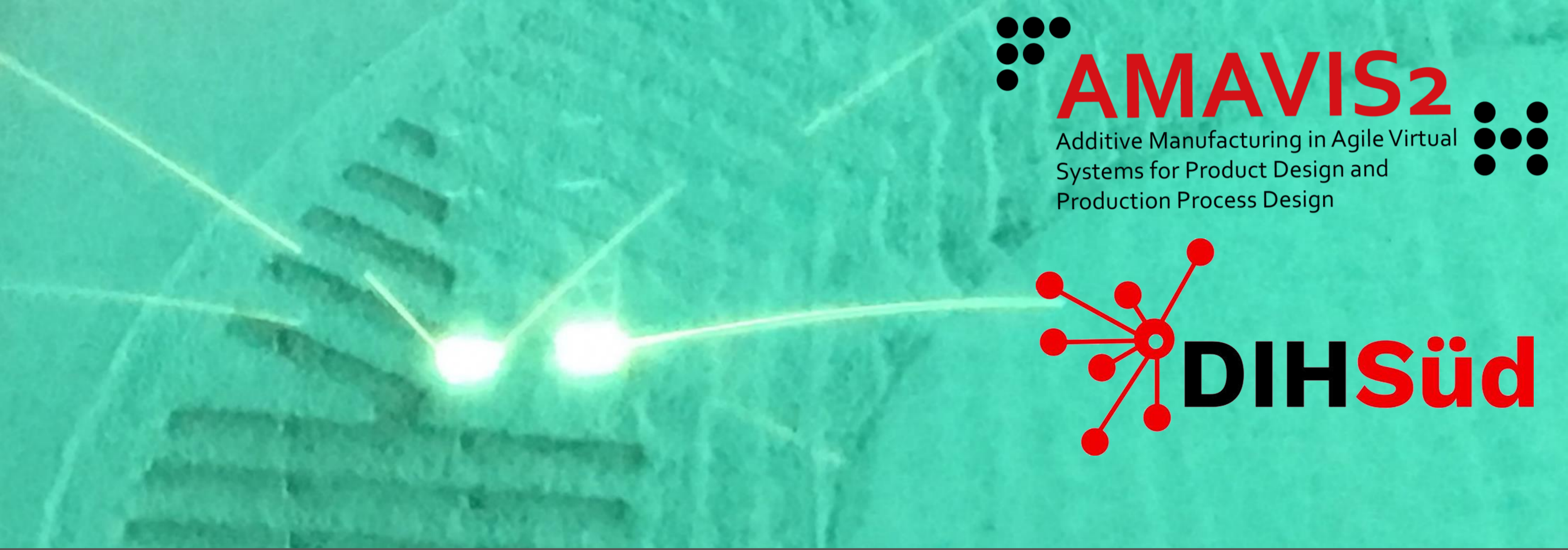


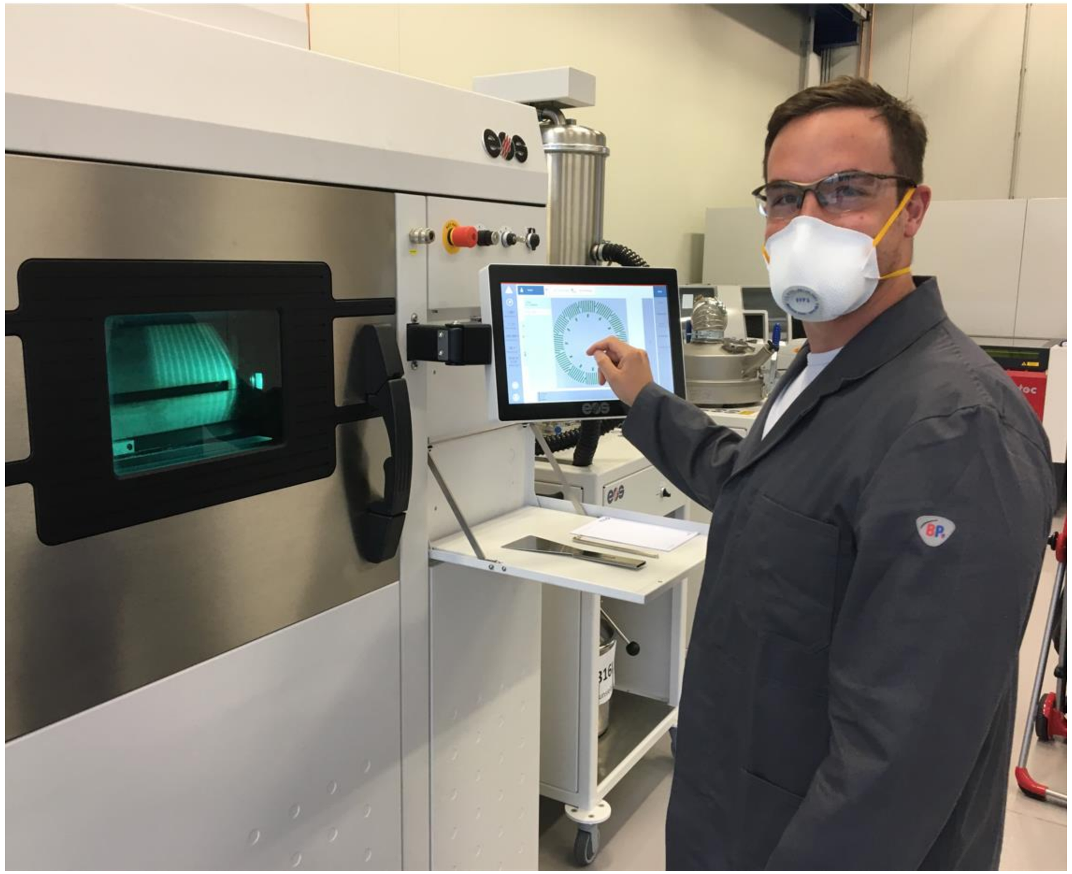
Industrial application of Metal Additive Manufacturing

Villach | 12 September 2023

Ing. Dominic Zettel, BSc MSc

Dominic Zettel

June 2019	Junior Researcher | **CUAS | AMAVIS²**
3 years	Quality Engineer, Auditor | **Flowserve**
8 years	Quality Engineer | **Kostwein**
2020	Dissertation - DMLS | **CUAS, AMAVIS²**
2017-2019	Master of Science | Industrial Engineering | **CUAS**
2014-2017	Bachelor of Science | Industrial Engineering | **CUAS**
2019	AM Engineer | **Additive Minds (EOS)**



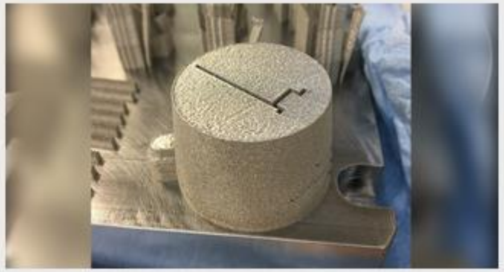
AMAVIS²

Projects & Papers

MONDI GmbH

Economic feasibility study of 3D-Printing processes for optiming spare parts management

K-UNI GmbH



Application of additive manufacuring processes for the fabrication of extrusion tools

AMAVIS²/CISMAT

Acoustic absorbing meta-surface

S3HubsinCE

Linking regional strengths in emerging technologies in Central Europe

HTL Wolfsberg

Development and fabrication of wheel suspension via Generative Design and Direct Metal Laser Sintering

AMAVIS²

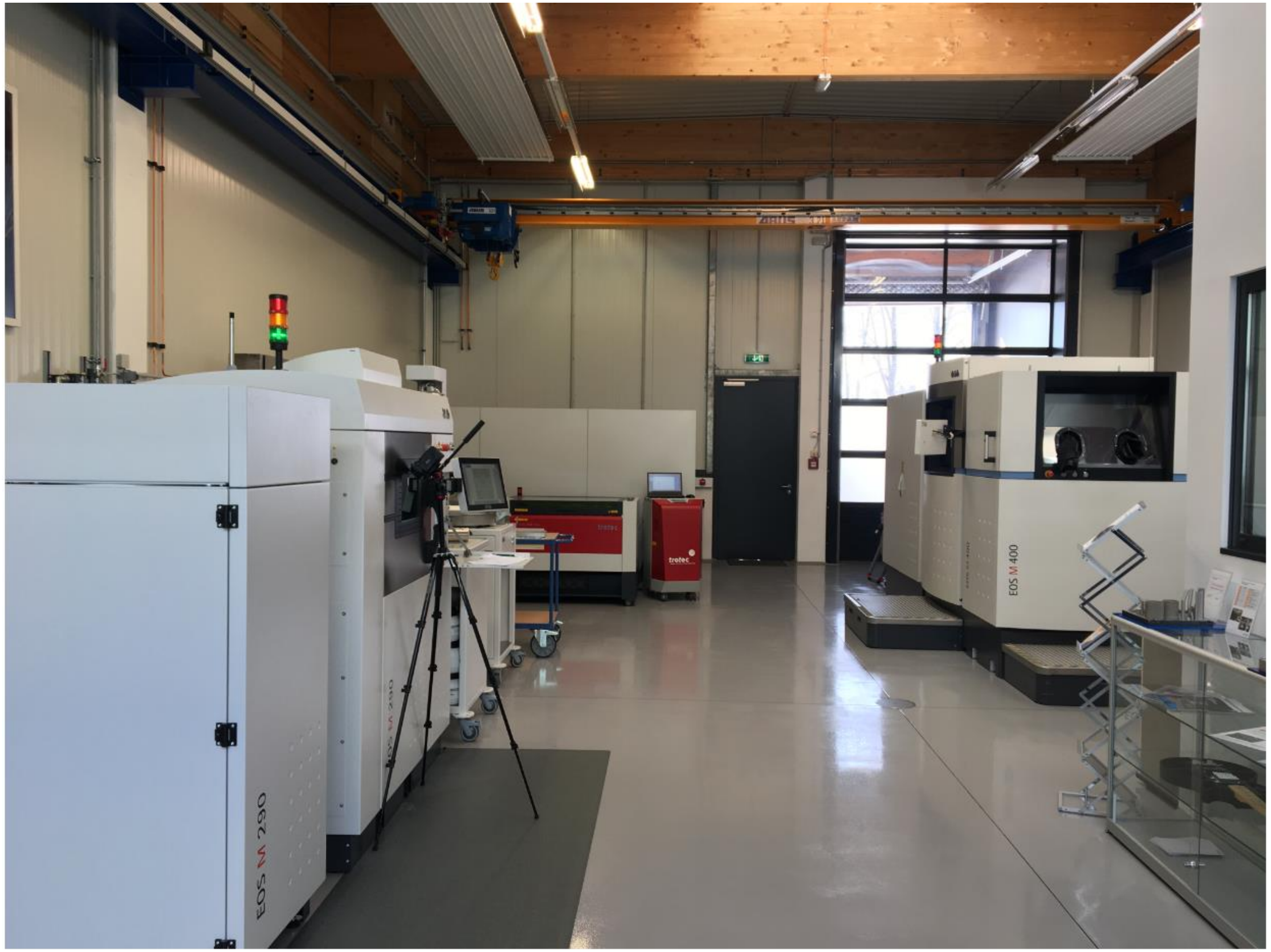
Optimization of heat distribution within an extrusion tool via Direct Metal Laser Sintering

https://forschung.fh-kaernten.at/amavis/

AMAVIS2 Additive Manufacturing in Agile Virtual Systems for Product Design and Production Process Design

KÄRNTEN University of Applied Sciences

Cooperation & Collaboration

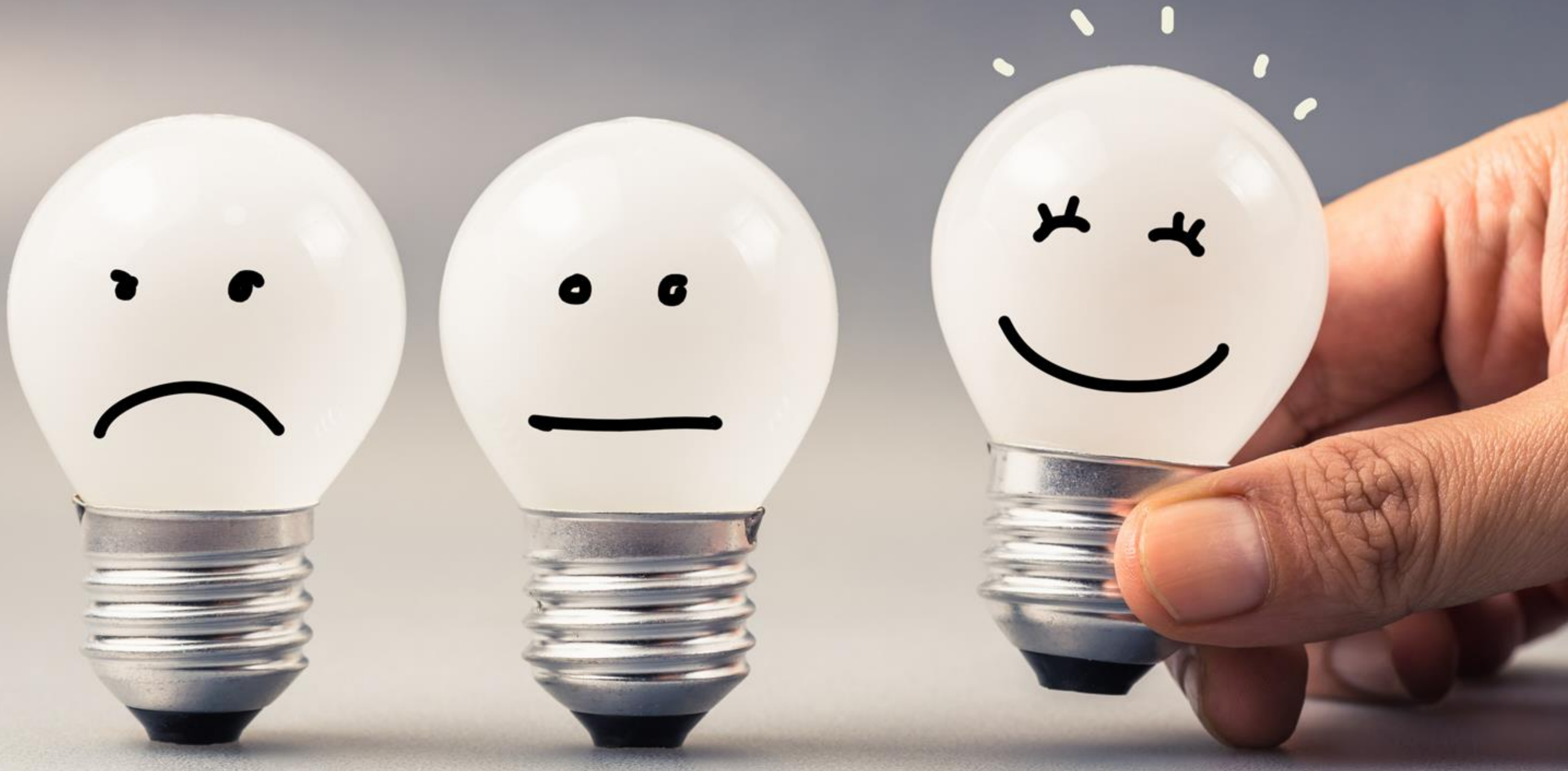


AMAVIS2
Additive Manufacturing in Agile Virtual Systems for Product Design and Production Process Design

GPS GEMEINNÜTZIGES PERSONALSERVICE KÄRNTEN GMBH

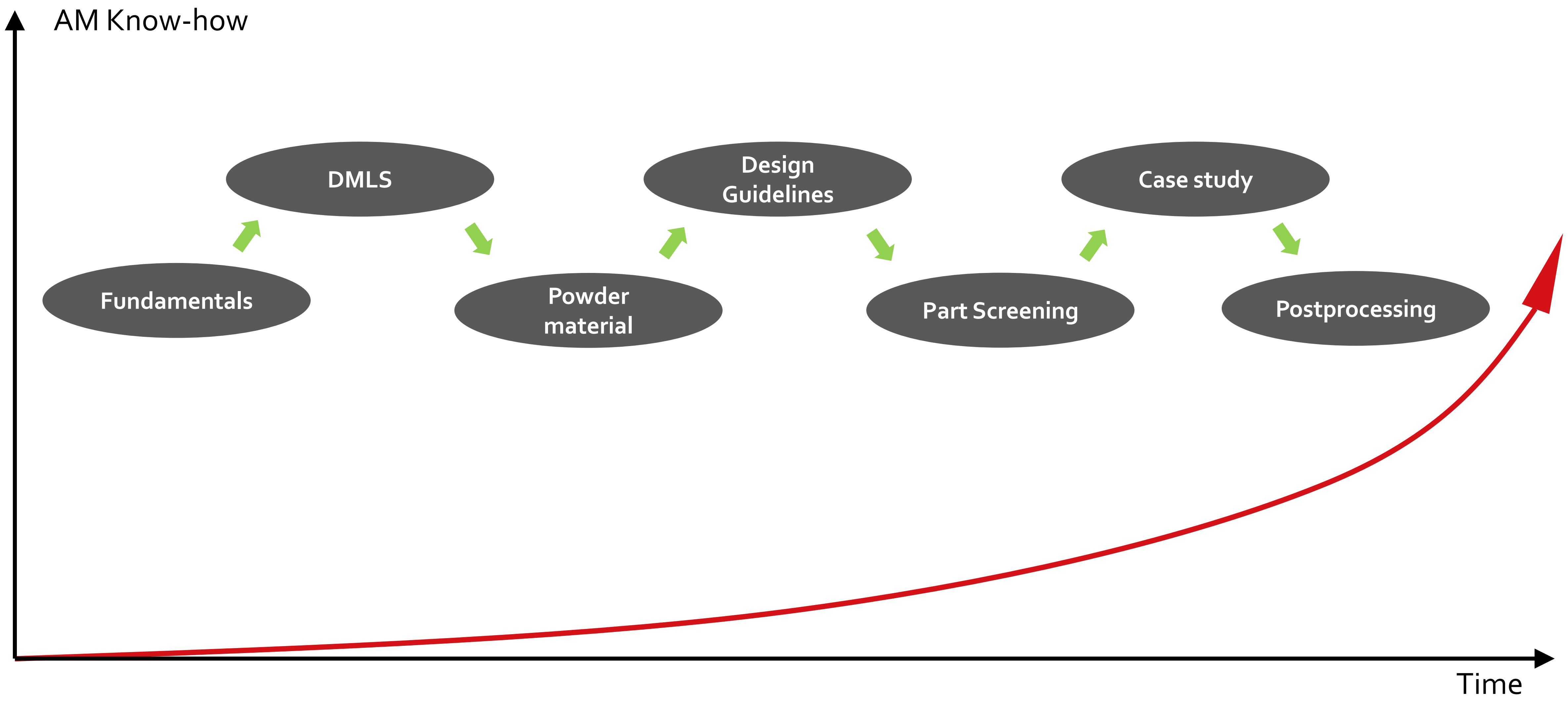
m4p

What is your experience with 3D-printing?



Source: blog.eqs.com, 2019

Overview


AM Know-how
DMLS
Design Guidelines
Case study
Fundamentals
Powder material
Part Screening
Postprocessing
Time

KÄRNTEN University of Applied Sciences

Fundamentals

What is Additive Manufacturing?

→ Inspired by nature (bionics)

→ Natural phenomena work by adding material (layers) only where required

Source: naturparkmagazin.de, 2019

Source: pixabay.com, 2019

Source: baumportal.de, 2019

Source: apotheken-umschau.de, 2019

Conventional Manufacturing VS. Additive Manufacturing

Conventional Manufacturing	Additive Manufacturing
Removal of excessive material	**Material only added where required**
Material waste	**Re-use of material**
Geometric restrictions	**No geometric restrictions**
Tools required (e.g. milling tool)	**No tools required**

Source: intratec-schmock.de, 2019

Source: 3dnatives.com, 2019

Challenge for the designer

Rethinking of design process

Conventional Manufacturing

- Removal of material (Raw material)
- Difficult integration of several functions
- Design within the limits of producibility

Additive Manufacturing

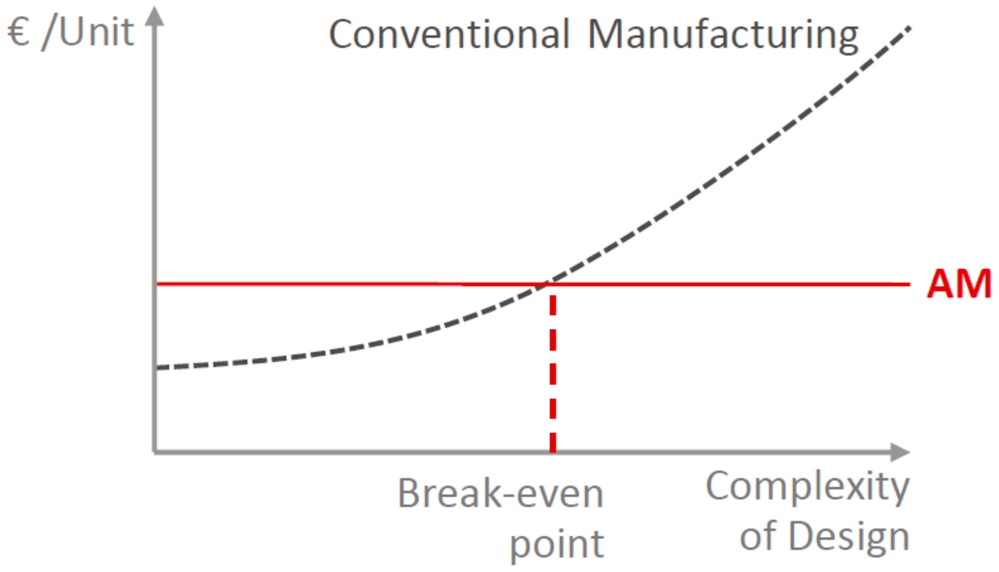
- Addition of material
- Easy integration of several functions
- Design for the function of a part

→ **<u>The design for AM focuses on the function of a part and not on its production possibilities!</u>**

Characteristics of Additive Manufacturing

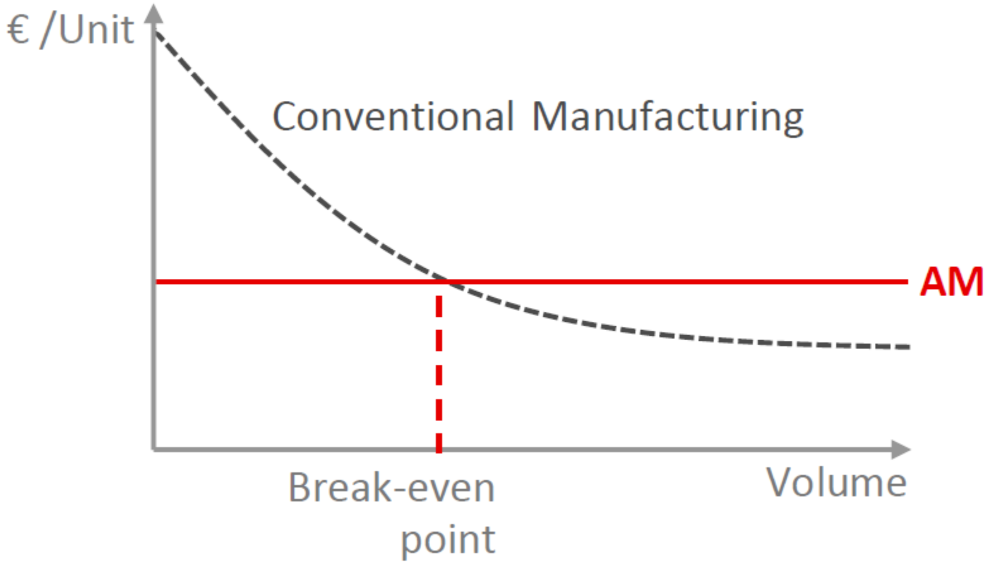
→ Compared to conventional manufacturing, AM has strong advantages regarding complex parts and small volumes

