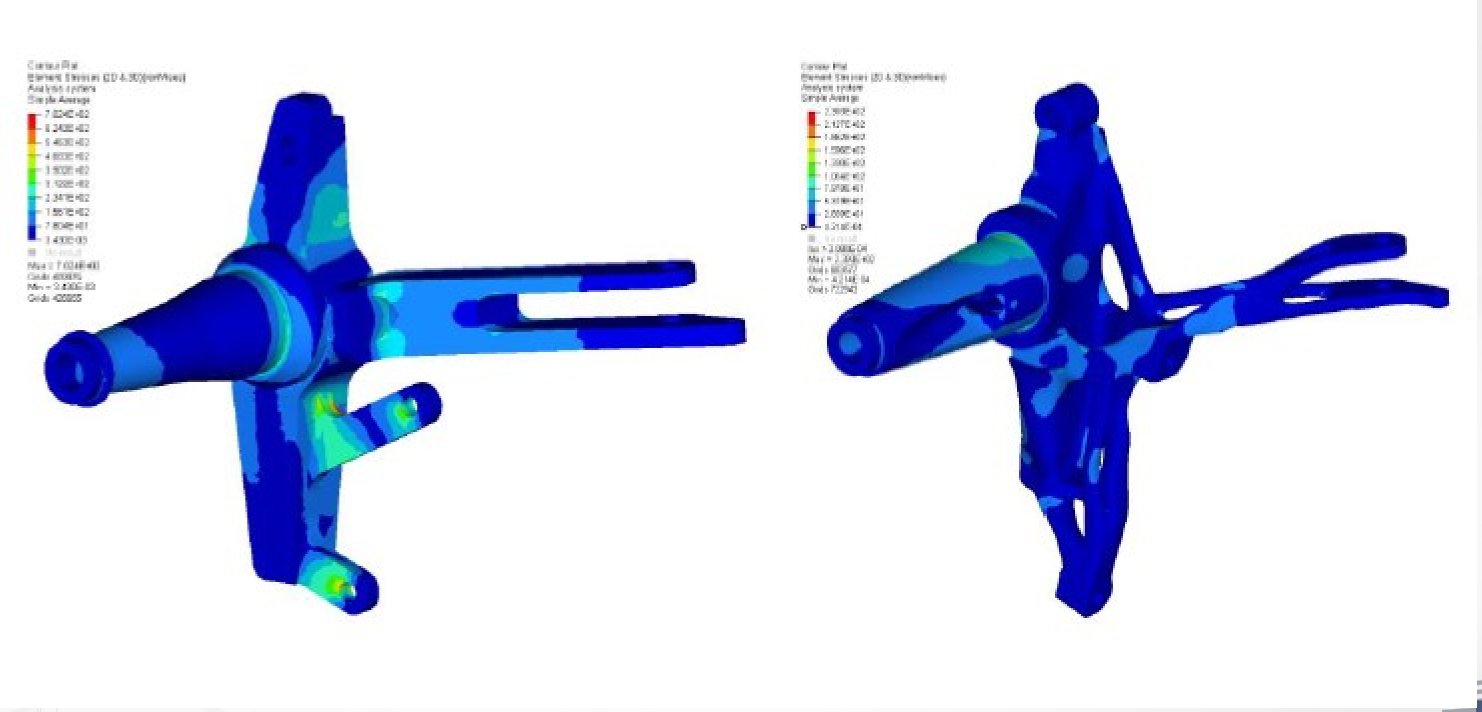






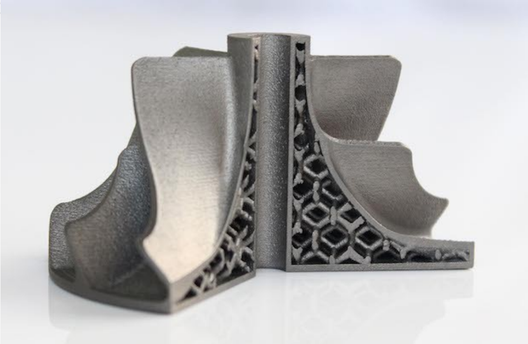
Optimization

- Toplogical optimization – stress distribution



Optimization

- Lattice structures
  - Creating a "lattice" structure that can
    - provide appropriate mechanical characteristics
    - Reduce the mass
    - Take care of the dimension of the lattice structure and the possibility to removal dust