Complexity advantage



Strong cost advantage for complex components

Volume advantage

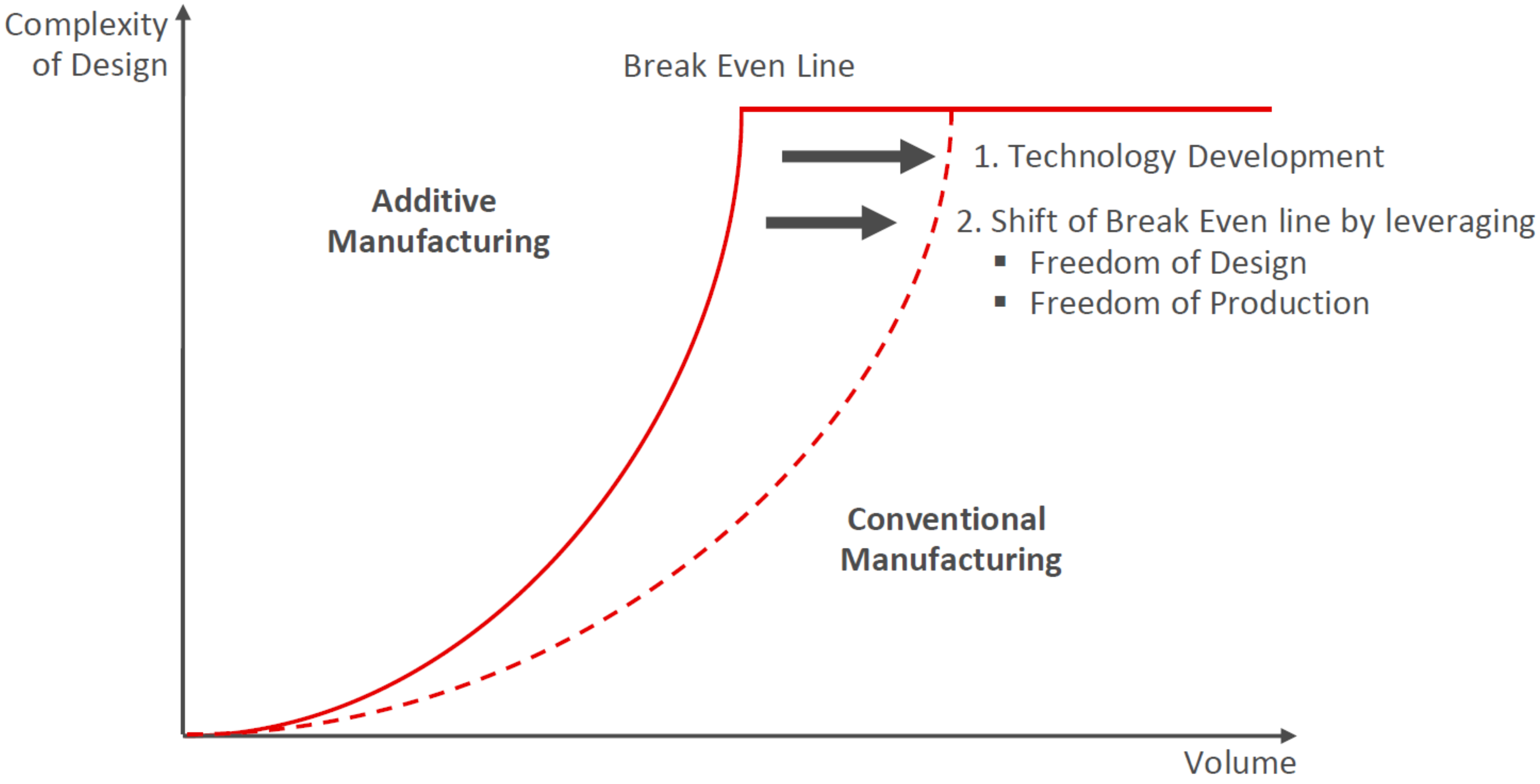


Strong cost advantage for small volume production

Source: Additive Minds, 2019, Workshop

Characteristics of Additive Manufacturing

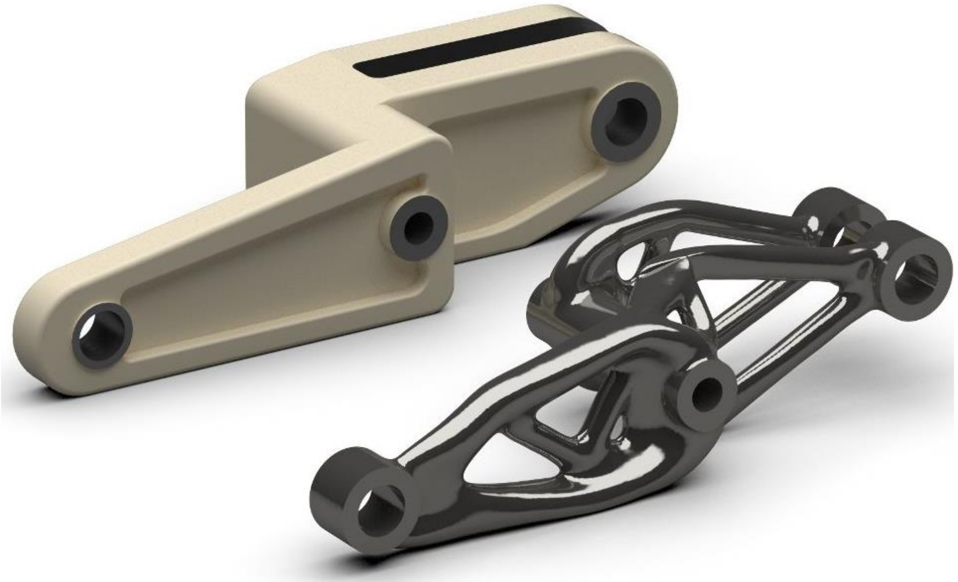
→ Productivity of AM technologies increaseses by a factor of 8-10 in the next 5 years



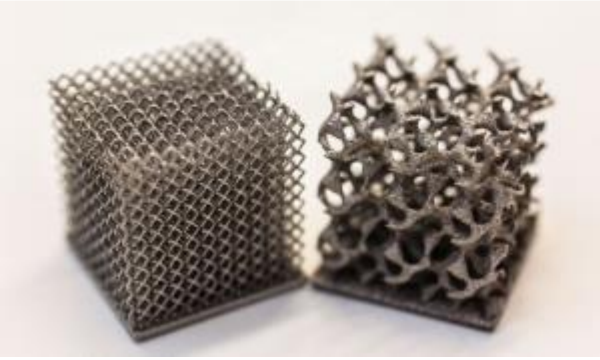
Source: Additive Minds, 2019, Workshop

Characteristics of AM

Complex geometries

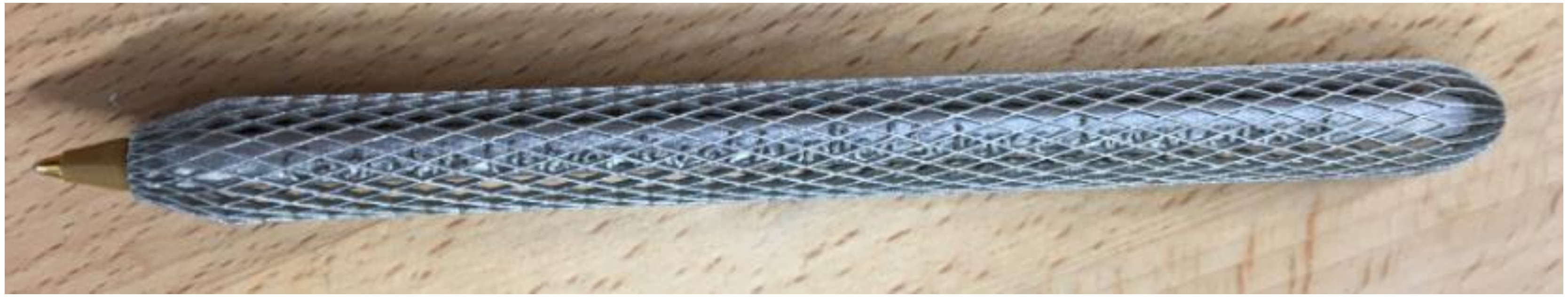


Source: plm.automation.siemens.com, 2019



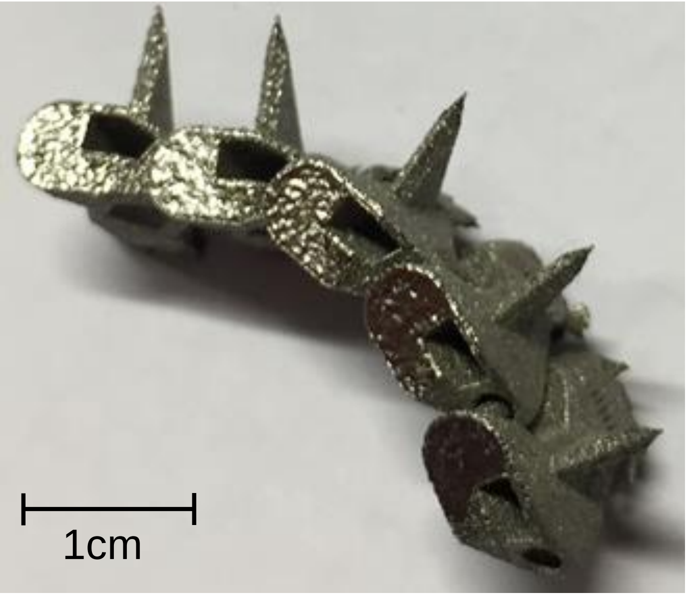
Source: imperial.ac.at, 2019

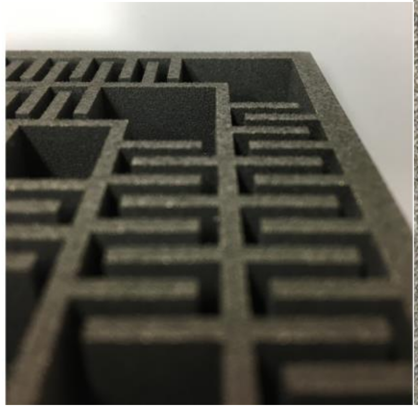
Complex structures based on Generative Design!

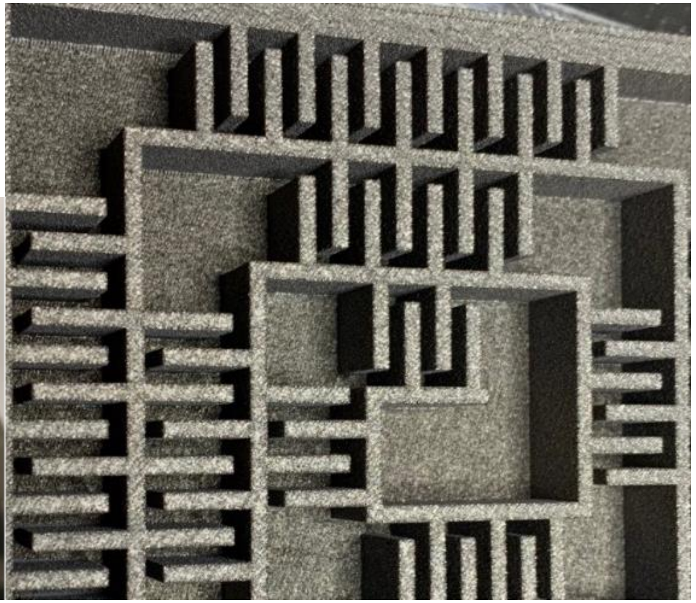


Characteristics of AM

Complex geometries





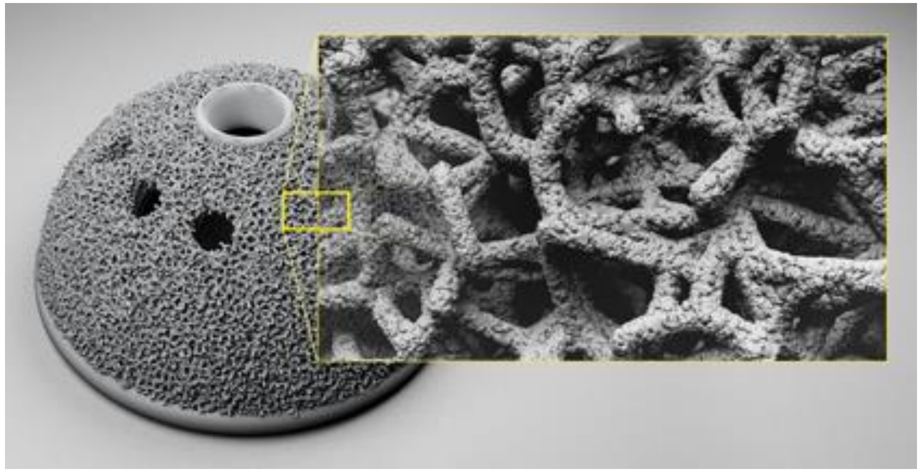


Characteristics of AM

Complex geometries

Cases & Best practices

Customization



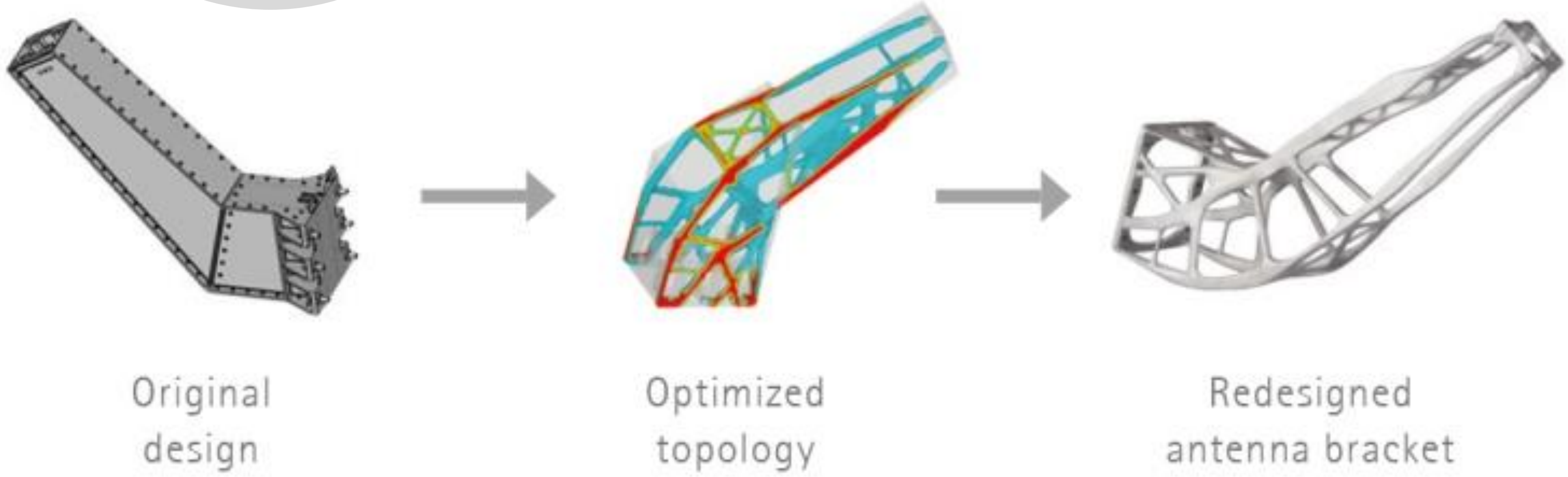
Source: eos.info, 2019

Cases & Best practices

Functional integration

Source: eos.info, 2019

Source: hslu.ch, 2019



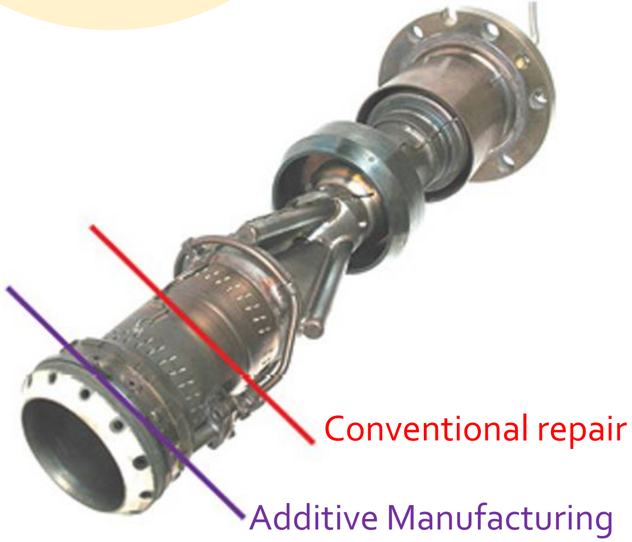
Source: eos.info, 2019

Source: digital-can.com, 2019

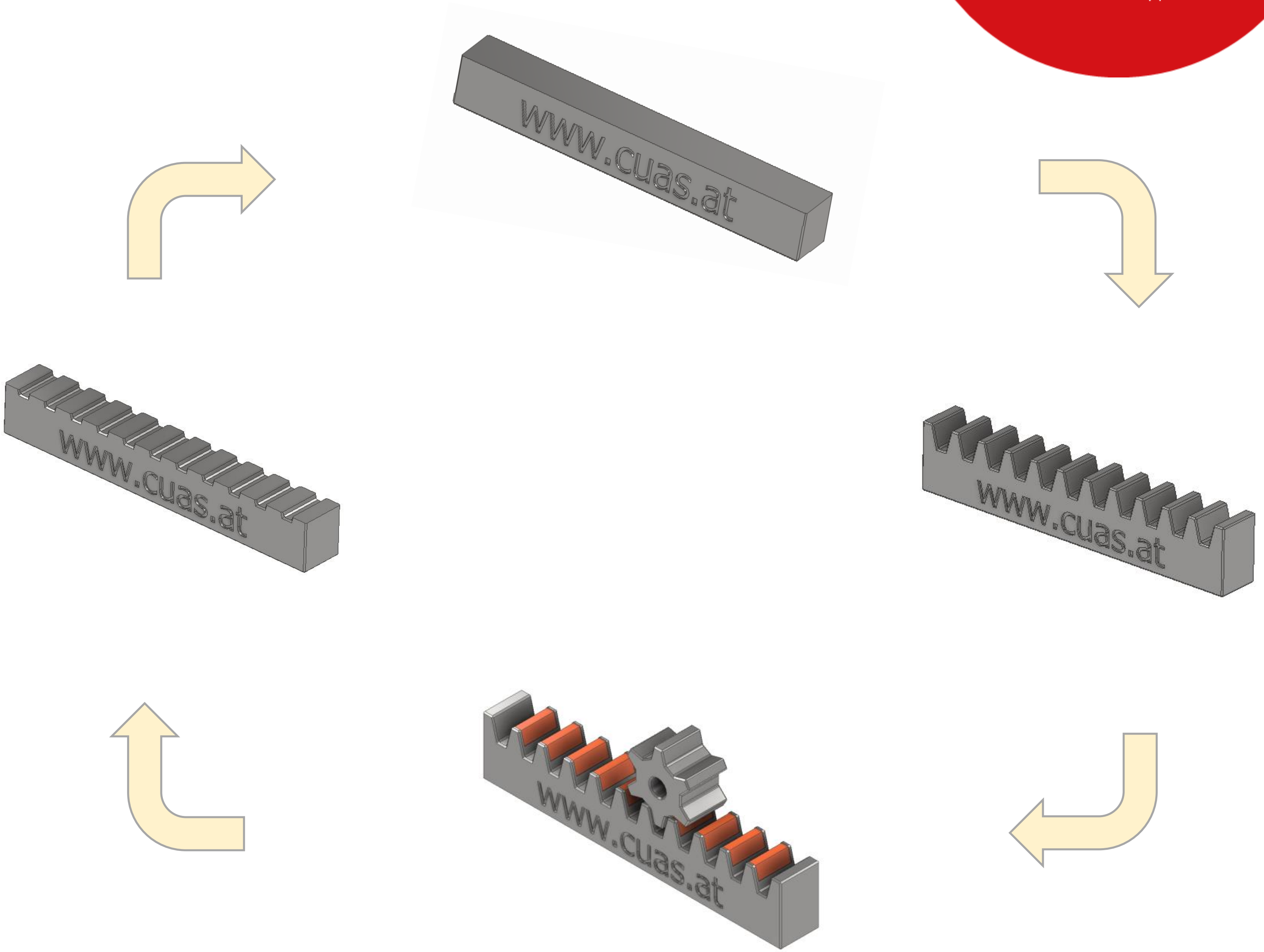
AMAVIS2 Additive Manufacturing in Agile Virtual Systems for Product Design and Production Process Design

Cases & Best practices

Hybrid constructions

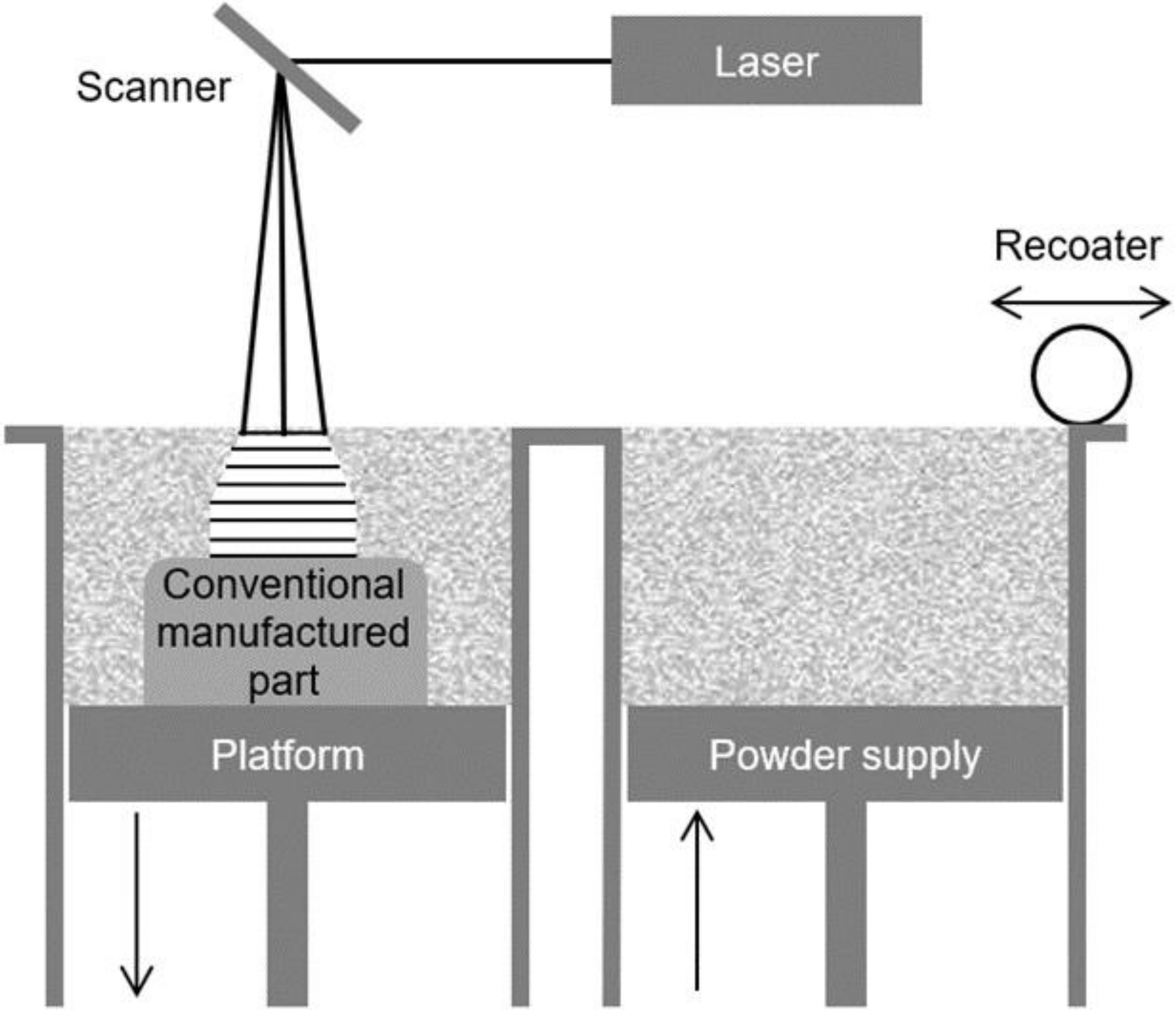


Source: industrial-lasers.com, 2019

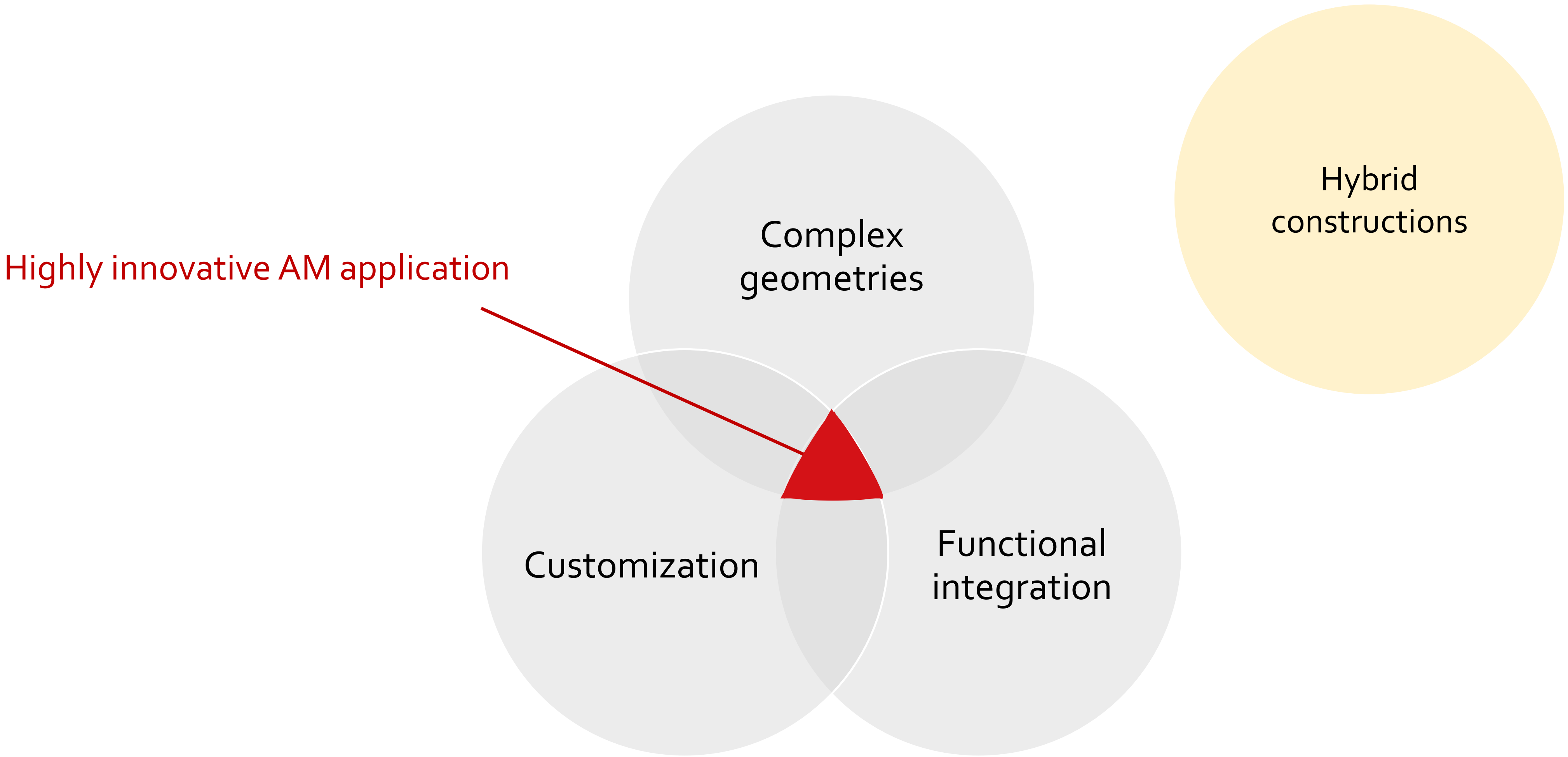


Cases & Best practices

Hybrid constructions



Characteristics of Additive Manufacturing



Enterprise „Additive Manufacturing“

→ We have now reached the „Plateau of Productivity“

Source: Gartner Emerging Technology Hype Cycle, 2017

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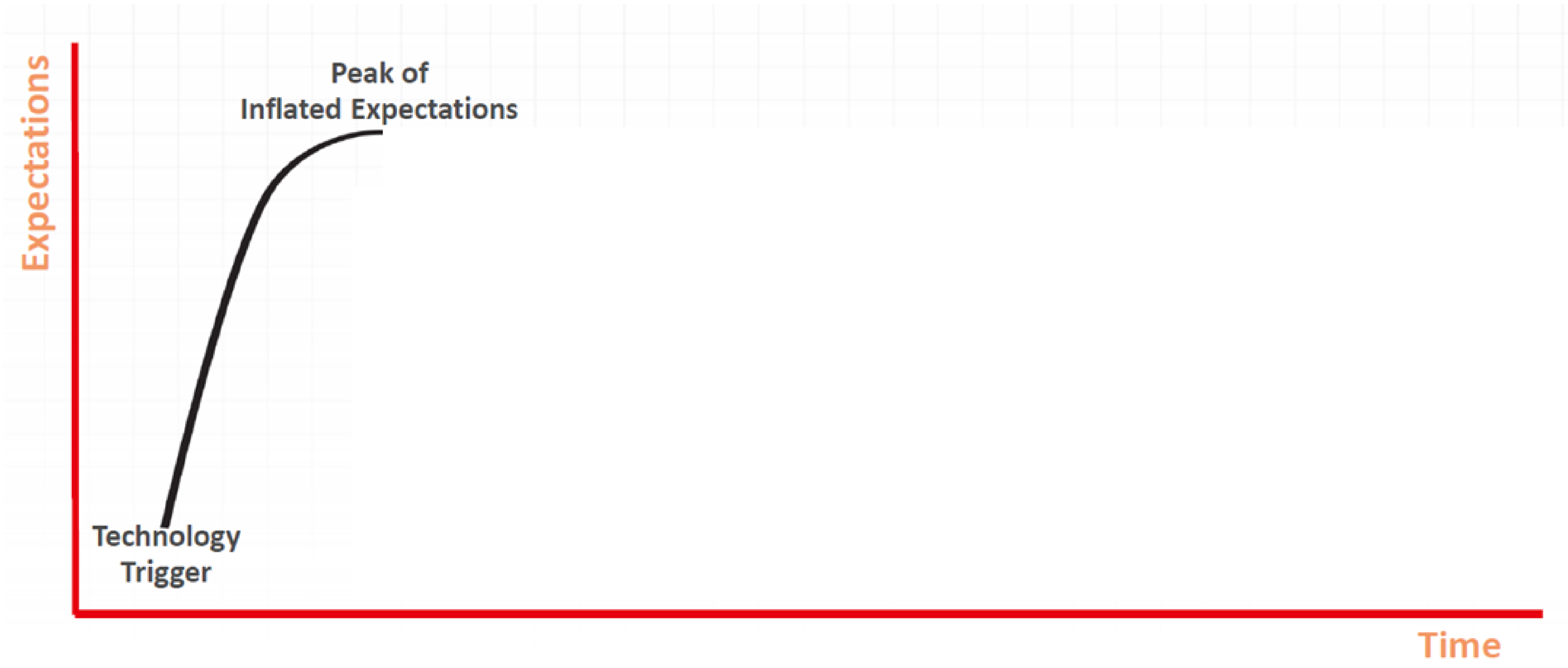

Source: Gartner Emerging Technology Hype Cycle, 2017

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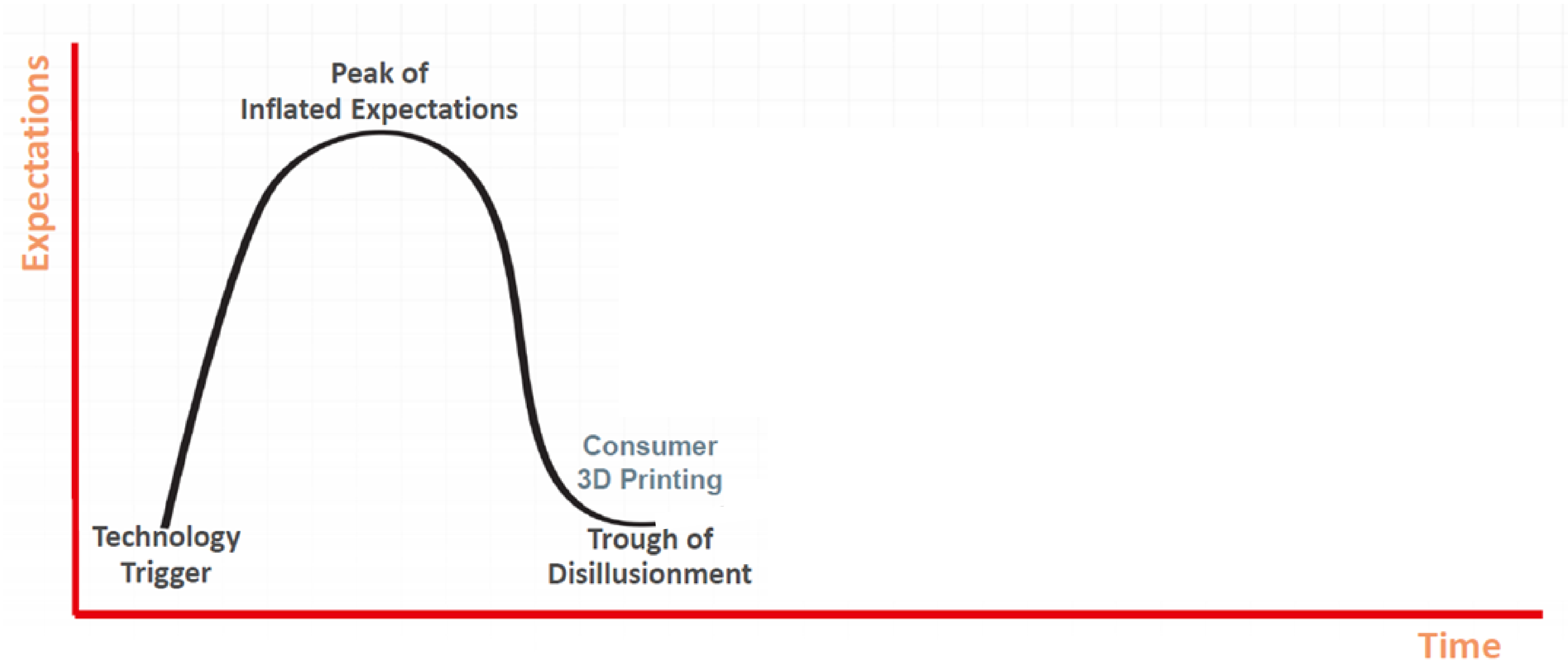

Source: Gartner Emerging Technology Hype Cycle, 2017

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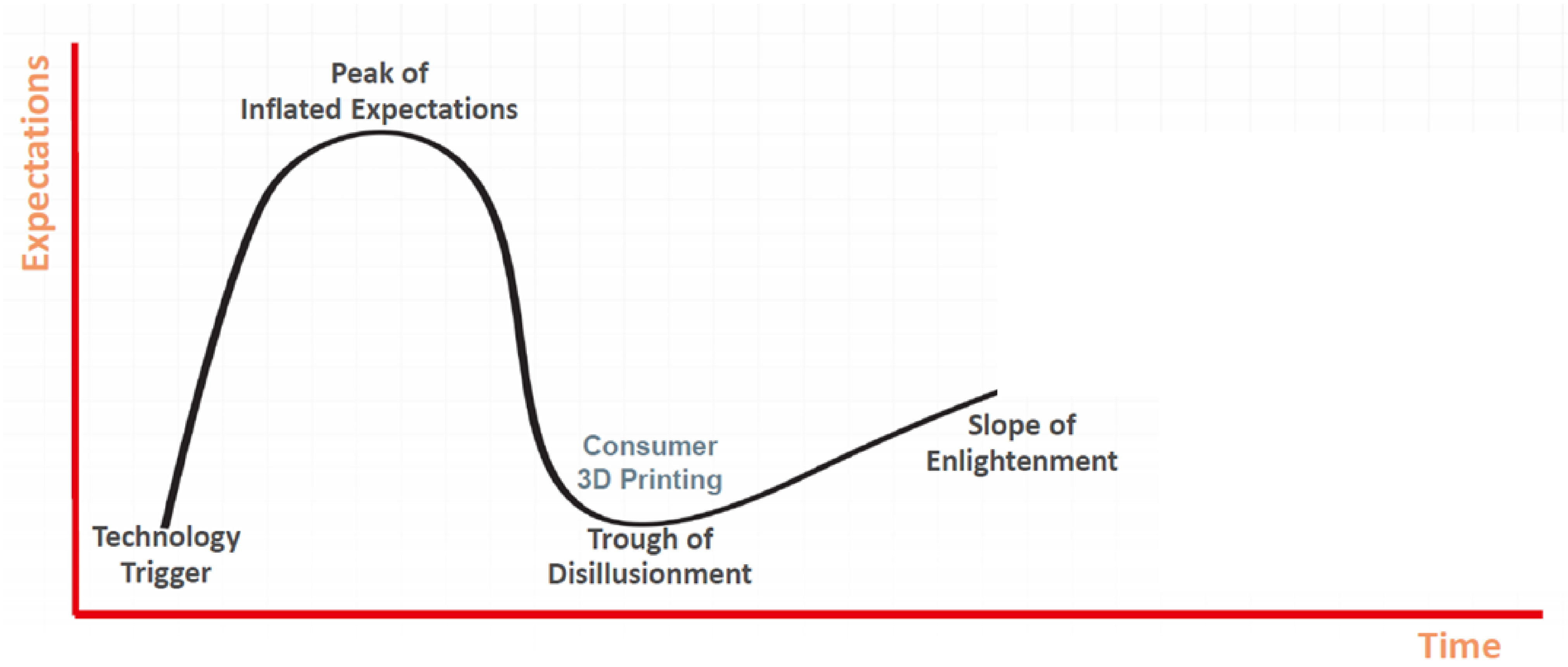

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Enterprise „Additive Manufacturing“

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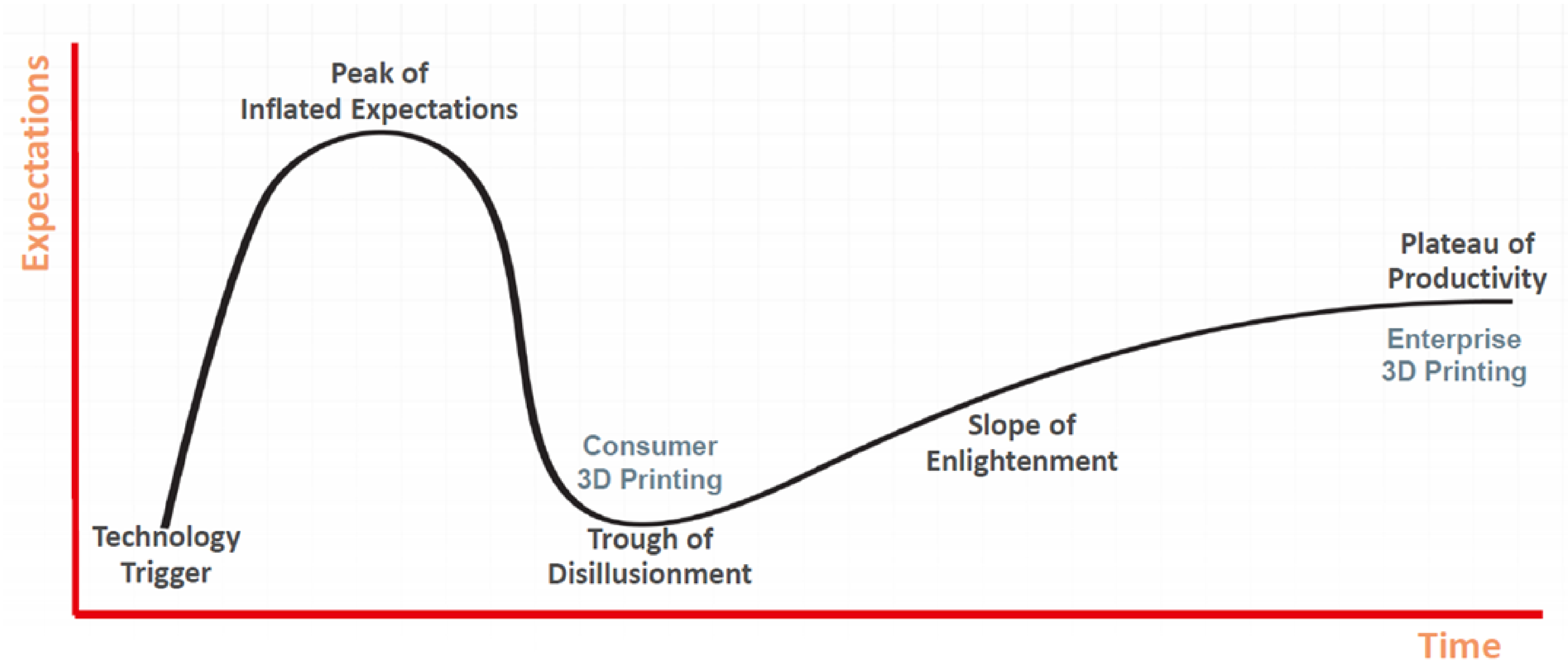
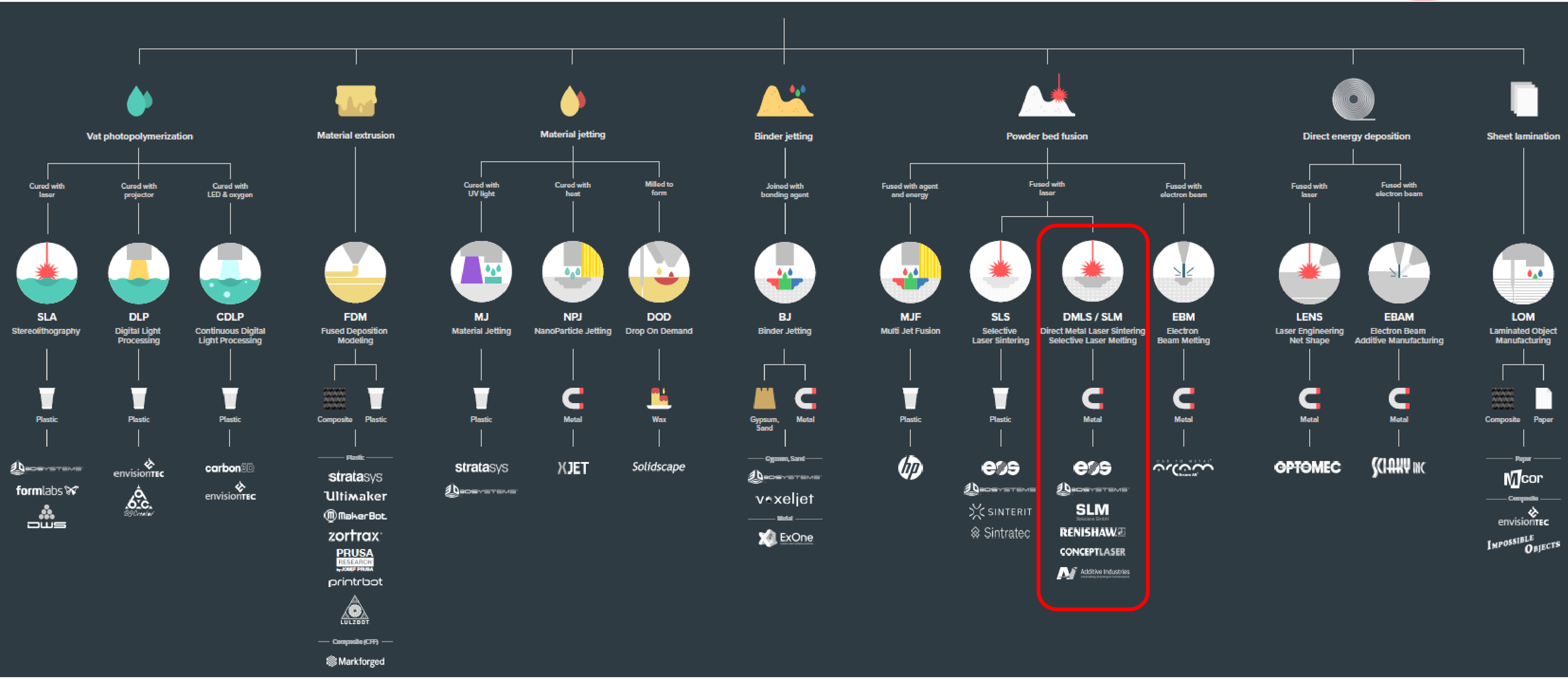


Source: Gartner Emerging Technology Hype Cycle, 2017

Additive Manufacturing Technologies

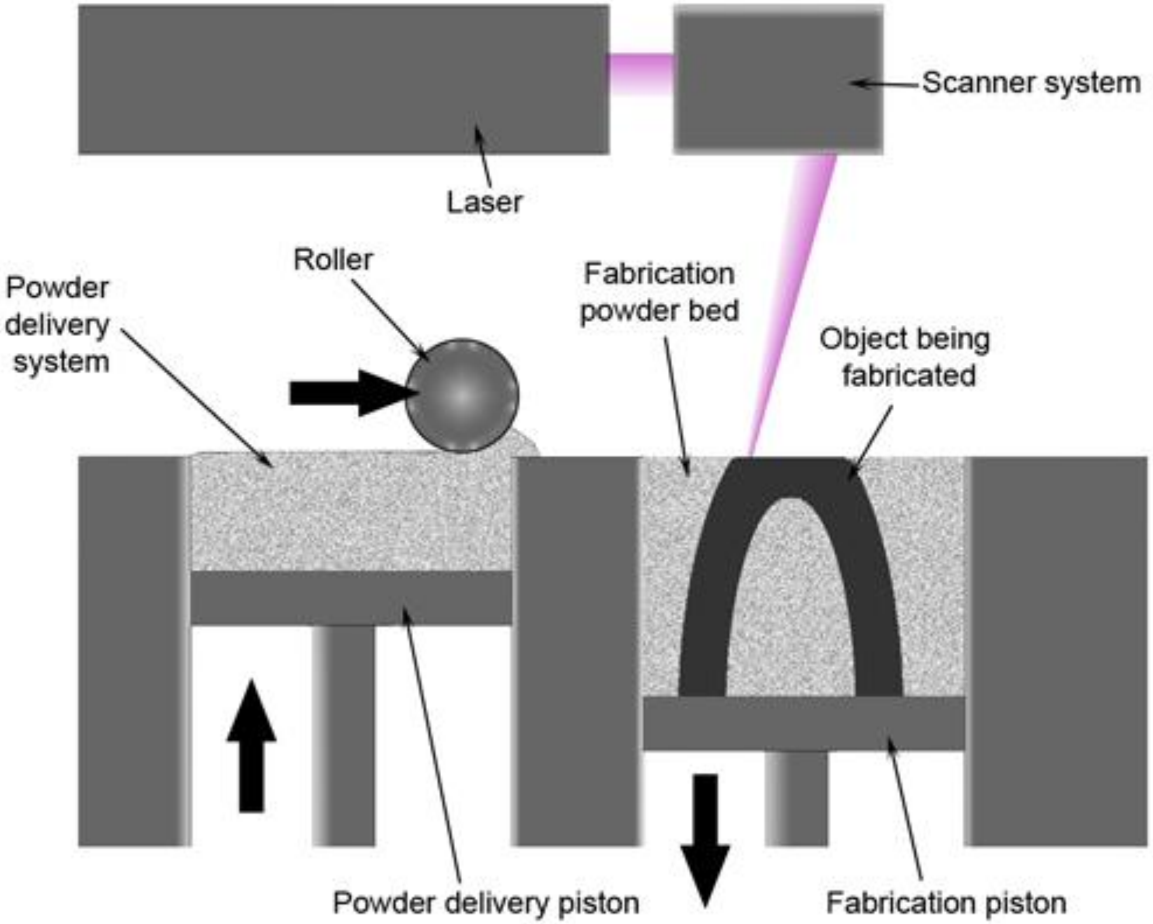
DIN EN ISO / ASTM 52900:2018



Source: 3dhubs.com, 2019

Direct Metal Laser Sintering

Powder Bed Fusion



Source: spilasers.com, 2019

Process

- Laser beam fuses selected areas of a powder bed

Markets

- Rapid prototyping
- Serial production

Advantages

- High mechanical properties
- High detail resolution

Disadvantages

- Limited build space
- High costs

Powder Bed Fusion - Examples

Source: eos.info, 2019

Source: 3dhubs.com, 2019

Source: cadalyst.com, 2019

Powder Bed Fusion

Additive Manufacturing Technologies

DIN EN ISO / ASTM 52900:2018 | Additive manufacturing – General principles – Terminology

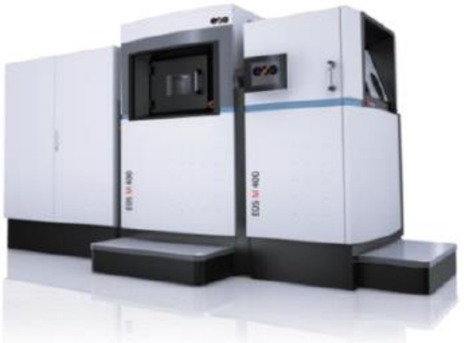
Customer	Consumer 		Industry 					
Technology	Material Extrusion FDM**	Vat Polymerization SLA	Sheet Lamination LOM UAM	Vat Polymerization SLA DLP	Material Extrusion FDM	Material & Binder Jetting	Directed Energy Deposition Laser Metal	Powder Bed Fusion SLS, DMLS, EBM
Investment								
Material	Polymer Filament	Liquid Resin	Paper Polymerblends	Liquid photopolymers	Plastic Composite	Wax Metal Plastic	Metal	Polymer Powder Metal Powder
Part quality*								

* Compared to traditional (subtractive) manufacturing

** Subtechnology

Source: Additive Minds, 2019, Workshop

Direct Metal Laser Sintering (DMLS) Systems

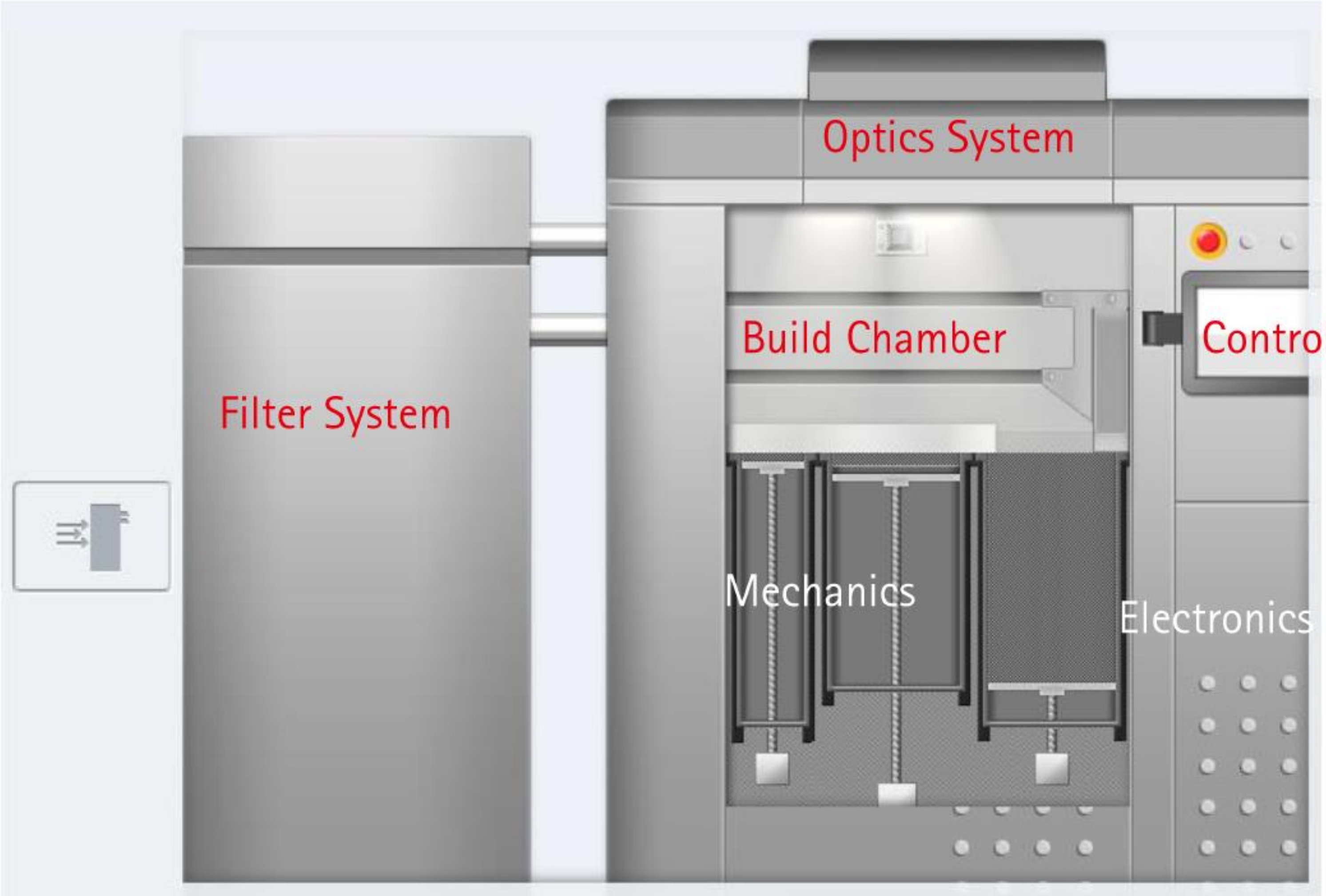
EOS M 100	EOS M 290	EOS M 400	EOS M 400-4
			