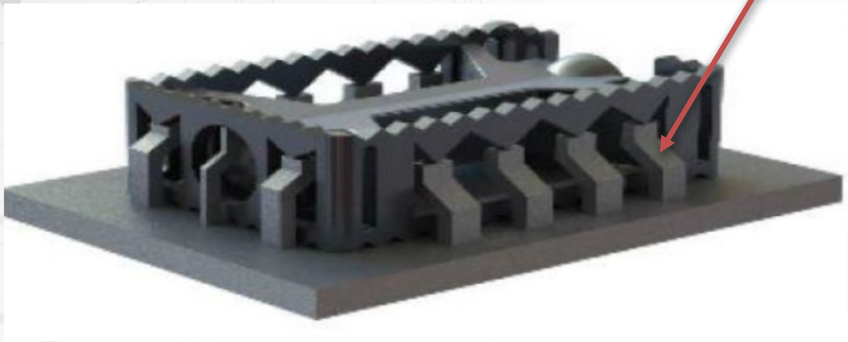
Optimization

- A combination of topological optimization and lattice structure
- Lattice structure can be placed in places where topological optimization has no solution and thus further improve the process of designing the final product
- The use of topological optimization and lattice structures, for now, conditions the mandatory use of AM

Example design for AM

- Conventional bike pedal shape
- Large amount of supports
- A small number of pieces on the base plate
- Possibility of occurrence of residual stresses - large contact surface
- Relatively large post processing to remove the supporting structure

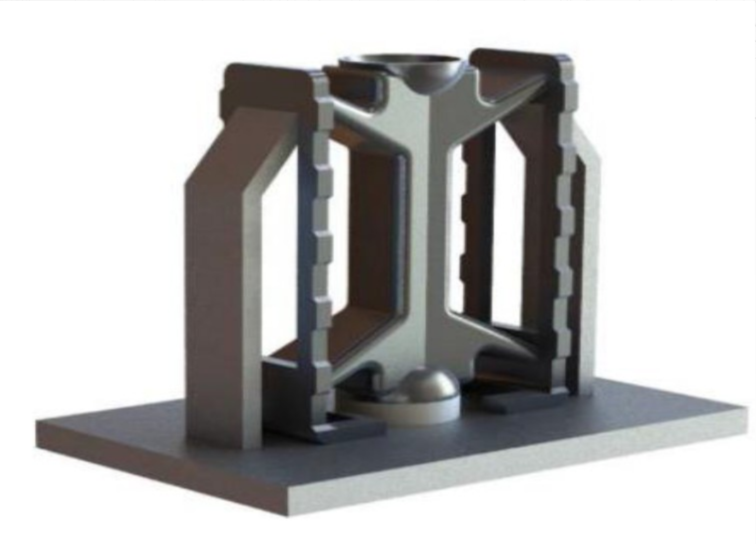
Example design for AM



- Let's apply some of the recommendations to reduce supports

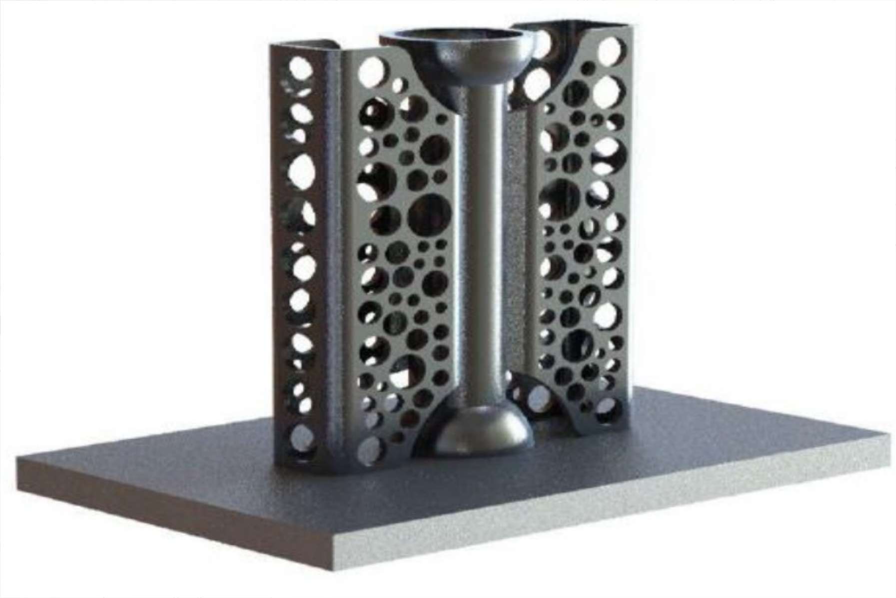
- Low height of the part for building
- The amount of support structure is reduced
- Post processing has been reduced, but it is still needed
- Residual stress are still present
- A small number of pieces on the base plate

Example design for AM



- Part reorientation
  - Reduced amount of support structure
  - Reduced post processing
  - The contact area of the part and the plate is reduced - the possibility of the occurrence of residual stresses is reduced
  - It is possible to do several parts at the same time
  - The building time is long

Example design for AM



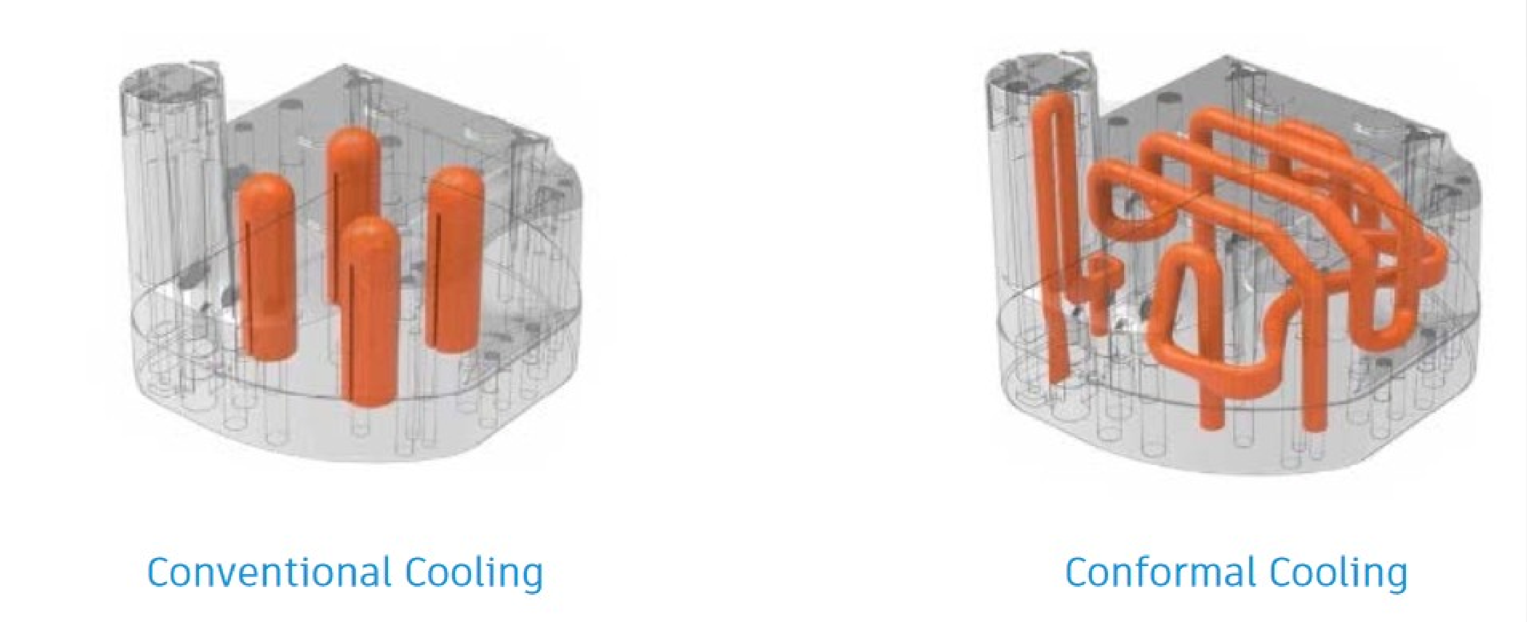
- Re-design part
  - Avoid of the support structure
  - Small contact area
  - Multiple parts on one base plate
  - Small contact area - small residual stresses
  - A little post processing
  - The building time is still long