Proven DMLS quality for small-scale production	Proven DMLS quality with enhanced quality management	Proven DMLS Quality for the production of large parts	Proven DMLS Quality with up to 4x higher productivity
Build volume: Ø 100 mm x 95* mm	Build volume (wxdxh): 250 x 250 x 325* mm	Build volume (wxdxh): 400 x 400 x 400* mm	Build volume (wxdxh): 400 x 400 x 400* mm
Laser: 200 W Yb-fiber, focus diameter 40 µm	Laser: 400 W Yb-fiber laser, focus diameter 100 µm	Laser: 1000 W Yb-fiber, focus diameter 90 µm	Laser: 4x 400W Yb-fiber, focus diameter 100 µm

SMALL FRAME — MEDIUM FRAME — LARGE FRAME

* Height including building plate

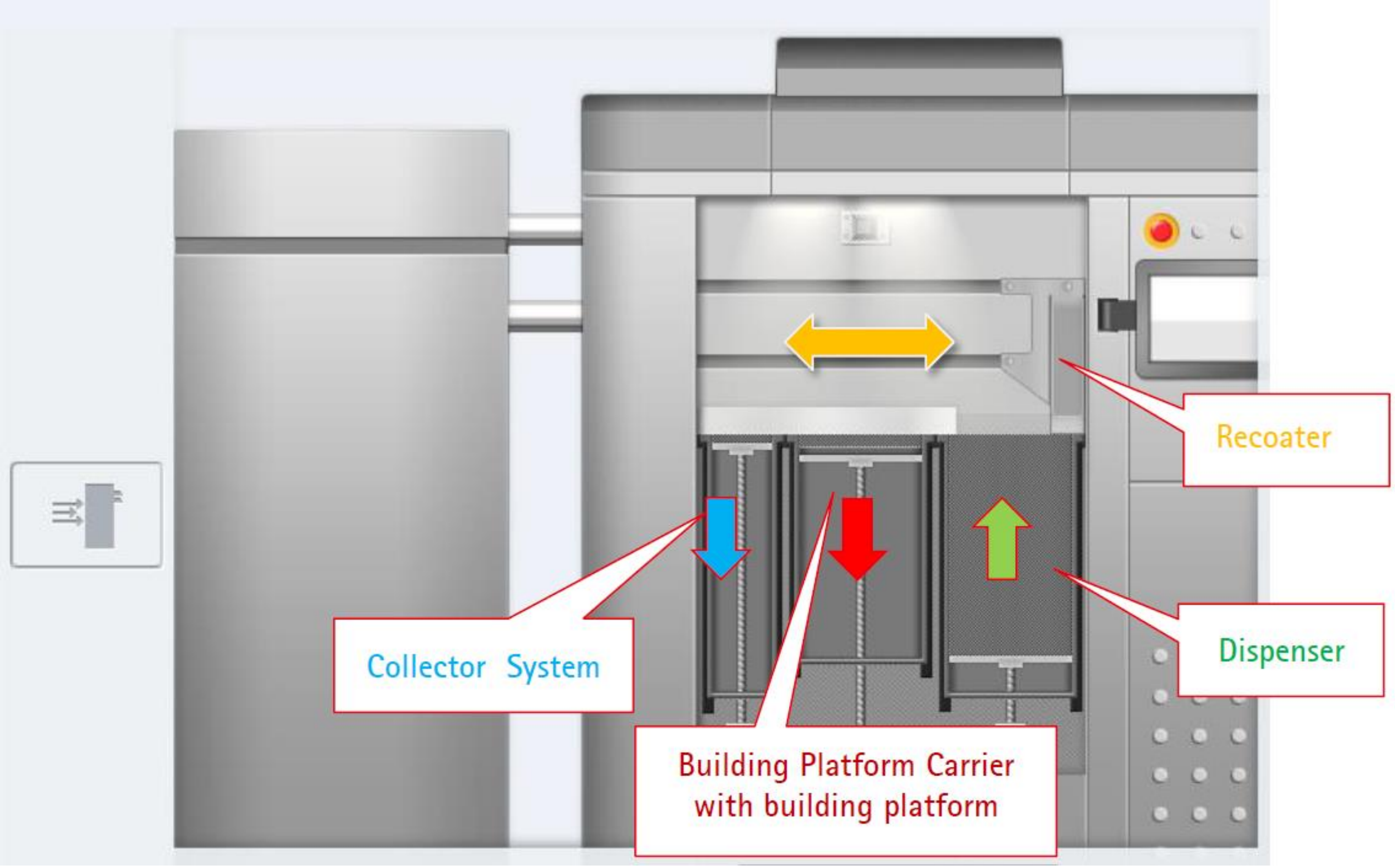
Source: Additive Minds, 2019, Workshop

Mechanical system – EOS M290



Source: Additive Minds, 2019, Workshop

Mechanical system – EOS M290



Source: Additive Minds, 2019, Workshop

Additional systems/tools

Gas supply

Source: bunnings.com, 2019

Dial gauge

Source: hroberts-di.com, 2019

Feeler gauge

Source: rs-online.com, 2019

Spatulas

Source: saekulum.de, 2019

Vacuum module

Source: eos.info, 2019

Sieving module

Source: eos.info, 2019

Lifting trolley

Source: hroberts-di.com, 2019

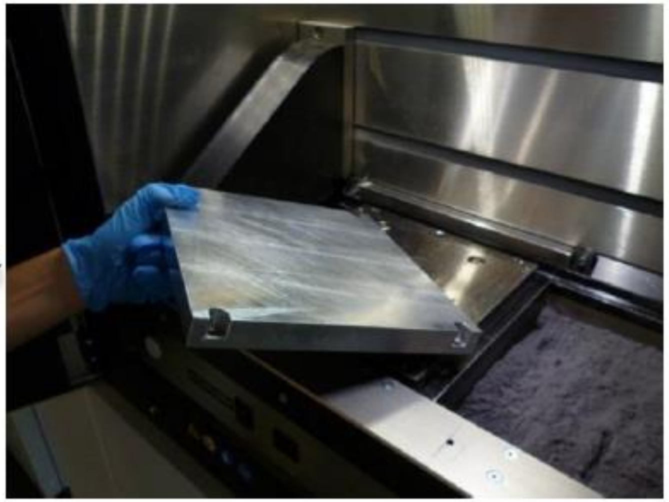
Wet separator

Source: ruwac-asia.com, 2019

Machine setup – EOS M290

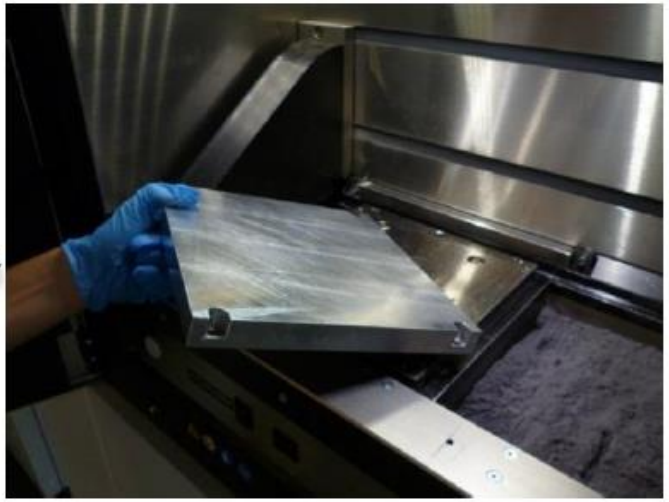
Source: Additive Minds, 2019, Workshop

Machine setup – EOS M290



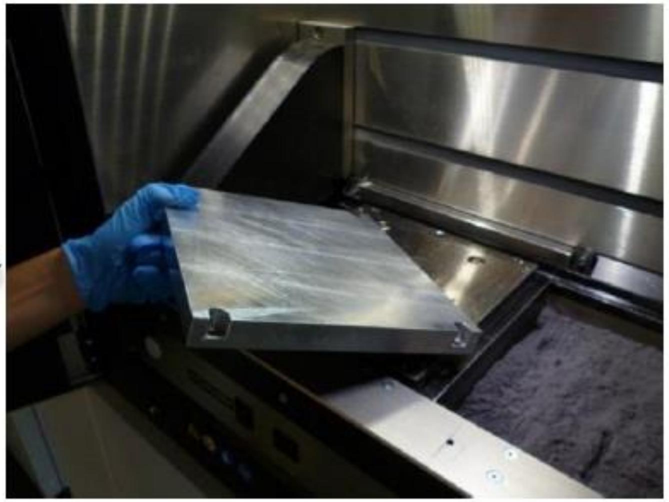
Source: Additive Minds, 2019, Workshop

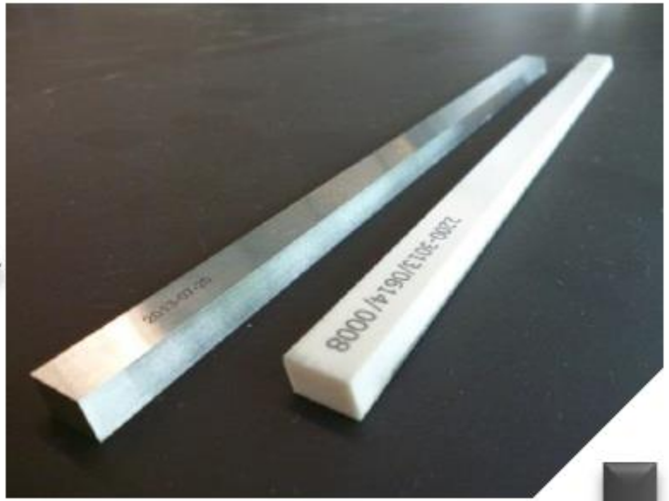
Machine setup – EOS M290

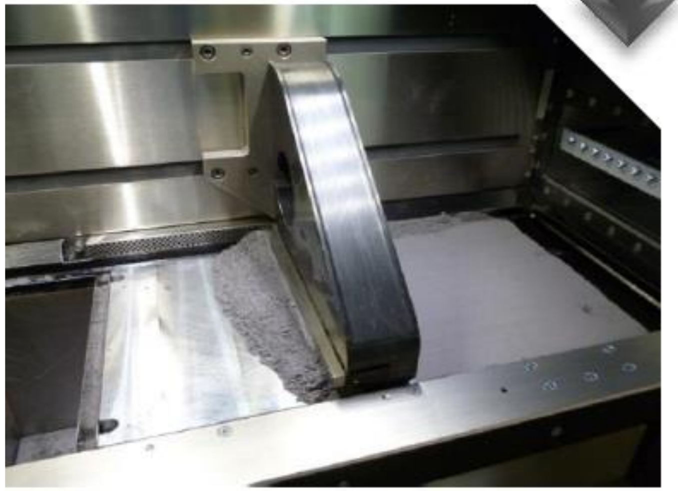


Source: Additive Minds, 2019, Workshop

Machine setup – EOS M290

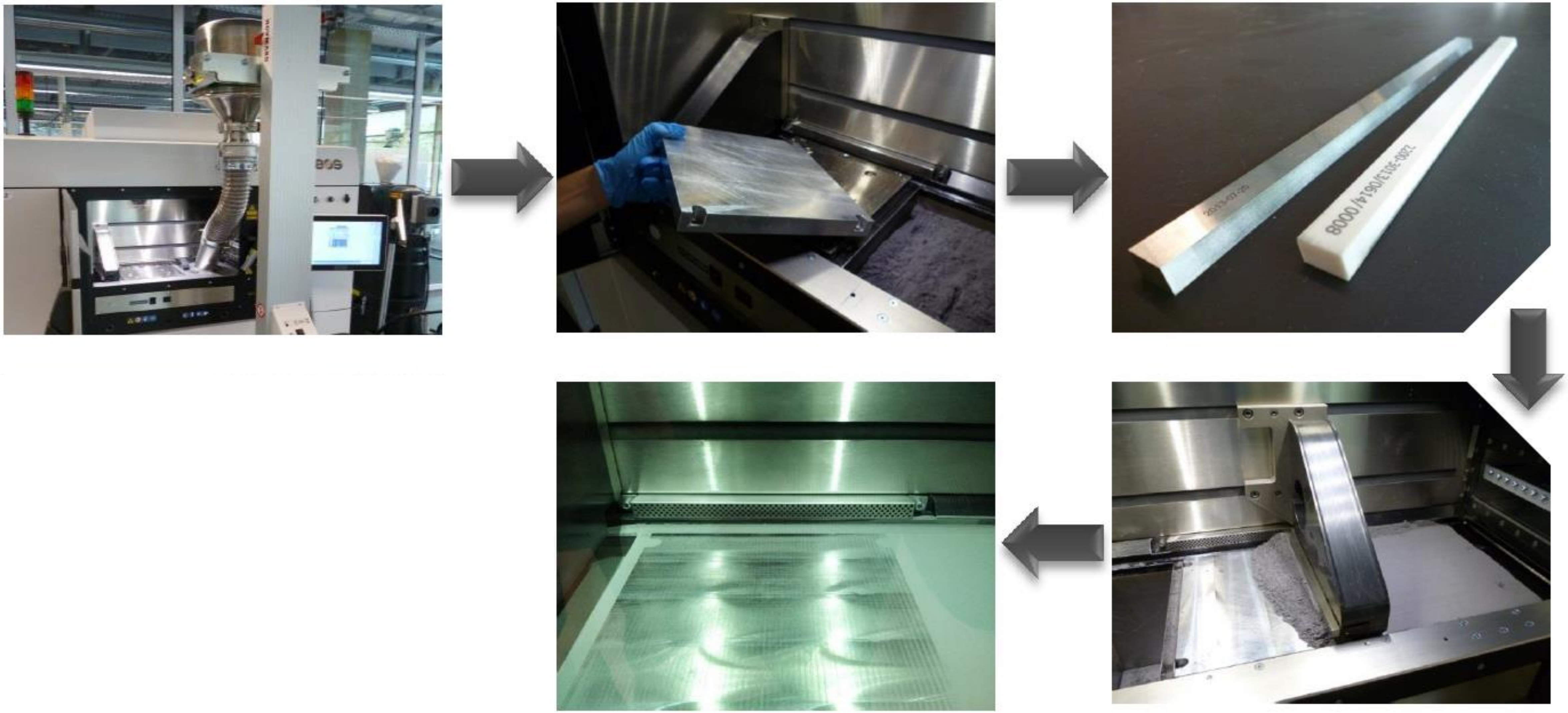






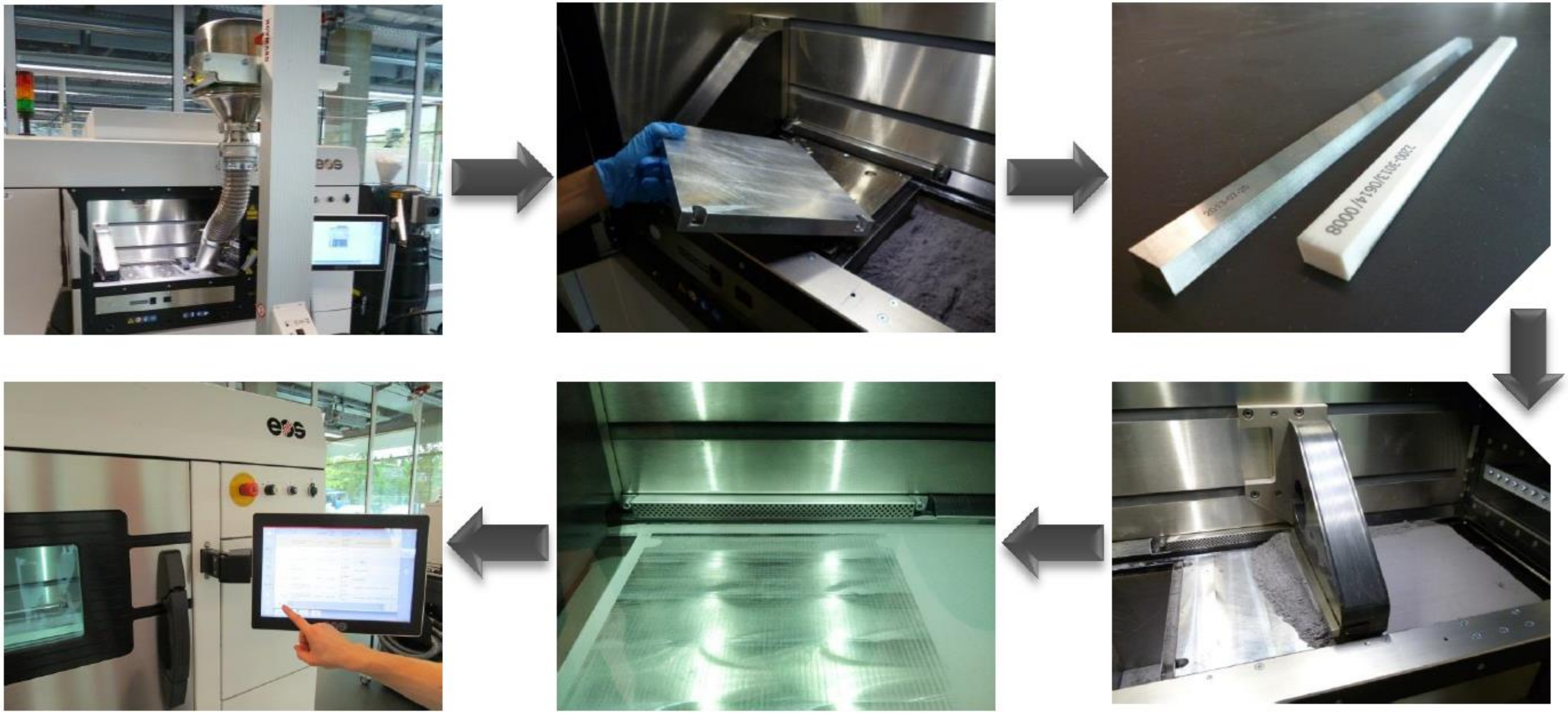
Source: Additive Minds, 2019, Workshop

Machine setup – EOS M290



Source: Additive Minds, 2019, Workshop

Machine setup – EOS M290



Source: Additive Minds, 2019, Workshop

Safety instruction

→ Danger of explosion and health hazard due to powder material!

(EN 374)

(EN 166)

(EN 407)

EN 61340-4-3)

(Filter category P3)

Source: Additive Minds, 2019, Workshop

Powder Material

Powder material

In general:

- Particle size: 10-75µm (depends on system)
- Reusable (Filter)
- Storage: dry & inert atmosphere

Source: amp-powders.com, 2019

High development costs!

Qualified materials:

- Mechanical strenght tests
- Chemical analyses
- Powder flowability
- Particle distribution
- Bulk- and tap density

Source: amp-powders.com, 2019

Source: konstruktion-entwicklung.de, 2019

→ **Powder and machine parameter are development simultaneous!**

Powder material

Chemische Richtanalyse [Gew.%]		
Element	Min	Max
Sn	9,0	11,5
Andere	<0,5	
Cu	Basis	

Korngröße Laser PBF

Fülldichte ~5,3 g/cm³

Source: eos.info 2019

Powder material

EOS StainlessSteel 17-4PH

EOS StainlessSteel 17-4PH ist ein Metalllegierungs-pulver auf Eisenbasis, das für die Verarbeitung in EOS DMLS®-Systemen bestimmt ist.

Dieses Dokument enthält Informationen und Daten für Bauteile, die unter Verwendung des Pulvers EOS StainlessSteel 17-4PH, EOS-Art.-Nr. 9011-0041, auf der Basis der folgenden Systemspezifikation gebaut werden:

DMLS®-System: EOS M 290

→ Keramikklinge (2200-3013)
→ Gitterdüse (2200-5501)
→ Siebmodul IPCM-M extra mit einer Maschenweite von 75 µm (200000315) empfohlen
→ Manuelles Sieb mit einer Maschenweite von 75 µm (200000321) empfohlen; manueller Standardsieb mit einer Maschenweite von 80 µm möglich
→ Argon-Schutzgasatmosphäre

Software:
EOSYSTEM 2.5 oder neuer / EOSPRINT 1.5 oder neuer

EOS-Parametersatz: 17-4PH 40µm Stainless
→ (Standardauftrag: 17-4PH_040_StainlessM291_100)

Source: eos.info 2019

Powder material

Beschreibung

Aushärtbare Stähle werden häufig in technischen Anwendungen verwendet, die Korrosionsbeständigkeit und Festigkeit erfordern. Aus EOS StainlessSteel 17-4PH hergestellte Bauteile können direkt nach dem Bau oder nach einer Wärmebehandlung bearbeitet, mikrogestrahlt und poliert werden. Lösungsglühen zusammen mit Alterungsbehandlung sind erforderlich, um die richtige Härte und die richtigen mechanischen Eigenschaften zu erzielen (ASTM A564 – 13). Aufgrund der schichtweisen Baumethode besitzen die Bauteile eine gewisse Anisotropie, die durch Lösungsglühen gemindert werden kann.

Wärmebehandlung

Vakuum-H900-Wärmebehandlungsverfahren:

→ Lösungsglühen: Für 30 Minuten bei 1.040 °C ±15 °C halten, Luftkühlung unter 32 °C.

→ Alterung: Für eine Stunde bei 480 °C halten, Luftkühlung unter 32 °C.

Wärmebehandlung unter Schutzgas (bevorzugte Schutzatmosphäre: Argon):

→ Lösungsglühen: Für 30 Minuten bei 1.040 °C ±15 °C halten, Luftkühlung unter 32 °C.

→ Alterung: Für eine Stunde bei 460°C halten, Luftkühlung unter 32 °C.

Source: eos.info 2019

Powder material

Qualitätssicherung des Pulvers EOS StainlessSteel 17-4PH

Die Qualität jeder der gelieferten Pulvercharge von EOS StainlessSteel 17-4PH wird durch Qualitätssicherungsverfahren gewährleistet, die Bestandteil des Qualitätsmanagementsystems von EOS sind. Die Verfahren beinhalten die Qualitätssicherung des Pulvers und des Prozesses.

Die Qualitätssicherung des Pulverprodukts umfasst:

→ die Probenahme (ASTM B215)
→ das Sieben (ASTM B214)
→ die Analyse der Teilchengröße (ASTM B822)
→ die chemische Analyse (ASTM E2823/E1479/E1019)
→ die scheinbare Dichte (ASTM B212/B329/B417)

Die Qualität des Prozesses wird für jede gelieferte Pulvercharge durch die Durchführung eines Qualitätssicherungsauftrags mit einem zugelassenen EOS-M-290-System sichergestellt.

Die Prozessqualität wird geprüft durch:

→ Zugprüfungen (ISO6892, ASTM E8M)
→ Dichtemessung (ISO3369)
→ Härtemessung (ISO 6508)
→ chemische Analysen der festen Bauteile (ASTM 2823/E1479/E1019)

Die Ergebnisse der Qualitätssicherungstests werden gemäß EN-10204 Typ 3.1 in chargenspezifischen Werkstoffprüfbescheinigungen (Mill Test Certificates, MTC) angegeben.

Source: eos.info 2019

Powder material

Technische Daten

Pulvereigenschaften

Die chemische Zusammensetzung des Pulvers entspricht den Normen „F899 – 12b Standard Specification for Wrought Stainless Steels for Surgical Instruments" (Spezifikation für Schmiedeedelstähle für chirurgische Instrumente) und „A564M – 13 Standard Specification for Hot-Rolled and Cold-Finished Age-Hardening Stainless Steel Bars and Shapes" (Spezifikation für warmgewalzte und kalt bearbeitete aushärtende Edelstahlstäbe und -formteile).

Materialzusammensetzung	Laut Norm	
Element	**Min.**	**Max.**
Cr	15,00	17,50
Ni	3,00	5,00
Cu	3,00	5,00
Si	–	1,00
Mn	–	1,00
C	–	0,07
P	–	0,040
S	–	0,030
Nb + Ta	0,15	0,45

Source: eos.info 2019

Powder material

Mechanische Eigenschaften bei Raumtemperatur [12]

	Wie gebaut	Vakuum H900 (4 Sigma)	Wärmebehandlung unter Schutzgas	ASTM A564 (H900)
Zugfestigkeit, Rm				
In horizontaler Richtung (XY)	Mittel 886,0 MPa	Mittel 1335,8 MPa	Mittel 1340,0 MPa	min. 1310 MPa
	SD 70,4 MPa	SD 5,2 MPa	SD 5,9 MPa	
N (Anzahl der Proben)	72	144	36	
In vertikaler Richtung (Z)	Mittel 924,2 MPa	Mittel 1342,6 MPa	Mittel 1345,5 MPa	min. 1310 MPa
	SD 65,9 MPa	SD 7,7 MPa	SD 2,8 MPa	
N (Anzahl der Proben)	84	168	42	

Source: eos.info 2019

Powder material

Base	Material Class	Product name	Material properties
Al	Aluminum	m4p™ AlSi10Mg	m4p™ AlSi10Mg is an aluminum-based alloy with good weldability
		m4p™ AlSi9Cu3	m4p ™ AlSi9Cu3 is an aluminum alloy with a favorable combination of high thermal conductivity, good strength and corrosion properties
		m4p™ AlSi7Mg	As compared to AlSi10Mg, with reduced specific values
		m4p™ ß-PureAl	Aluminum alloy with lowest alloy content and thus high thermal conductivity
		m4p™ ß-AW7075	High-strength wrought aluminum alloy of excellent polishability – limited suitability for welding.
		m4p™ ß-DuktAl	Aluminum alloy of highest ductility for forming-strained applications
		m4p™ ß-HardAl	Particle-enhanced aluminum alloy of high strength and increased wear resistance
		m4p™ ß-StrengthAl	Ultra-high-strength aluminum alloy as alternatibe to Scalmaloy
		m4p™ ß-AW6060	Aluminum wrought alloy with good corrosion resistance; very good anodizibility – conditionally suitable for welding

Source:metals4printing.com , 2020

Powder material

Base	Material Class	Product name	Material properties
Cu	Copper alloys	m4p™ CuNiSiCr	Copper-based precipitation hardening high-performance material of high electrical and thermal conductivity at high strength and stability; up to 42% IACS at good additive processing capability
		m4p™ PureCu	Ultra-pure copper powder for applications with highest electrical and thermal conductivity; purity degree >99.95%Cu
		m4p™ CuCrZr	Copper-based precipitation hardening high-performance material of high electrical and thermal conductivity and a high softening temperature; up to 80%IACS - more demanding additive processing capabilities than CuNiSiCr
		m4p™ Al-Brz9,5	Aluminum bronze; copper-material of highest mechanical strength and ideal tensile ductility - even at lowest temperatures. Has excellent additive processing capabilities and, next to its excellent mechanical properties, is highly resistant against abrasive wear. Traditionally used for marine applications.
		m4p™ ß-CoNiBe	Precipitation hardening copper alloy that stands out by high heat resistance. This material is particularly valuable if high strength combined with good electrical and thermal conductivity is required.
		m4p™ CuZn42	Brass alloy of extremely low lead content; thus particularly suitable for jewelry applications. Additionally, this material features a good balance between strength and formability which facilitates a large variety of industrial applications.
		m4p™ Brz10	Bronze/construction material; tin bronze with good mechanical strength properties and maximum corrosion resistance

Source:metals4printing.com , 2020

Powder material

Base	Material Class	Product name	Material properties
Fe	Stainless steels	m4p™ 316L	m4p™ 316L is a corrosion-resistant austenitic alloy with a wide range of applications
		m4p™ Fe-4542	Also known as 17-4PH (AISI-Standard). Hardenable stainless alloy with excellent strength properties
		m4p™ CrMo1	Low-alloyed, heat-resistant steel material for working temperatures up to 530 ° C. Used for boiler construction, power plant construction or power generation
		m4p™ Fe-4828	Stainless heat resistant austenitic steel. Standard quality for furnace construction and high temperature applications
		m4p™ Fe-4011	Ferritic, stainless chromium steel with good processability. In particular for the production of ferromagnetic components and prototypes
		m4p™ Fe-4021	Martensitic chrome steel, with good corrosion resistance. For construction parts, tools with cutting edges or workpieces which require increased wear resistance
		m4p™ Fe-4308	Corrosion-resistant austenitic alloy – (compared to m4p 316L with reduced pitting resistance)
			Stainless, well-polishable steel of medium to high strength, especially suited for non-corroding tools and molds
		m4p™ Fe-4405	Corrosion-resistant Fe base material with high thermal shock resistance, harder than m4p 316L

Source:metals4printing.com , 2020

Powder material

Base	Material Class	Product name	Material properties
Fe	Maraging steels	m4p™ Fe-2709	Tool steel (maraging steel) with excellent mechanical properties and extreme stability and high hardness after being heat-treated (490°C/6h)
		m4p™ MS2	Alternative maraging steel for highly stressed parts in tool and mold making – especially for better surfaces after eroding, com-pared to the m4p Fe-2709
Fe	Wear resistant steels	m4p™ Fe-2343	Tough and heat resistant steel for tooling and mold making with high "as built" hardness (48 HRC). Can be post cured to 52-56 HRC
		m4p™ H13	Versatile hot-work steel processed without preheating – the material tends to crack
		m4p™ ß-type26	High-temperature-resistant iron-based material for demanding applications in the engine manufacturing sector
		m4p™ FeCr-10V	Wear-resistant iron-vased alloy of good residual tensile ductility füor cutting applications or applications against fine-grinding abrasion.
Fe	Tempering steels	m4p™ Fe-6773	Tempered steel with high wear resistance
		m4p™ 42CrMo	Versatile tempered steel for highly stressed applications – processed without preheating – the material tends to crack
Fe	Case hardening steel	m4p™ 18CrNiMo7-6	Tough case hardened steel, good usability for gear parts and gears
Fe	Soft magnetic Fe-material	m4p™ FeSi2,9	Fe-based soft magnetic material with good processability in the additive process
		m4p™ FeSi6,5%	Fe-based soft magnetic material with good capability for additive processing
		m4p™ CoFe48	Soft magnetic material with highest saturation polarization
		m4p™ FeCo50	Soft magnetic material with high saturation polarization

Source:metals4printing.com , 2020

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Powder material

Base	Material Class	Product name	Material properties
Ni	Nickel alloys	m4p™ Ni-718	Nickel alloy with high corrosion and oxidation resistance combined with high temperature strength (700 ° C) and good fatigue behavior
		m4p™ Ni-625	Metal powder with alloying elements nickel-chromium-molyb-denum-niobium. The material has excellent resistance under a variety of oxidizing and reducing conditions
		m4p™ ß-Ni-247LC	Special
		m4p™ H C22	High corrosion resistant Ni-Cr-Mo-W alloy
		m4p™ Ni-C22mod	High corrosion resistant, optimized Ni-Cr-Mo-W alloy
W	Tungsten	m4p™ APV5	Tungsten powder giving acceptable levels of density even under standard conditions
		m4p™ Hart12	Typical hard metal compound
		m4p™ Hart17	Typical hard metal compound with increased binder amount and thus higher ductility
		m4p™ sWC	Ultrahard material

m4p

Source:metals4printing.com , 2020

Powder material

Base	Material Class	Product name	Material properties
Ti	Titanium	m4p™ Ti64	Ti-64 is a Ti-based powder suitable for laser-based powder bed fusion (PBF)
		m4p™ Ti64 grade5	Versatile Ti-alloy, with excellent strength-to-weight ratio and best corrosion resistance
		m4p™ Ti64 grade23	This material shows an excellent strength-to-weight ratio combined with high corrosion resistance. Predestined for demanding applications
Mo	Molybdenum	m4p™ APV6-2	Molybdenum-based material for additive manufacturing
Co	Cobalt	m4p™ CoF75	Special
			Special
		m4p™ CoT800	Special

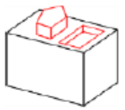
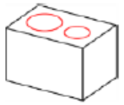
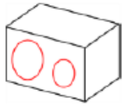
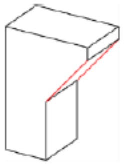
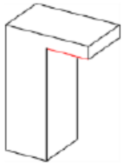
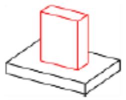
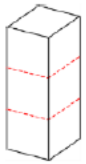
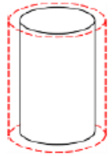
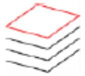
Source:metals4printing.com , 2020

KÄRNTEN University of Applied Sciences

Design Guidelines

Design process

Machine settings (Machining offset, Layer Thickness)

	Wall Thickness	Embossed and engraved details	Vertical Holes	Horizontal Holes	Interlocking parts clearance	Overhangs	Un-supported edges	Powder removal holes	Min. feature size	Min. Pin diameter	Aspect Ratio	Machining offset	Layer Thickness
													
Polymer (PA2200)	~0,5	+/- 1 mm	1,5 mm	1,5 mm	~0,5 mm			~10 mm	~0,5 mm	>0,8			60 – 180 µm
Metal (Ti64)	> 0,4 mm	+/- 0,5 mm	> 2 mm	< 8 mm		45°	~ 1mm	~2mm	120 µm	> 1mm	8:1	~0,5 mm	20 – 90 µm

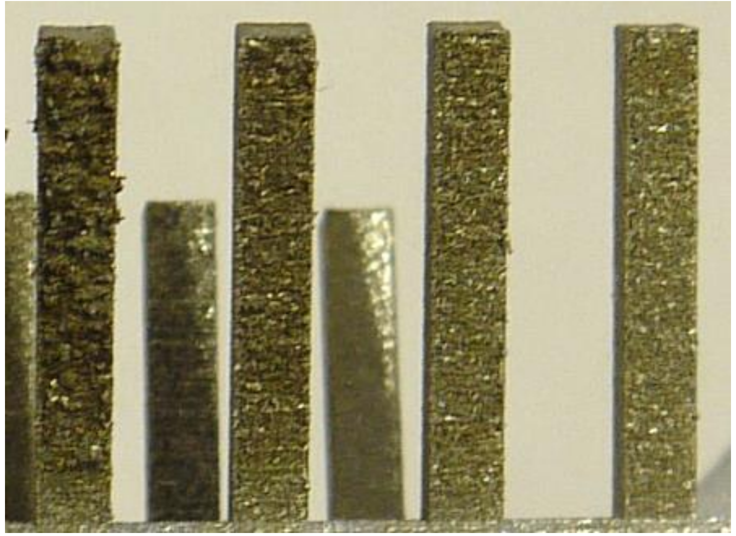
Source: Additive Minds, 2019, Workshop

Upskin / Downskin

- The Up- and Downskin effect occurs within the layer based part generation
- Down facing segments of a part result in a lower surface quality
- Only downskin surfaces can be supported
- Up facing segments of a part enable sharp edges and a high surface quality

→ **<u>Because AM parts are generated layer by layer, characteristic surfaces occur!</u>**

Example: Downskin surfaces



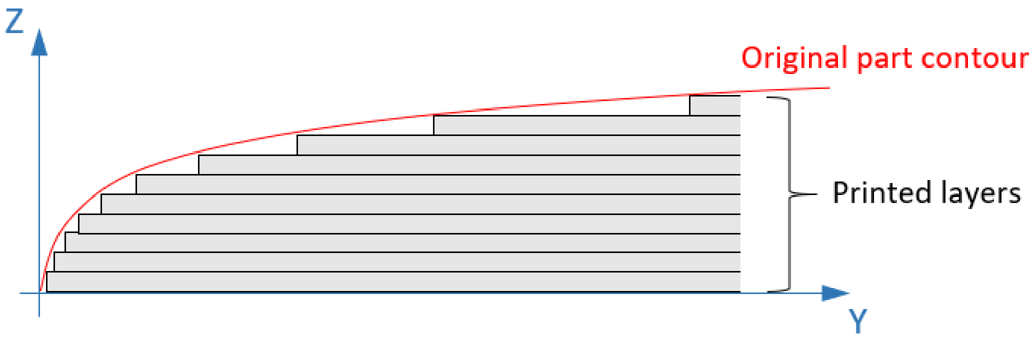
Source: Additive Minds, 2019, Workshop

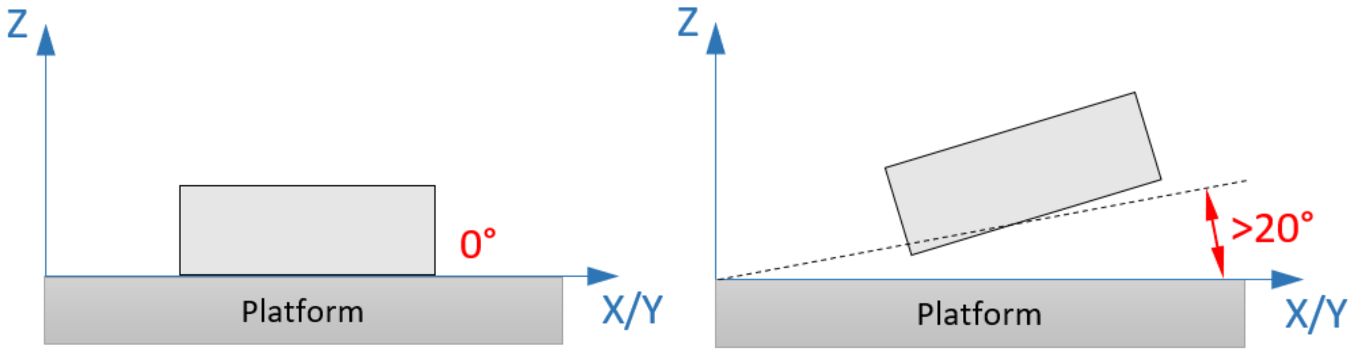
Part orientation

Stepping effect

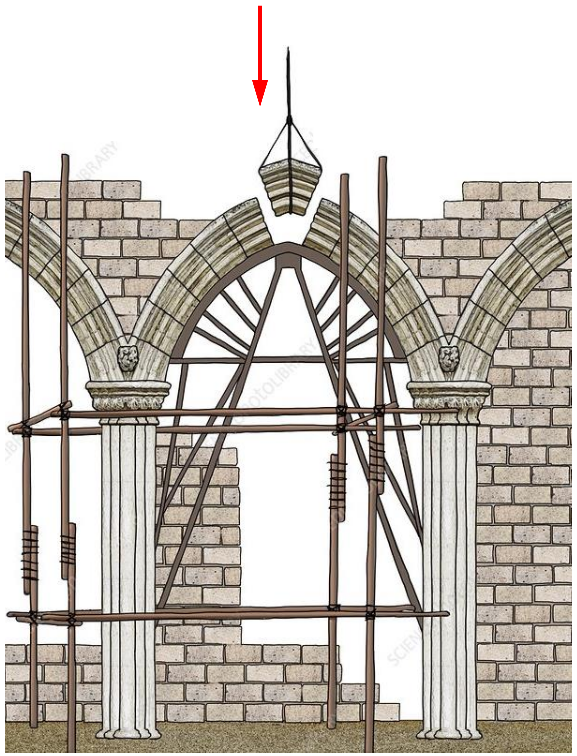
- Geometric incurracy compared to original part
- Visibility and size depending on layer thickness and part orientation
- Impact on: - dimensional accuracy
  - surface quality
  - detail resolution

→ **<u>To avoid steps on the surface, the angle of the plane should be 0° or > 20° to the XY-plane</u>**





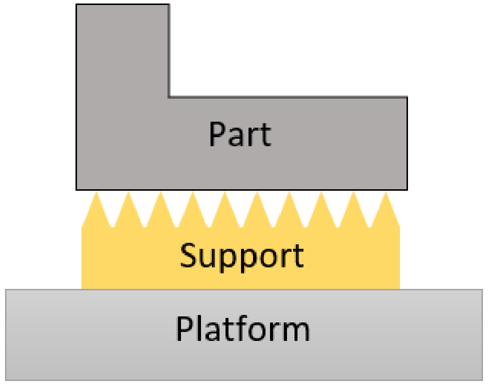
Support structure



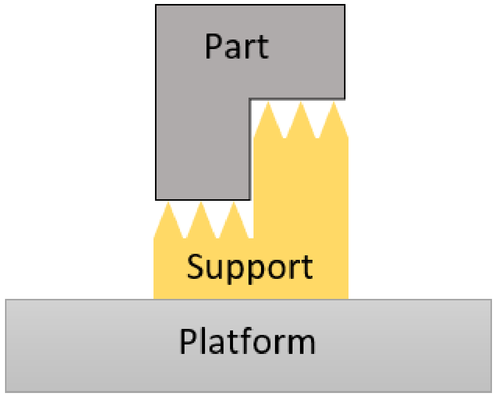
Source: sciencephoto.com, 2019

→ The purpose of support structure is to…

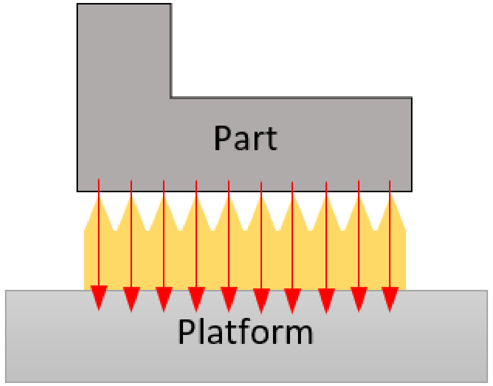
… attach part to platform



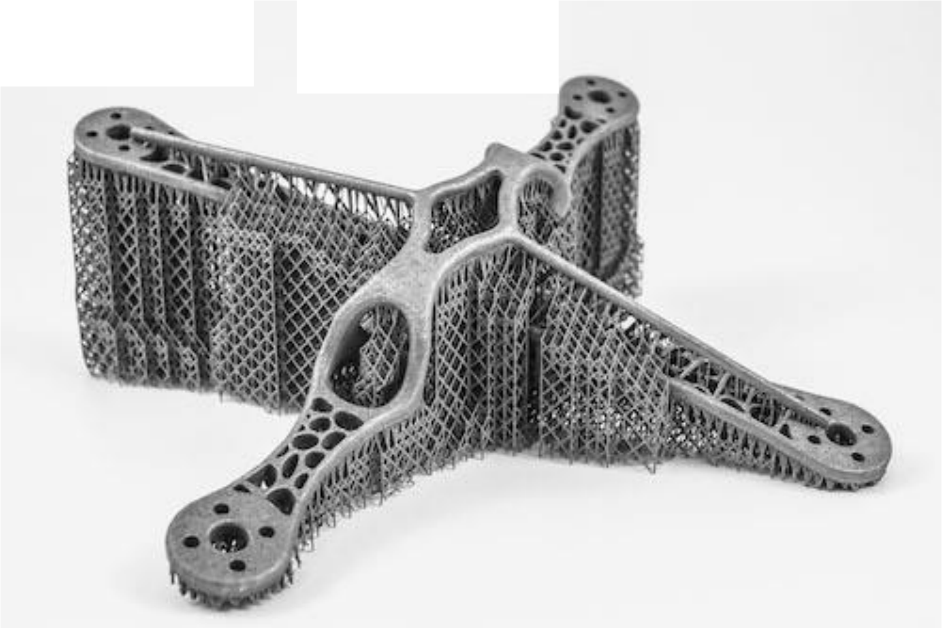
… support steep angles/overhangs



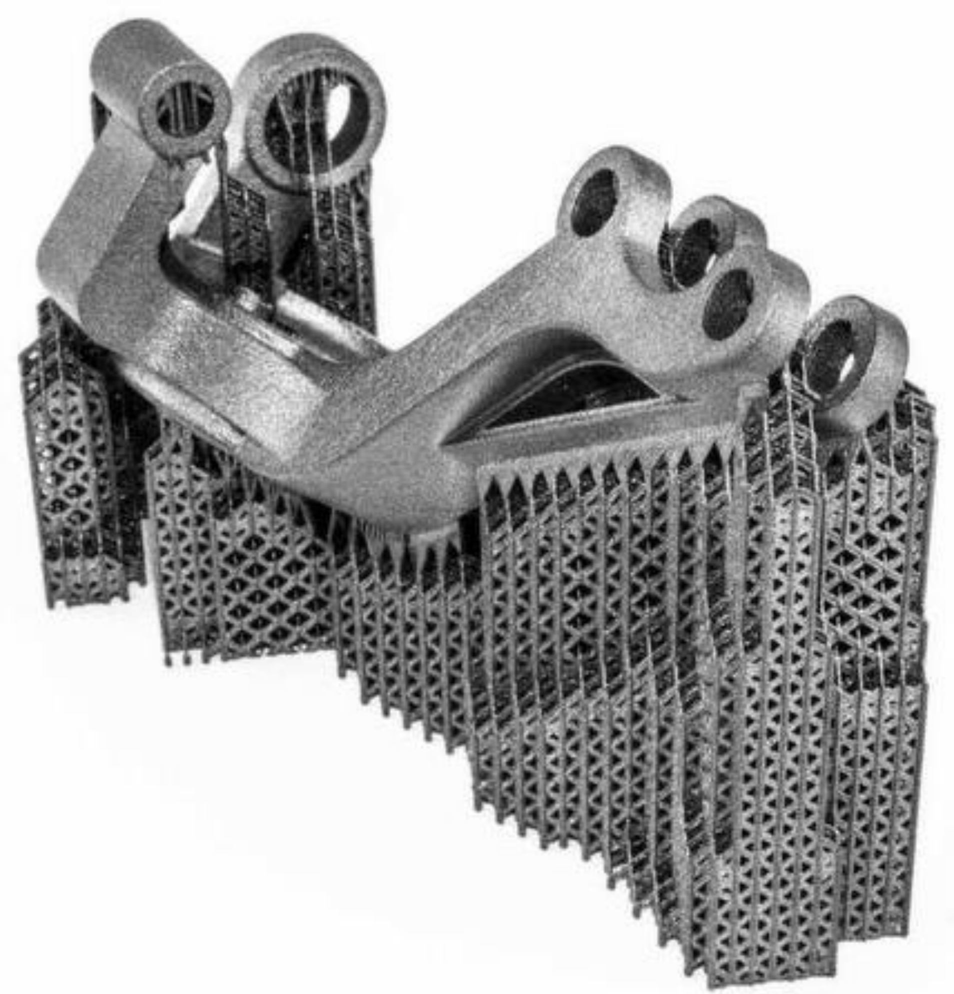
… conduct heat away



Support structure - Examples



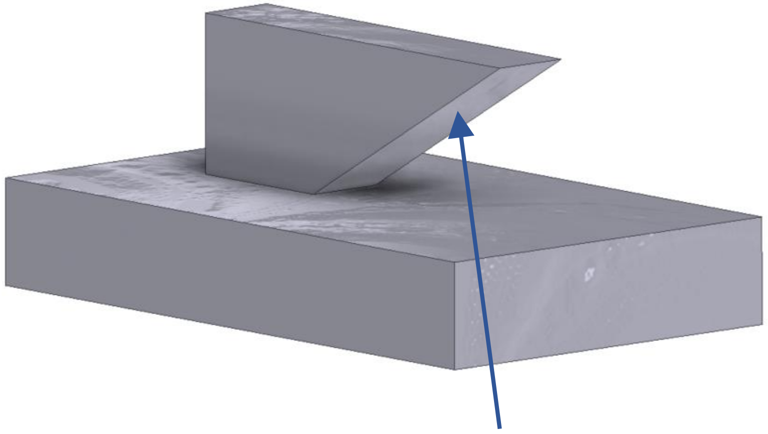
Source: old.rapidreadytech.com, 2019

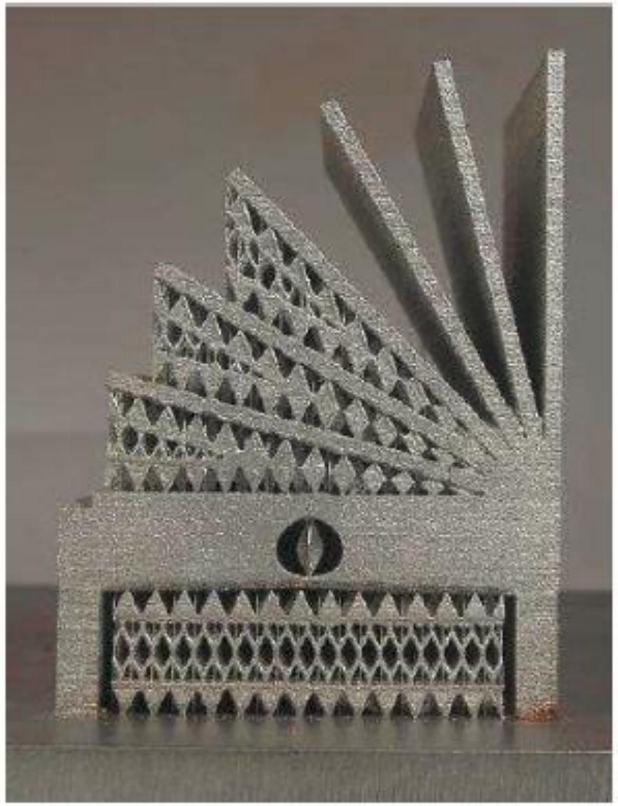


Source: konstruktionspraxis.vogel.de, 2019

Support-free overhanging surfaces

- Minimum self-supporting angles:
  - Stainless steel: ~30°
  - Inconel: ~45°
  - Titanium: ~20°-30°
  - Aluminium: ~45°
  - Cobalt Chrome: ~30°
- Critical angles may require considerable post-processing due to the rough surface




Source: Additive Minds, 2019, Workshop

→ **Smart orientation/part design can reduce or even eliminate the need of support structures!** (reduction of time and costs)