Conformal cooling

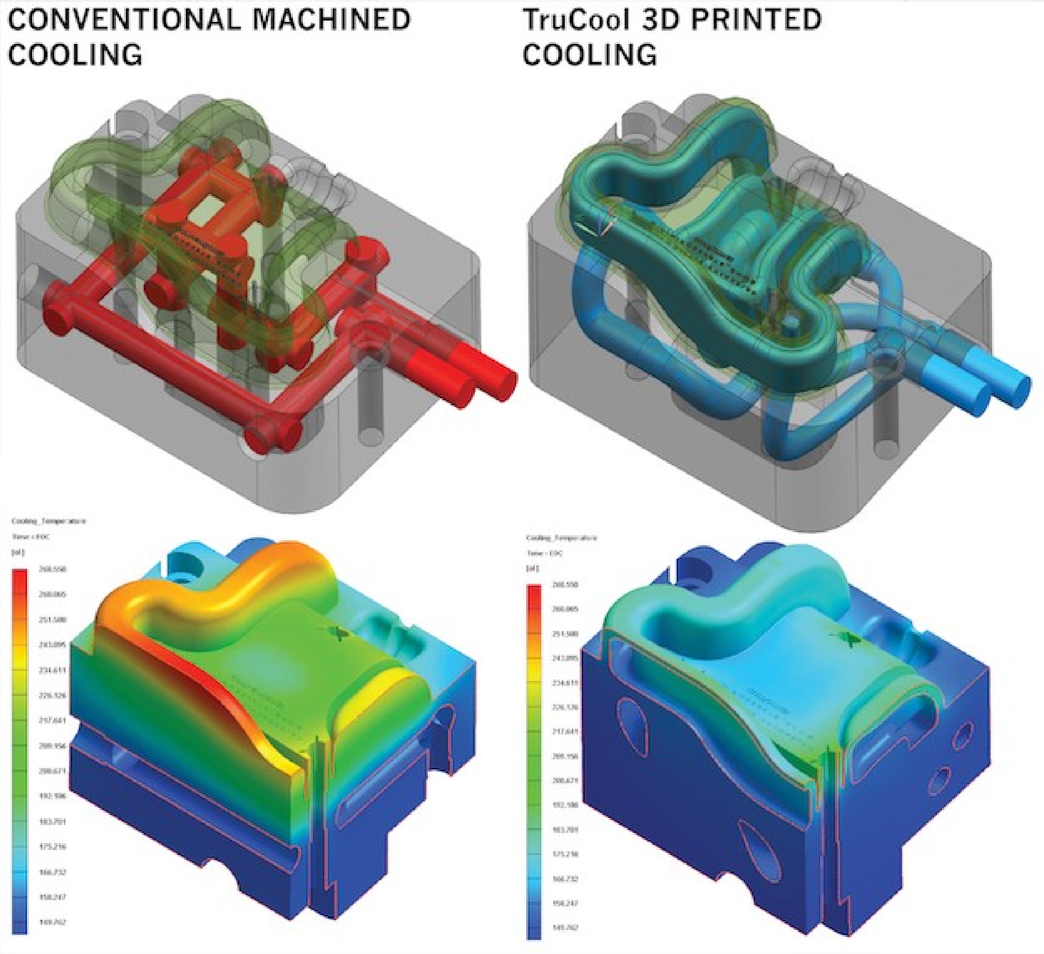
- Basic rules for designing cooling channels
  - The cross section of the channel should be constant
  - Make sure that the length of the channel is as short as possible
  - The distance of the channel from the surface of the mold according to the recommendations is 1.5 d
  - The equivalent diameter of the cooling channel can range from 2 mm or larger, which in turn depends on the thermal conditions and the mechanical load conditions to be achieved on the tool.
  - The shape of the opening no longer has to be a circle !!

Conformal cooling

- Improving the control of the temperture during the process of molding



Conformal cooling



AM

amadam

additive manufacturing

Coordinator
FAKULTET ZA MASINSTVO I GRADJEVINARSTVO
U KRALJEVO UNIVERZITETA U KRAGUJEVCU
www.mfkv.rs

Partners
ALMA MATER STUDIORUM - UNIVERSITA DI BOLOGNA
www.unibo.it DIN department

STUDIO PEDRINI SRL
www.studiopedrini.it

TOPOMATIKA DOO
www.topomatika.hr

PLAMINGO DOO
www.plamingo.net

HORIZON 2020

The framework programme
for research and innovation

734455 (A_MADAM) - MSCA-RISE
Call: H2020 MSCA RISE 2016
Topic: MSCA-RISE-2016
Unit: REA/A/03

Thank you!

PROJECT SUPPORTED BY European Commission