Creation of Support Structure

Support structure

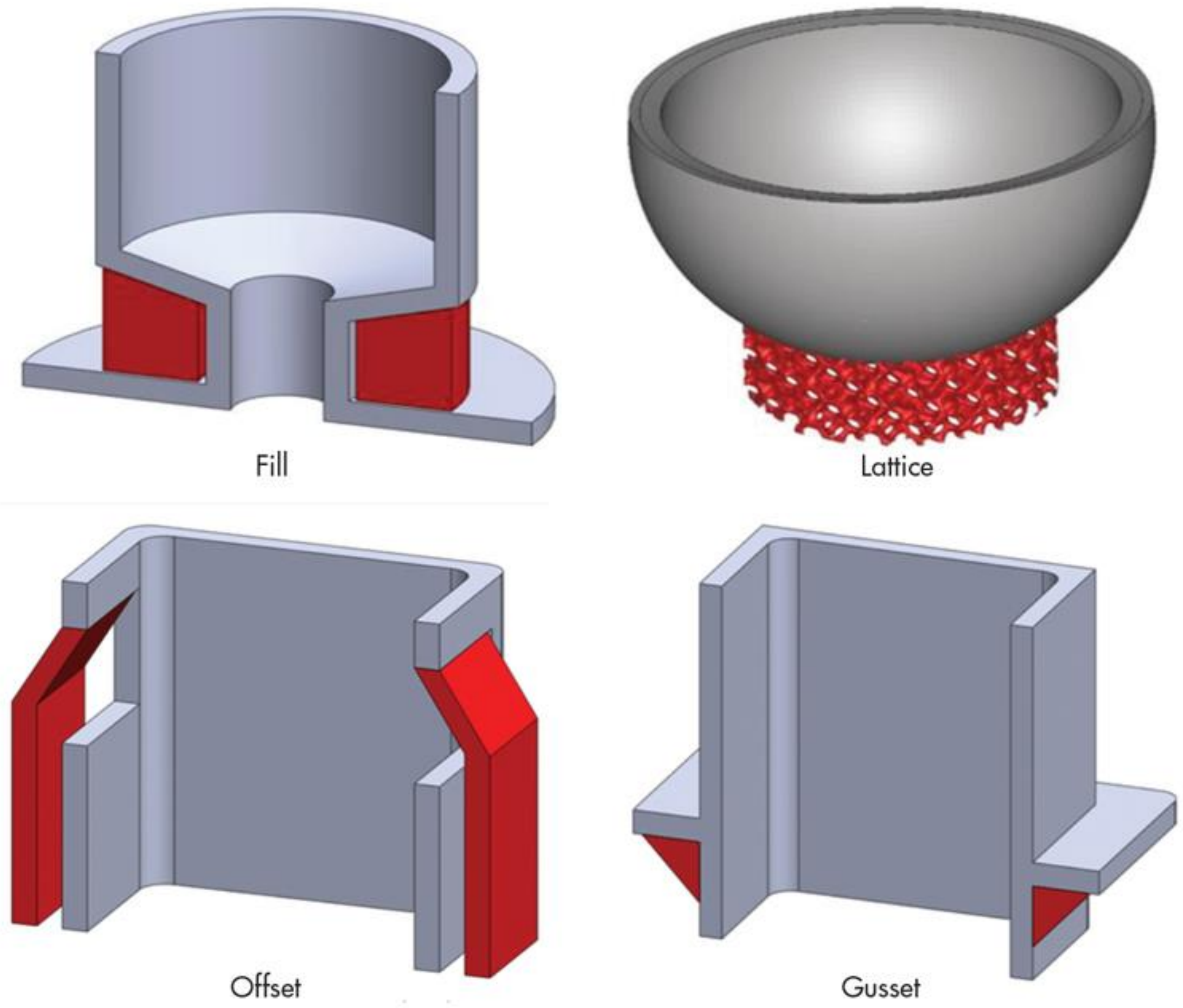
Standard CAD-program ← → Special software

SolidWorks
NX
AUTODESK INVENTOR
CATIA

Materialise Magics
netfabb

Source: Google, 2019, (Logos)

Examples of different support structure



Source: machinedesign.com, 2019

Support-free overhanging surfaces

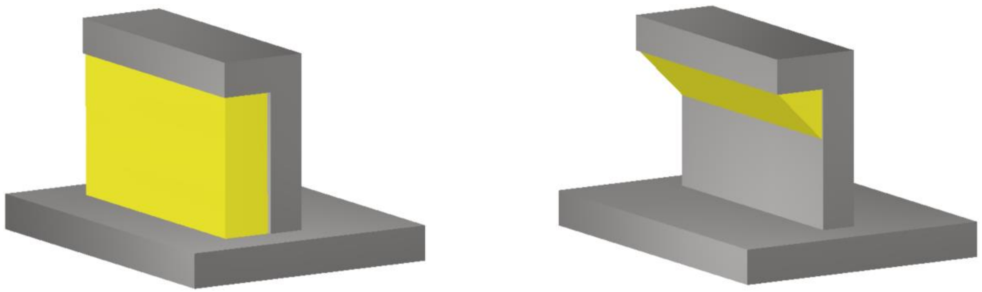
- **In general**
  Horizontal overhangs can be supported from the base → requires energy/material

- **Better solution**
  Support the overhanging surface from the main geometry at an angle

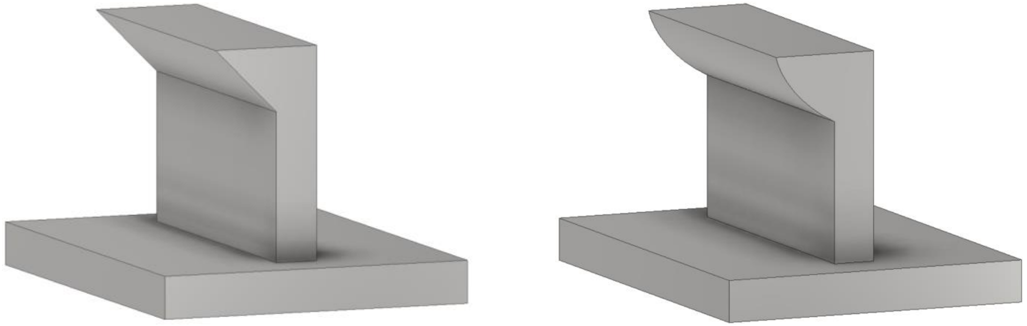
- **Best solution**
  „Integration“ of the support structure into the geometry of the part

→ **<u>Smart design can avoid unnecessary support structure!</u>**

Bad example: support needed for overhanging surfaces



Good example: support-free part design



Support Structure

Support structure…

… adds complexity to a part

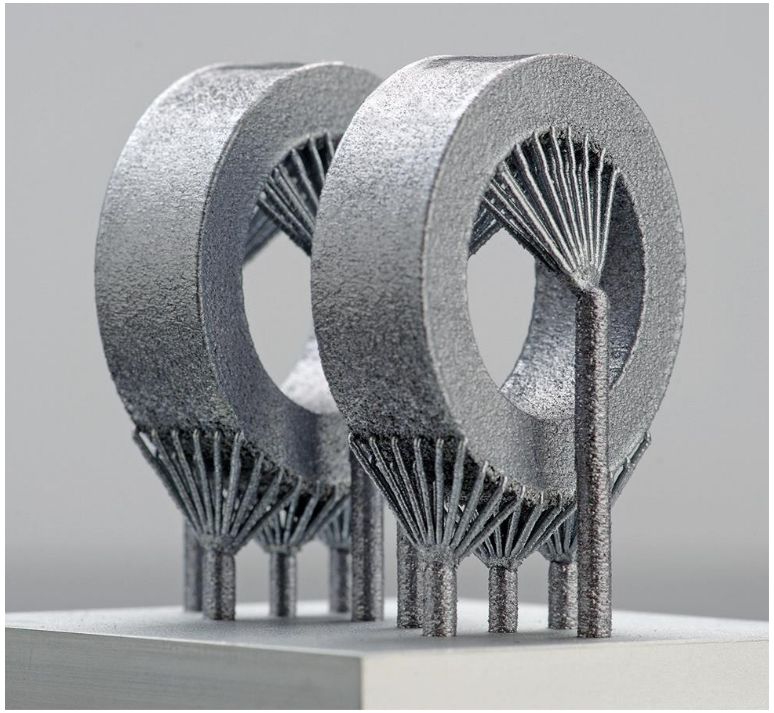
… rises the material consumption

… lowers the surface quality

… requires additional post-processing

… lowers the economic efficiency

Source: materialise.com, 2019



Source: ilt.fraunhofer.de, 2019

Holes

Support structure

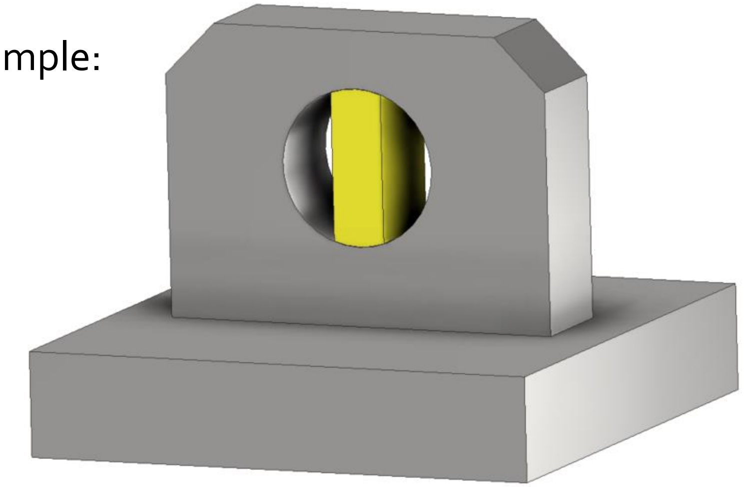
- Supports can improve the roundness and the microstructure in down facing overhangs

No support structure

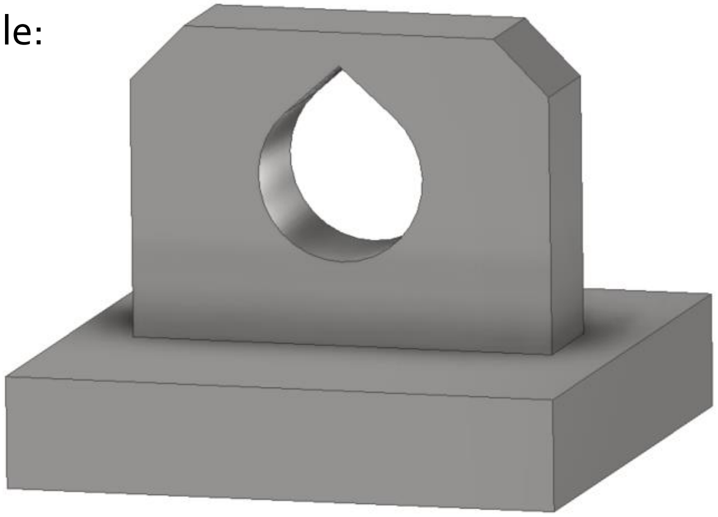
- Holes with angled or arched upper area will probably not require any support
- This feature of DMLS can have a significant impact on the overall design process

→ **Smart design reduces post-processing effort!**

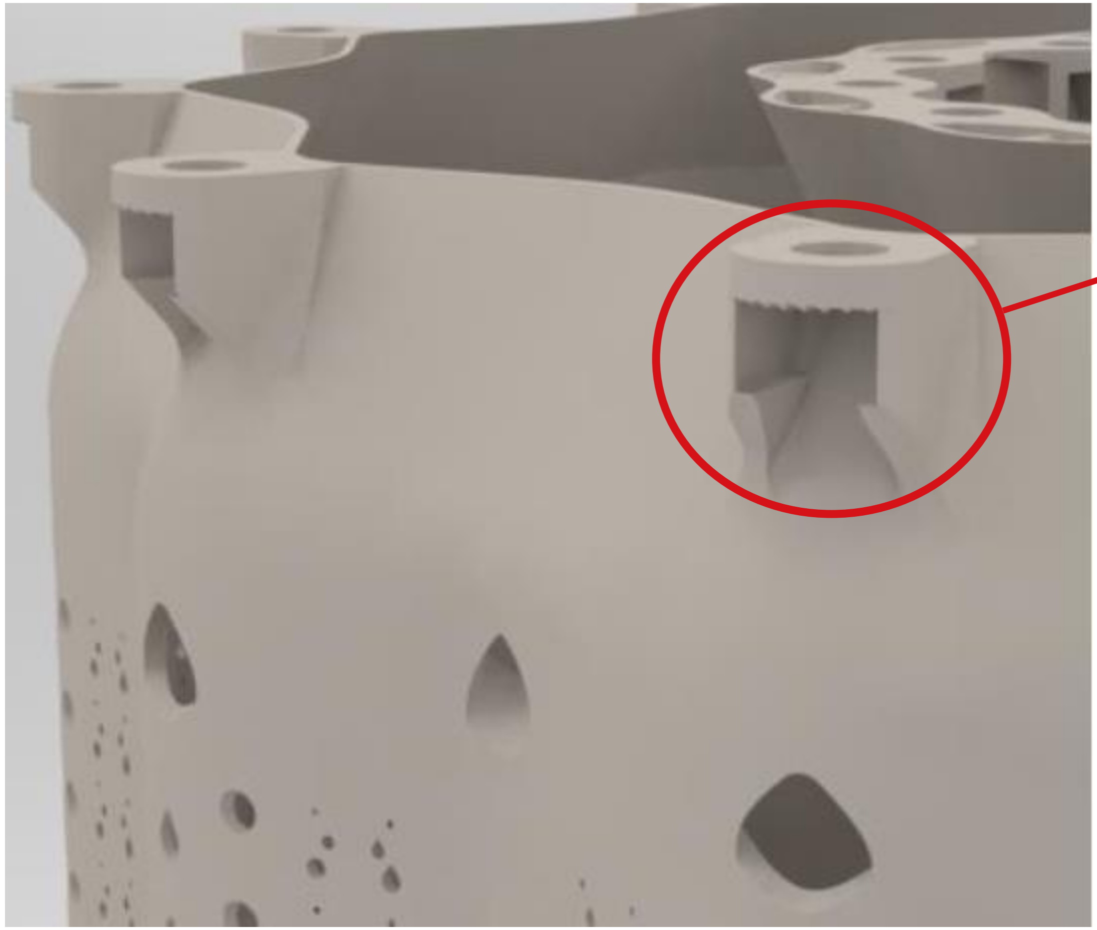
„Bad“ example:



Good example:



Smart solution – support structure

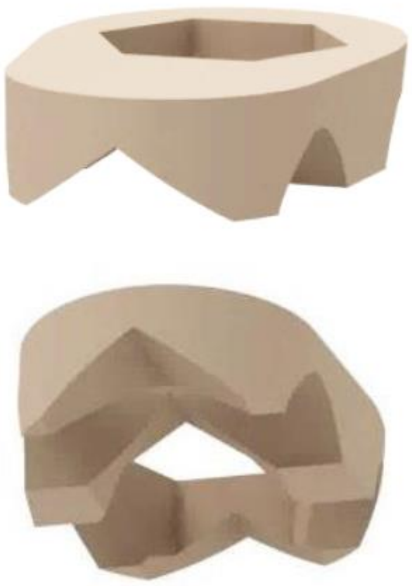


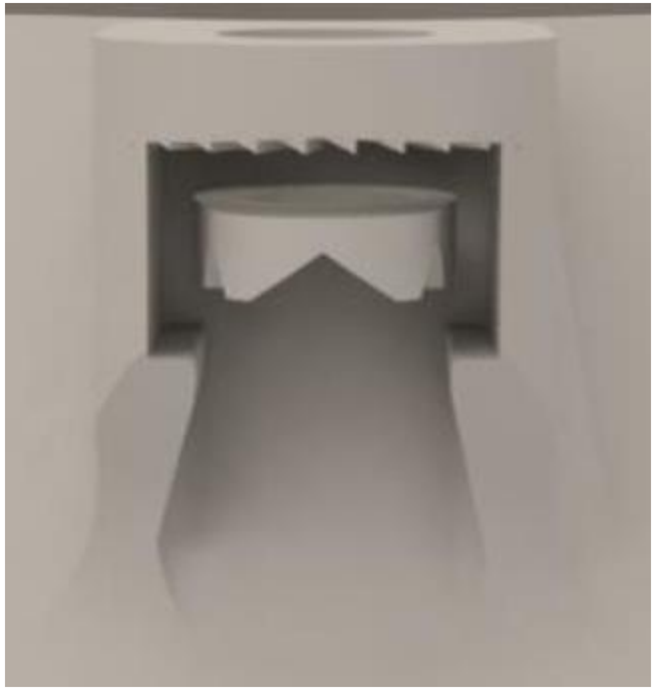
Support required

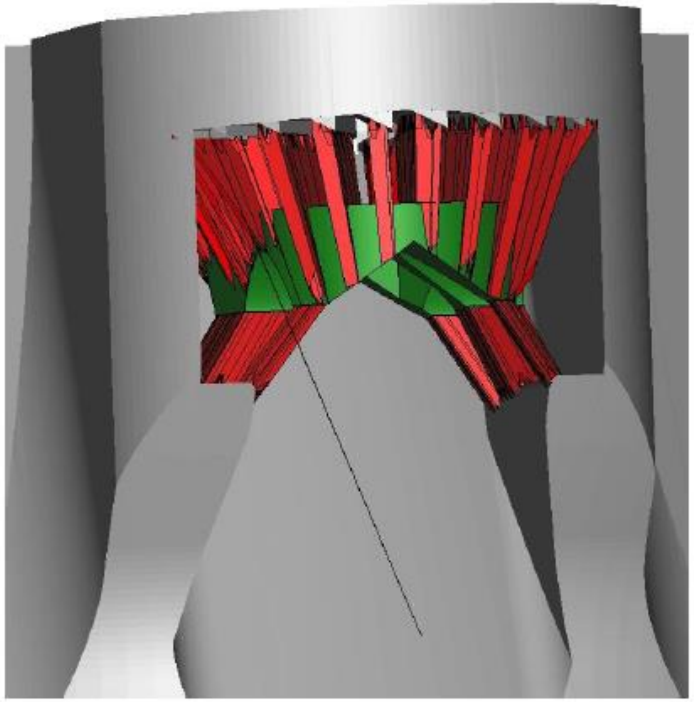
Source: Additive Minds, 2019, Workshop

Smart solution – support structure

→ Additional part to hold and remove support

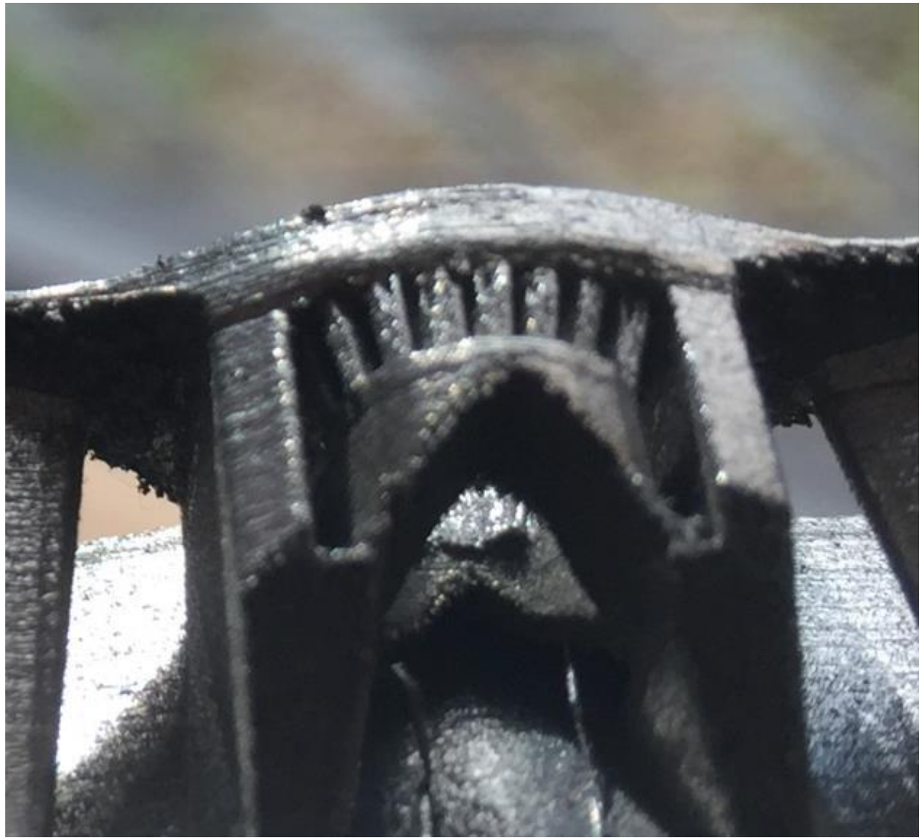


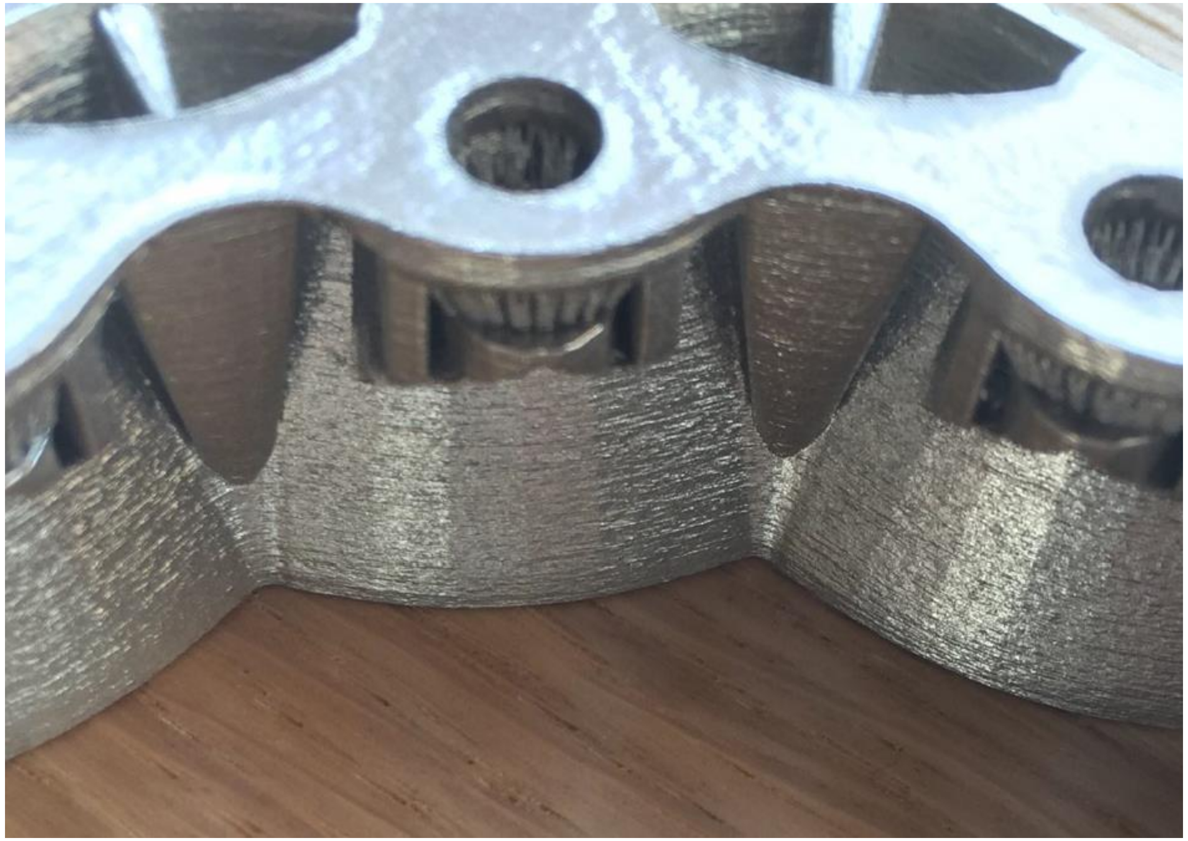




Source: Additive Minds, 2019, Workshop

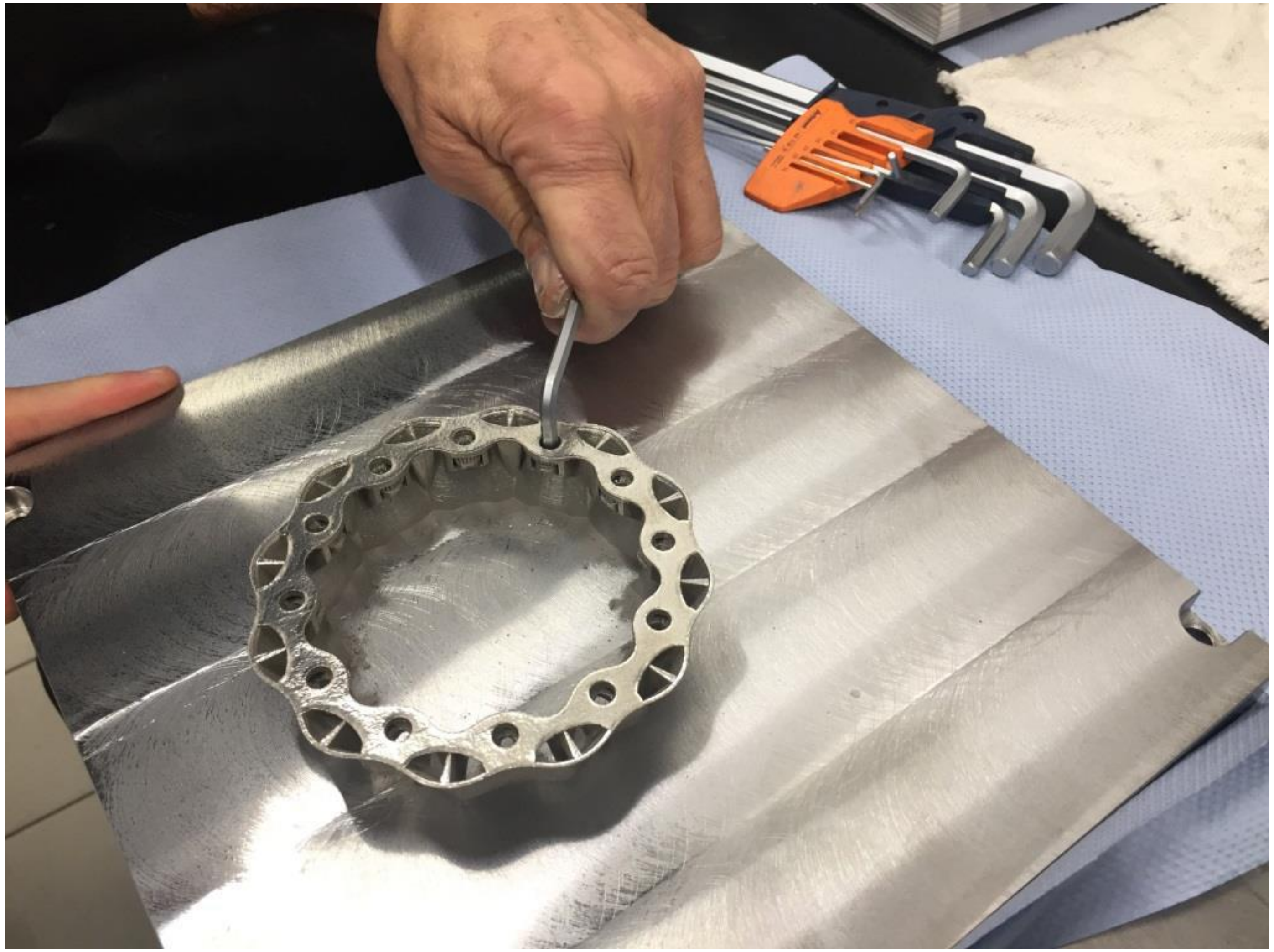
Smart solution – support structure





Source: Additive Minds, 2019, Workshop

Smart solution – support structure



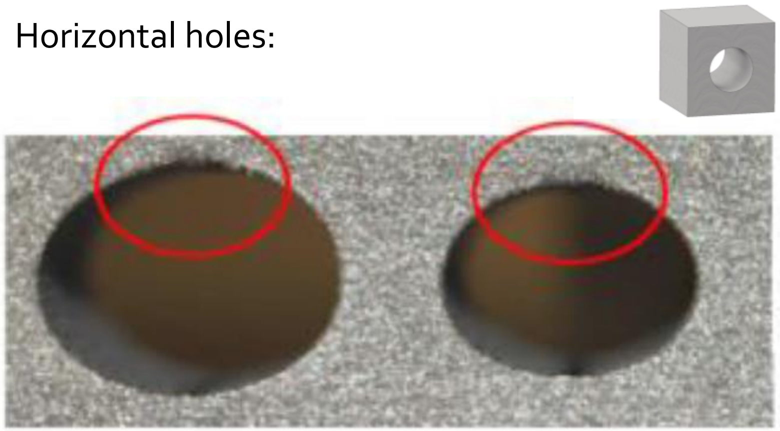
Source: Additive Minds, 2019, Workshop

Holes

- The size of bore holes limits the powder removal and the thermal distribution
- The quality of vertical holes is higher than horizontal holes
- In general: Bore holes **Ø > 2mm**

→ **<u>The minimum diameter of a hole is depending on the wall thickness and on the length of the feature!</u>**

Horizontal holes:



Source: Additive Minds, 2019, Workshop

Vertical holes:

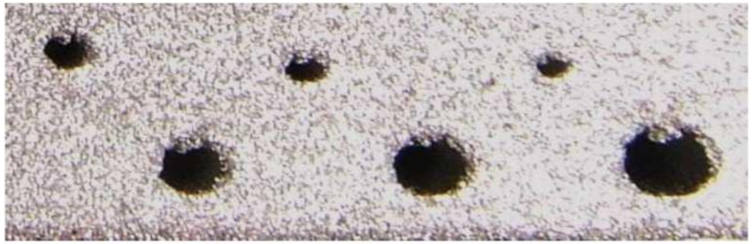
Source: Additive Minds, 2019, Workshop

Holes

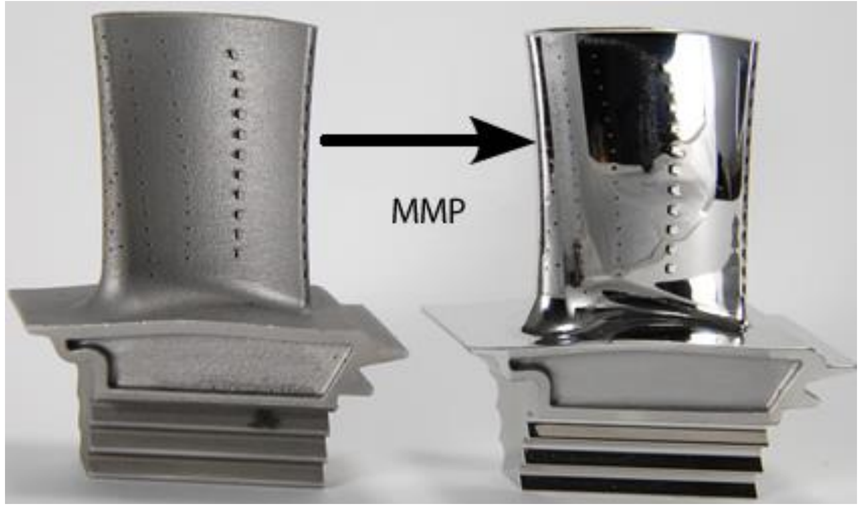
Detail Resolution

- Horizontal holes/passages can be build
- **Problems:**
  - Sagging
  - Rough top surface
- **Limitations:**
  Ø > 8mm needs support
  Ø < 0.5mm cannot be build
- **Solutions:**
  - Post-machining
  - Abrasive Flow Machining
  - Micro Machining Processing (MMP)

Specimen: Ø 0.5mm – 1.2mm



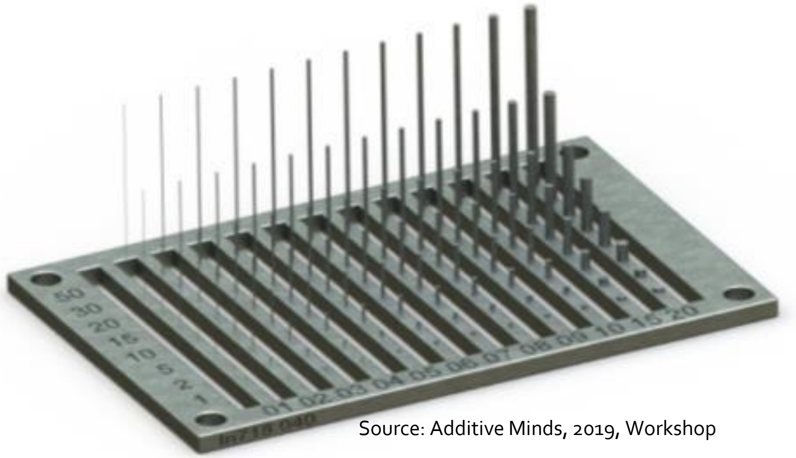
Source: Additive Minds, 2019, Workshop



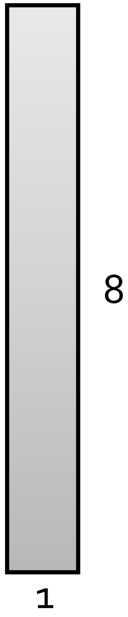
Source: firstsurface.co.uk, 2019

Aspect Ratio

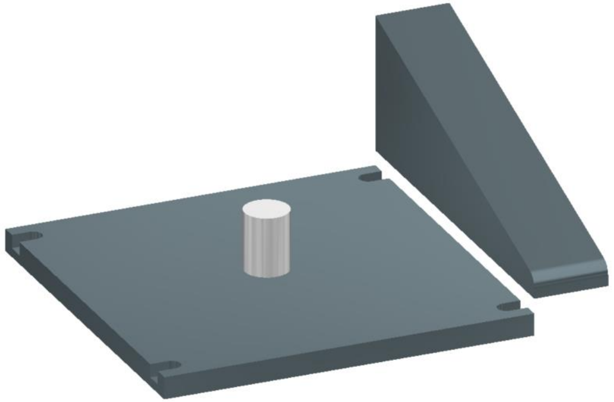
- Minimum reliable pin diameter: **1mm**
- Pin diameters < 1mm are producible but with losing detail resulution due to contour sharpness
- Aspect ratio: **Height/Diameter < 8:1**



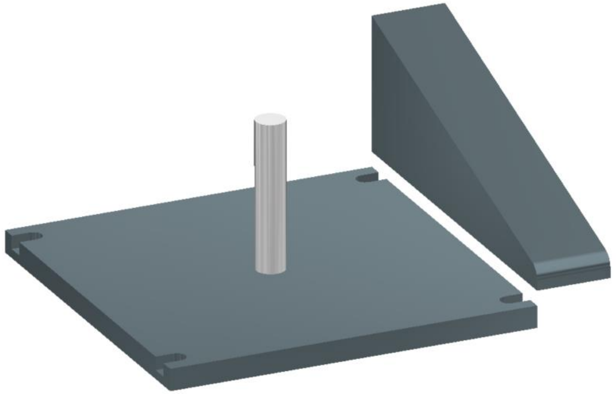
Source: Additive Minds, 2019, Workshop



Good example:



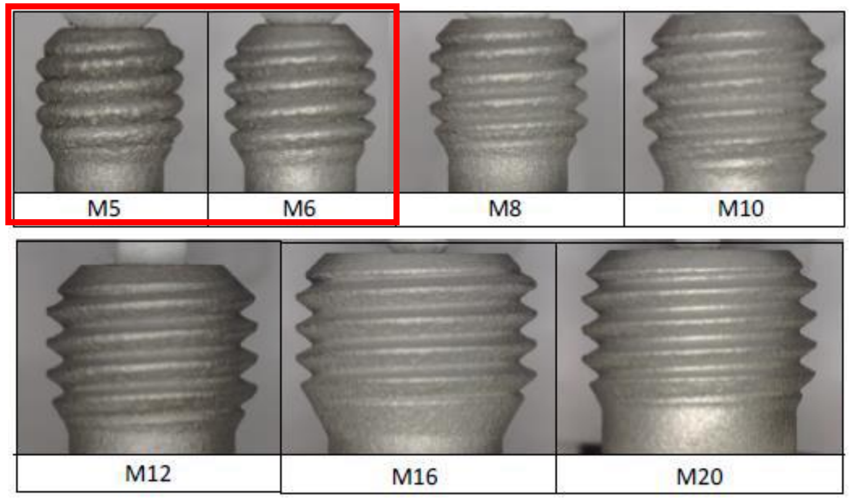
Bad example:



Source: Additive Minds, 2019, Workshop

External Threads

- Female/male threads > **M8**
- Female/male threads < **M8** possible
  → post-processing
- Limiting factors:
  - Aspect ratio (male threads)
  - Shape of thread
  - Tested only on EOS M290



Source: Additive Minds, 2019, Workshop

→ **<u>The decision between conventional thread cutting and AM depends on the quality requirements / function of the part!</u>**

Part orientation

- The orientation of parts on the platform influences the...

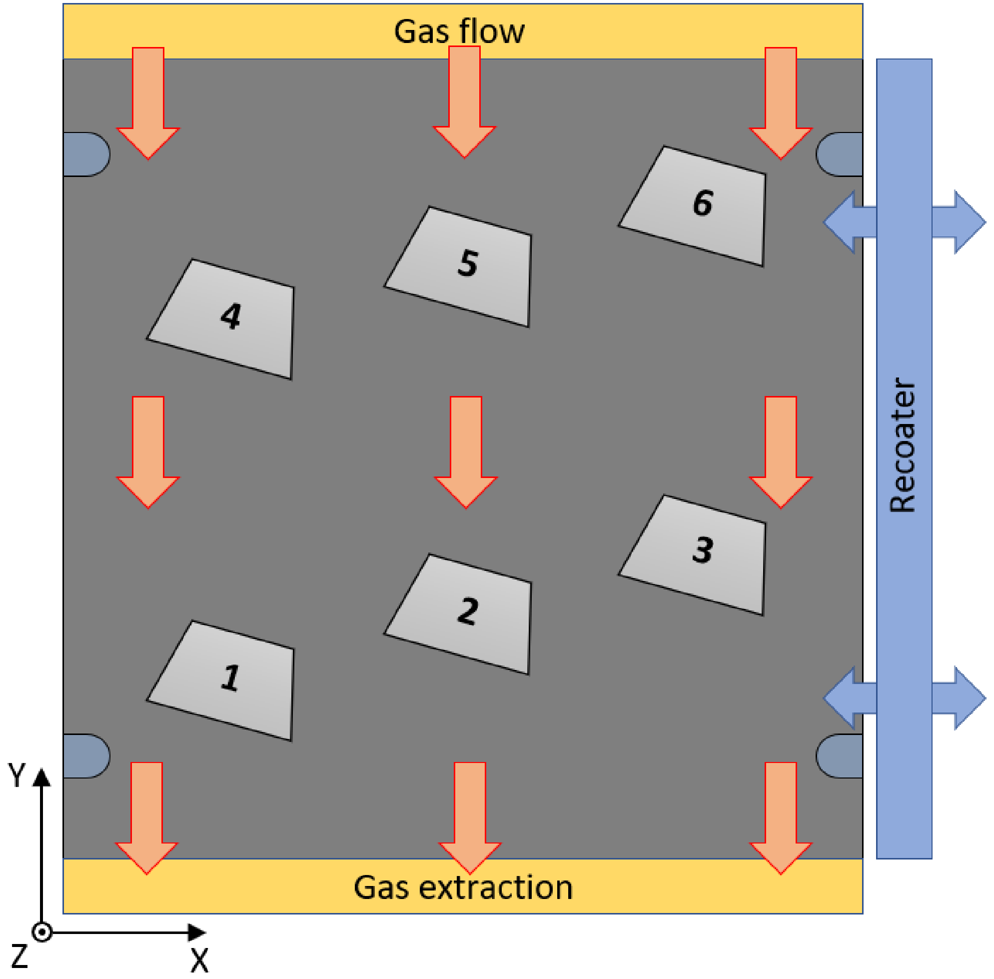
  ... quality
  ... quantity (nesting)
  ... build-time (recoating)
  ... post-processing (support)

  } Economic efficiency

- The order in which parts are exposed by the laser should be controlled due to following factors:

  - Condensate
  - Splashes
  - Laser Obstrution by smoke
  - Material properties

  } Part quality

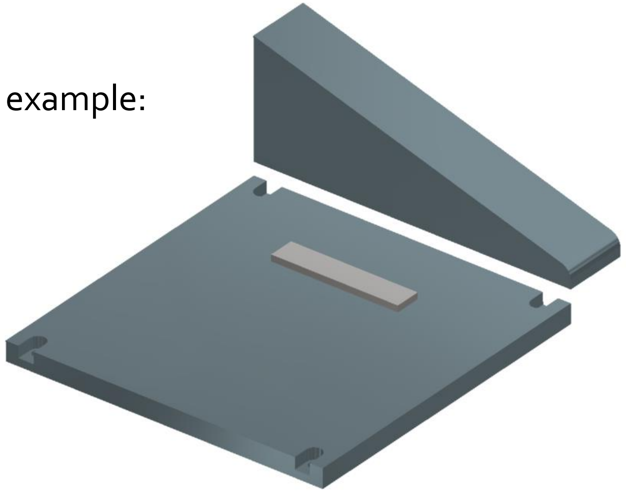


Part orientation

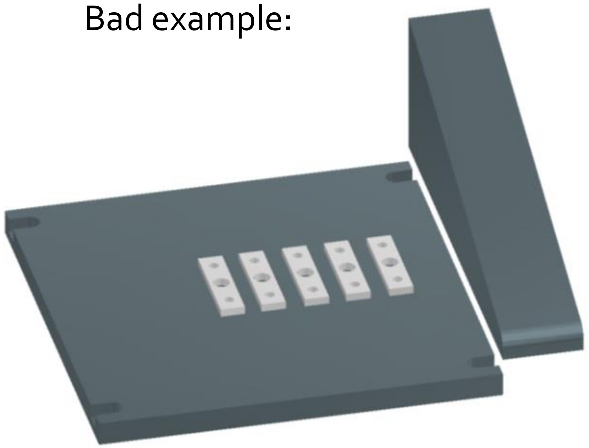
Alignment to the recoater

- Parts should not be aligned parallel to the recoater
- Flat surfaces need to be positioned at a 5° angle to the blade (single point of contact – not a whole line)

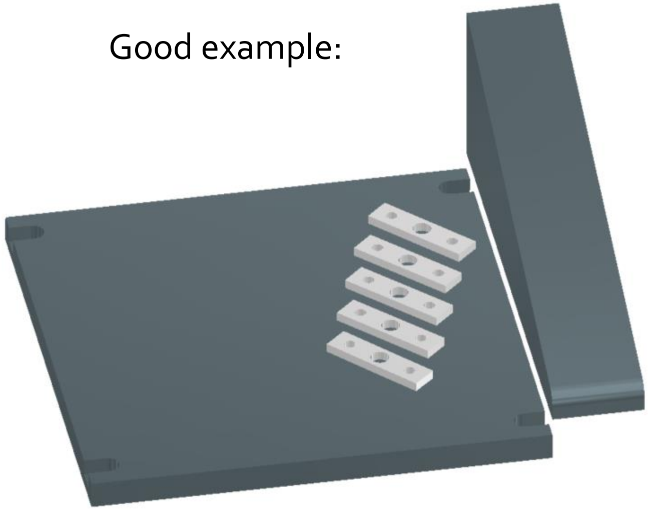
Bad example:



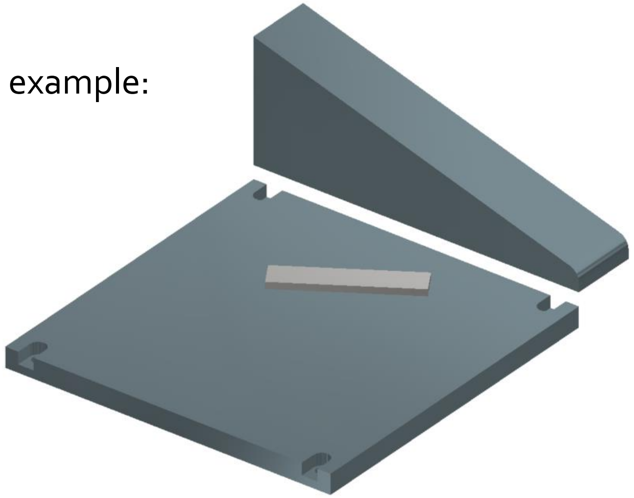
Bad example:



Good example:



Good example:



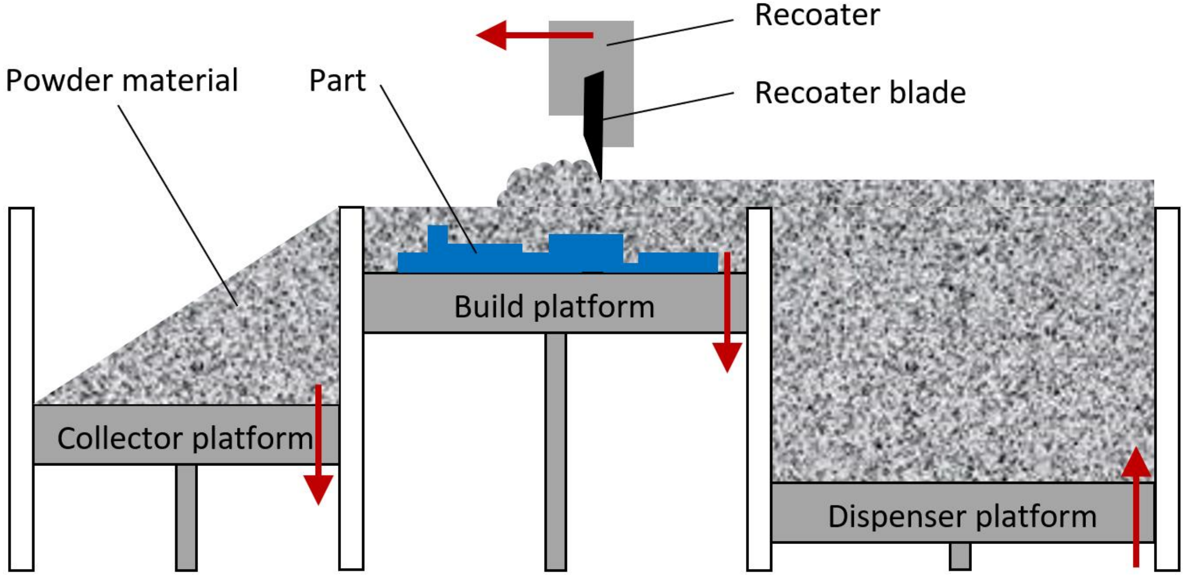
Part orientation

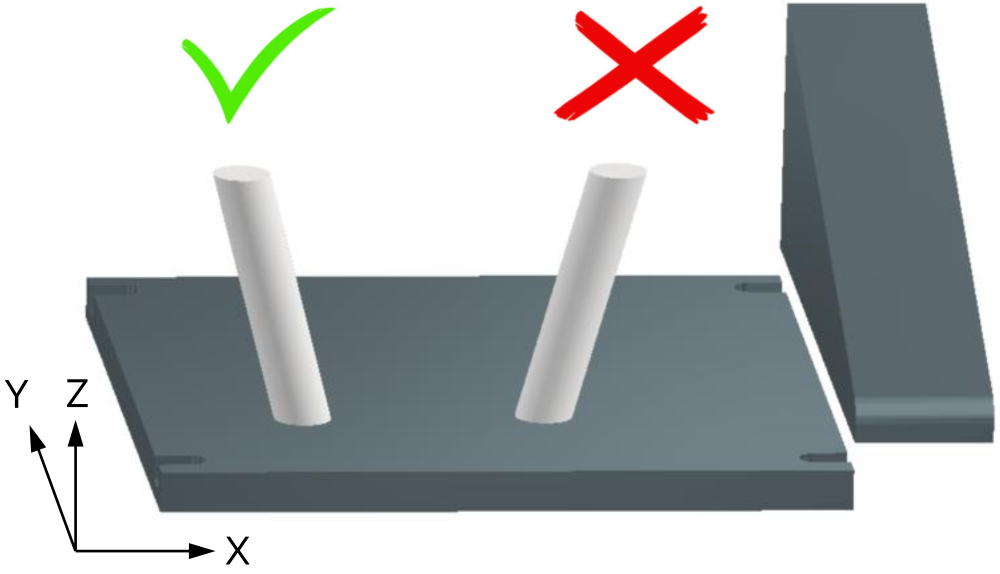
During the recoating process, the recoater blade exerts forces on the support/part when it gets in contact with:

- Bulged areas due to internal stresses
- Clumps and splashes of unintentionally sintered powder

→ Parts should not grow towards the recoater

→ Sharp edges should not be oriented towards the recoater





Part orientation

- Setting up a part for the upcoming printjob
  is one of the most important steps in the process

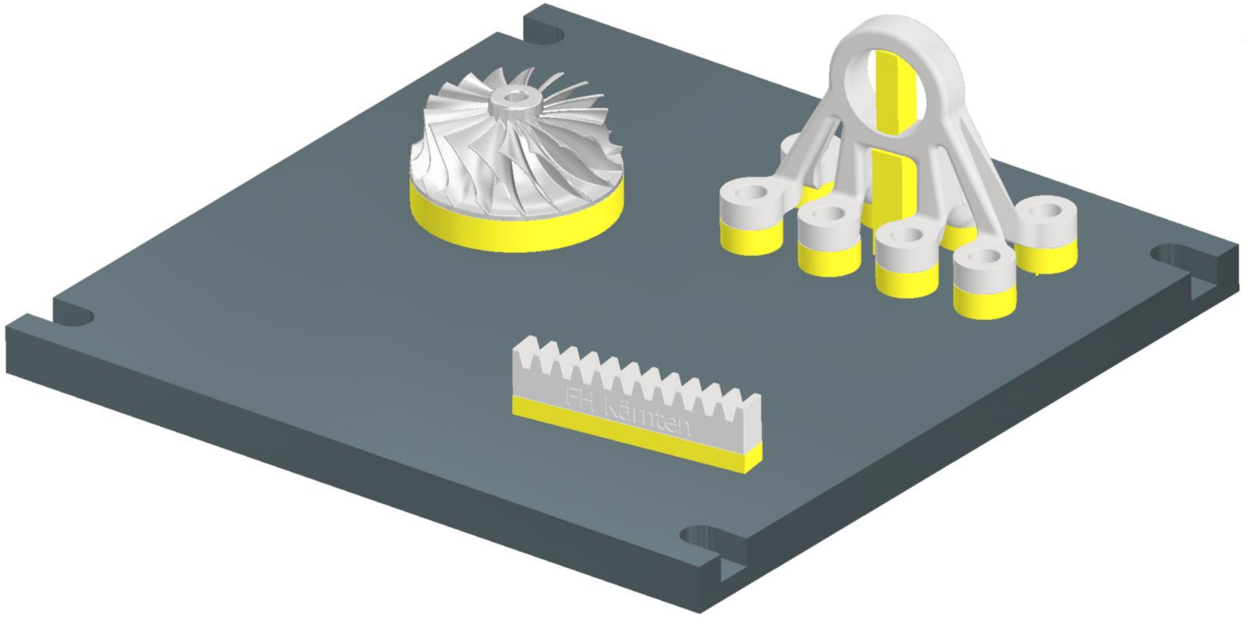
- Within this step, decitions are made regarding the …

  … costs

  … quality

  … buildability

  … post-processing



→ **<u>Therefore, to prepare the printjob in a structured way, the influencing factors have to be understood!</u>**

Part orientation

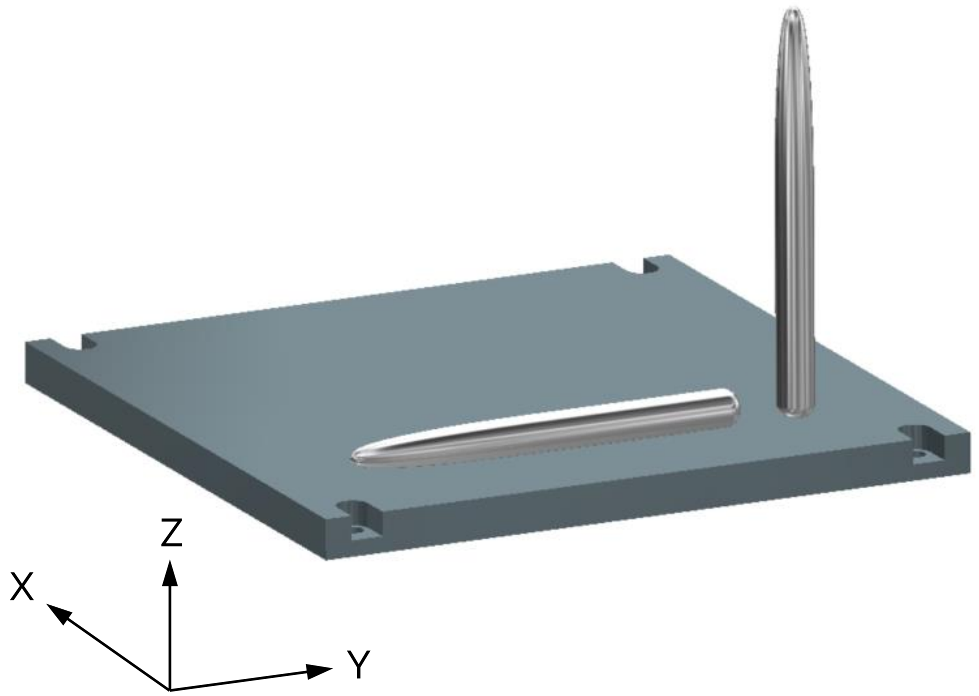
Costs: Build time

- The time of the build process depends on the z-height of the (highest) part on the platform
- The build time results from…

  … the number of layers (recoater passes)

  … the layer thickness

→ **<u>Minimize the maximum z-height of the print job to reduce build time!</u>**



Part orientation

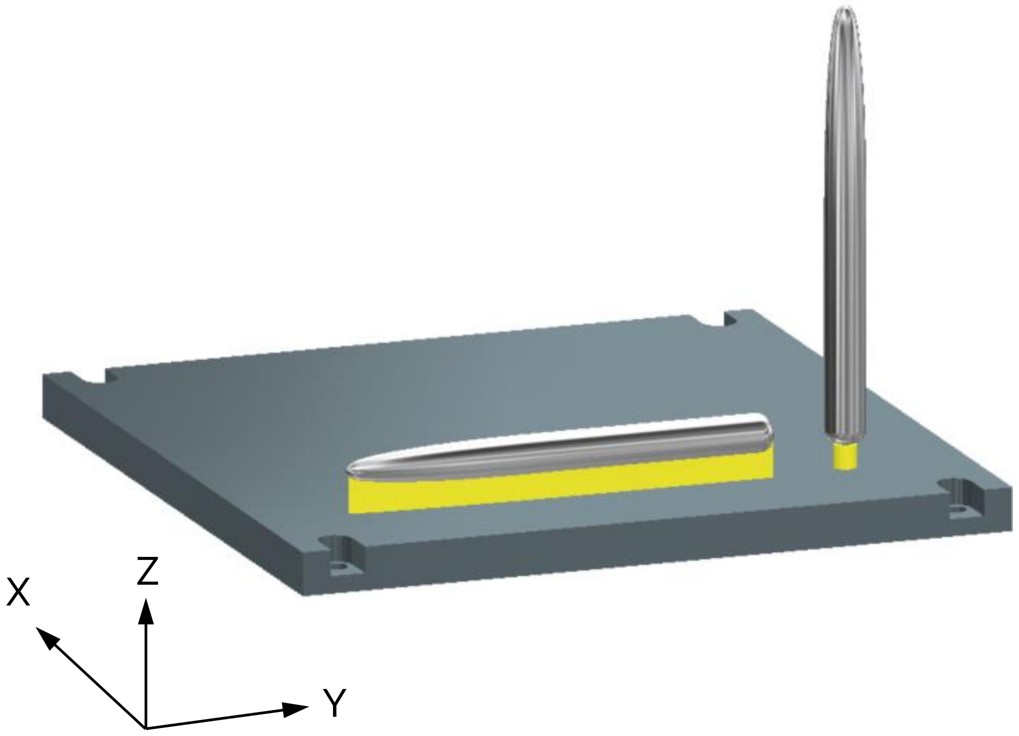
Costs: Powder amount

- The orientation of the part affects the amount of…

  … support structure

  … lost powder material inside the support structure

→ **<u>Avoid downfacing areas for less additional support structures!</u>**



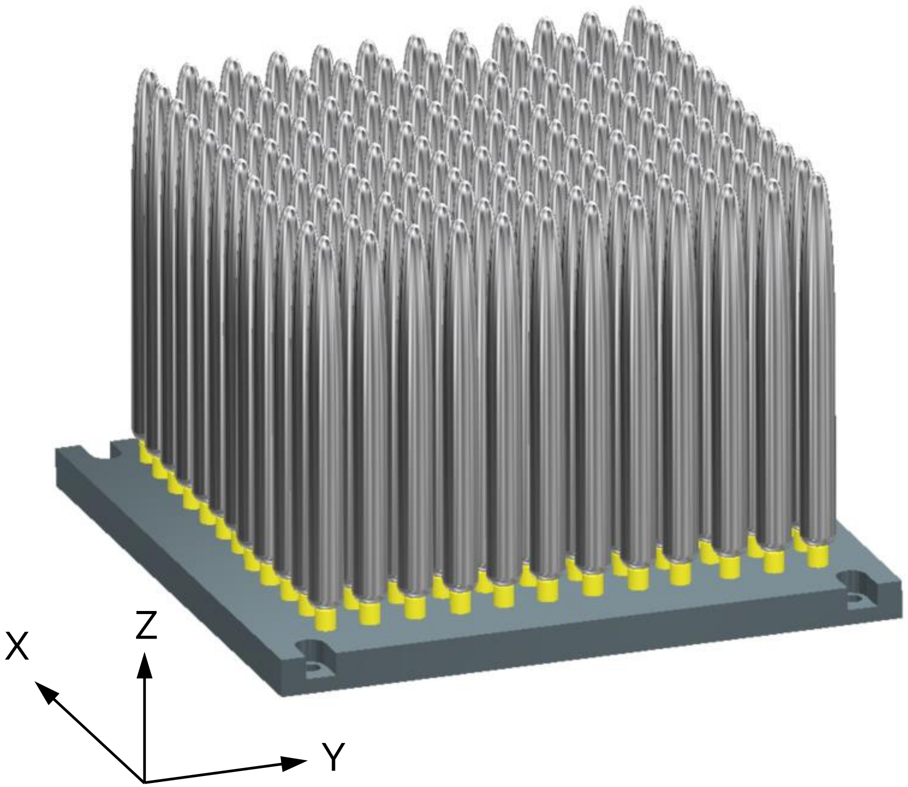
Part orientation

Costs: Nesting

Nesting = Placing as many parts on the platform as possible
(higher productivity)

Influencing factors:

- Orientation of parts (free space for support structure)
- Process quality of each part (prevention of job crash)



Thermal process

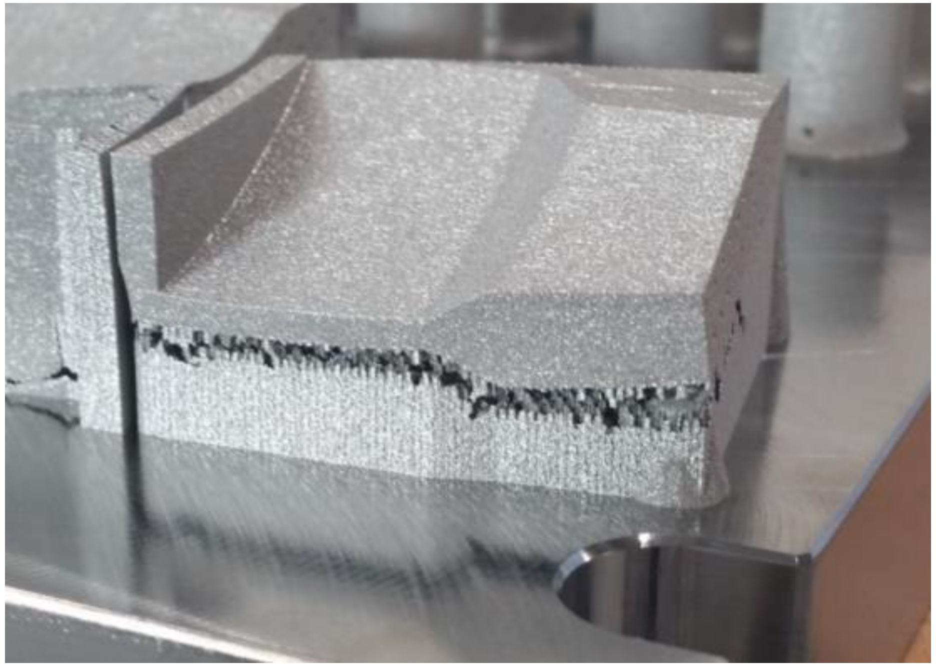
- DMLS is a metal melting process (no „sintering“)
- Significant stresses occur in the parts due to inhomogeneous temperature distribution

Effects:

- Cracks in the part
- Distortion & Warpage

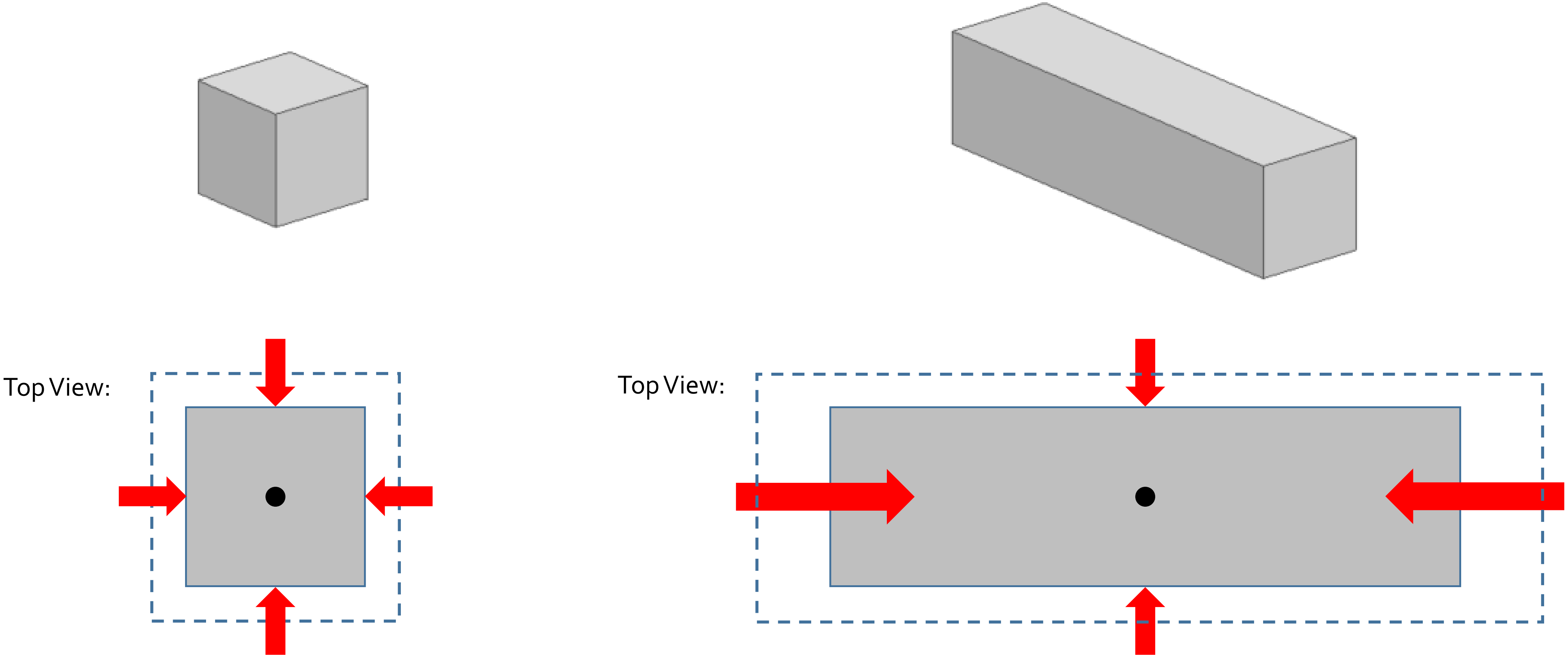
Impact on:

- Dimensional accuracy
- Process stability

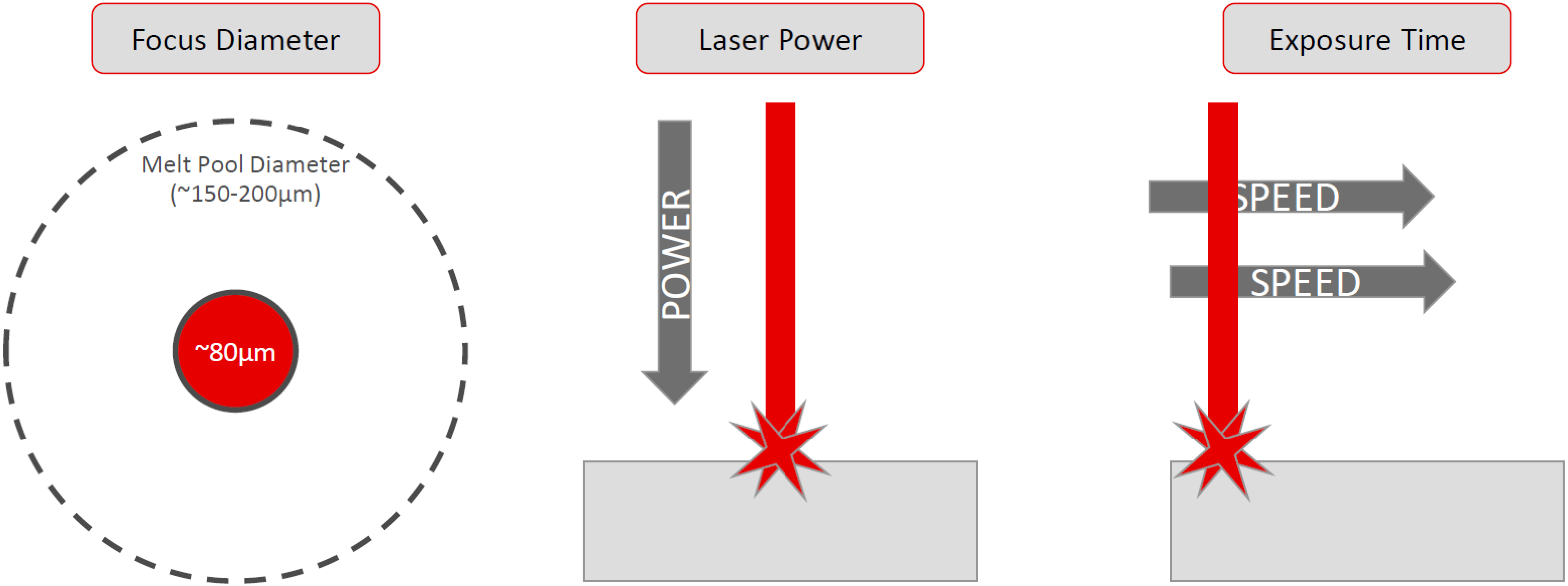


Source: Additive Minds, 2019, Workshop

Shrinkage

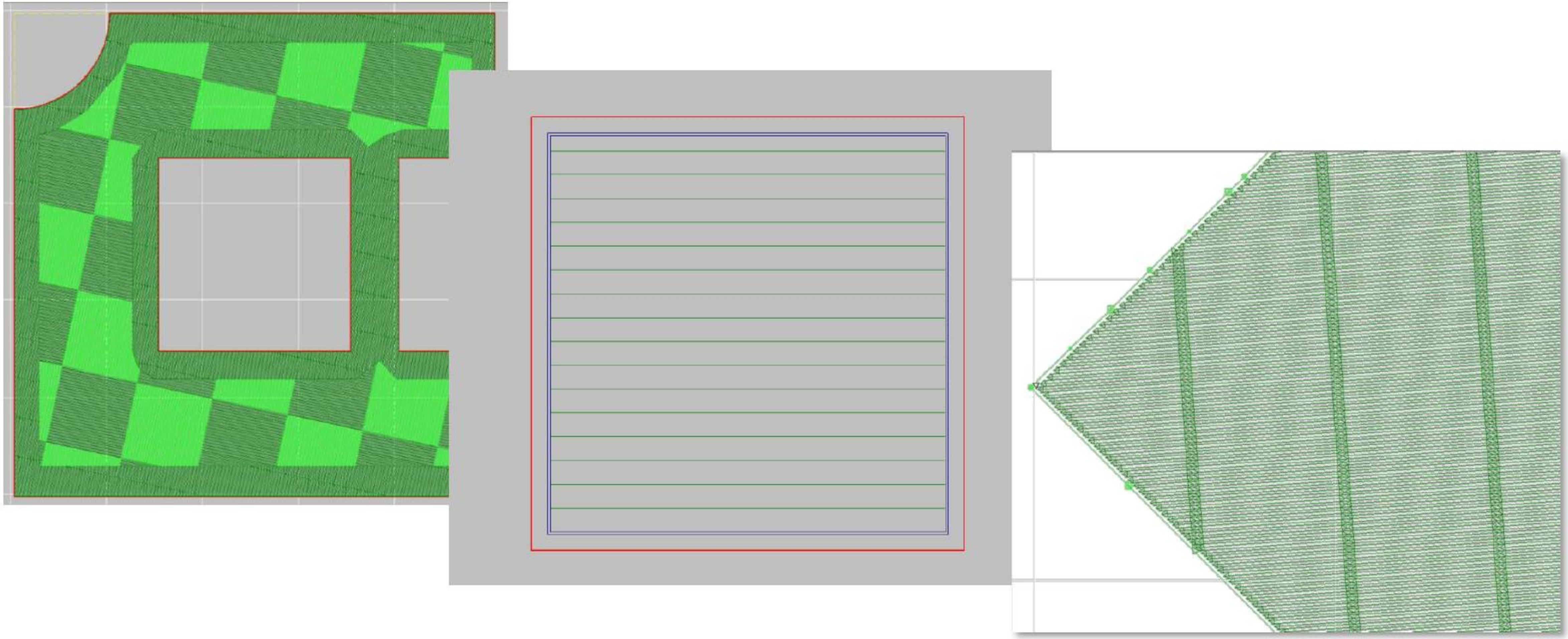


Exposure strategies



Source: Additive Minds, 2019, Workshop

Exposure strategies



Source: Additive Minds, 2019, Workshop

Part Screening & Selection Methodology

Part Screening

→ The process of identifying and evaluating parts with potential for Additive Manufacturing

→ Based on existing part designs that are produced via conventional manufacruting technologies

→ Part Screening Level depends on data quality

Source: zeltwanger.de, 2019

Source: tetrapak.com, 2019

Source: guh-group.com, 2019

Data volume

Part Screening

Preparation	High-Level Suitability		Detailed evaluation		Part production
Know-how	Technical fit	Economic fit	Application	Business case	Prototype

Source: amp-powders.com, 2019

Part Screening

Preparation	High-Level Suitability		Detailed evaluation		Part production
Know-how	Technical fit	Economic fit	Application	Business case	Prototype

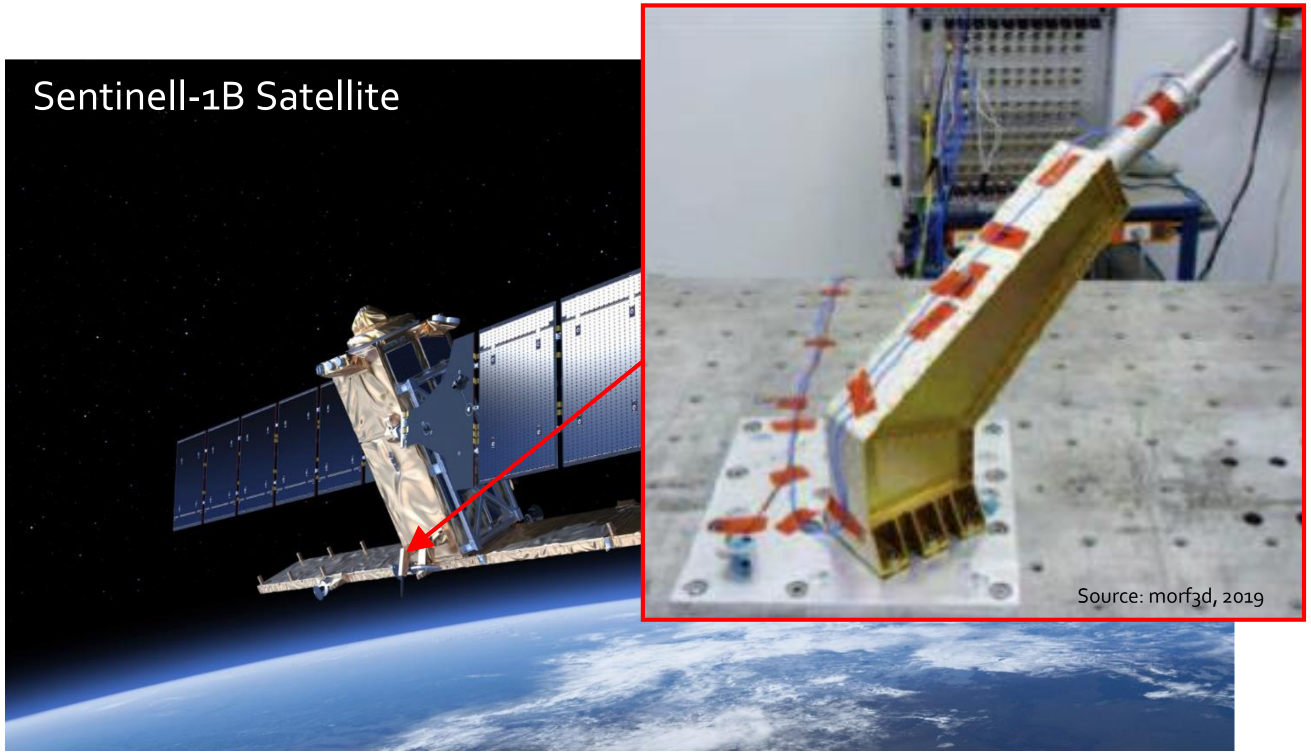
AM know-how

- AM Processes
- Materials
- Design rules

Individual process know-how

- Process parameters
- Quality requirements
- Environmental influences

Brainstorming



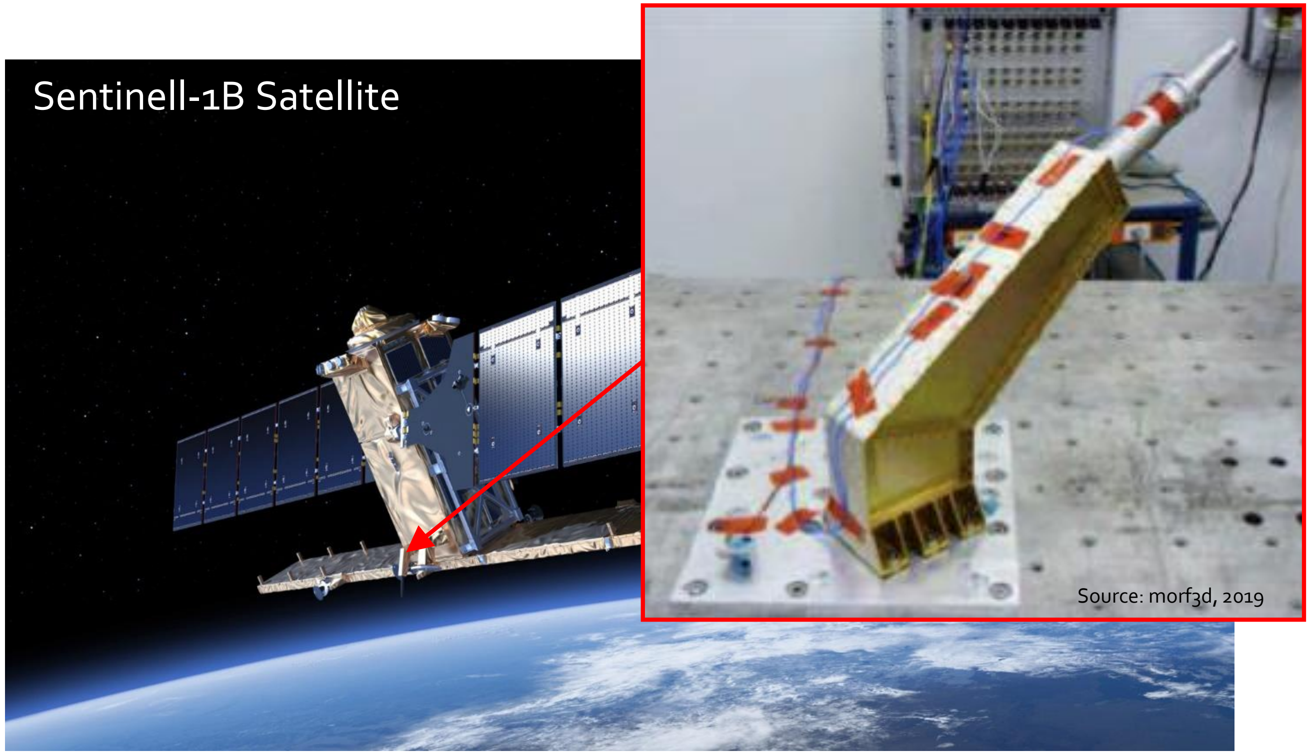
Source: m.esa.int, 2019

Part Screening

Preparation	High-Level Suitability		Detailed evaluation		Part production
Know-how	Technical fit	Economic fit	Application	Business case	Prototype

What are the „Pain Points"?

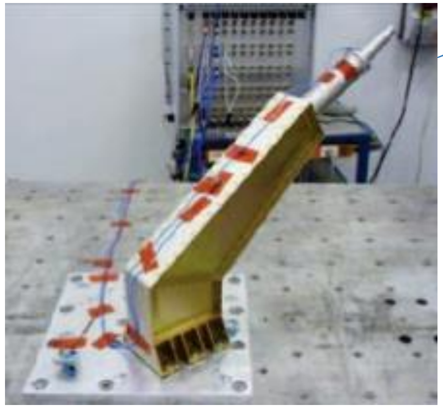
- Development/Production costs
- Lead time / Cycle time
- Long-term costs



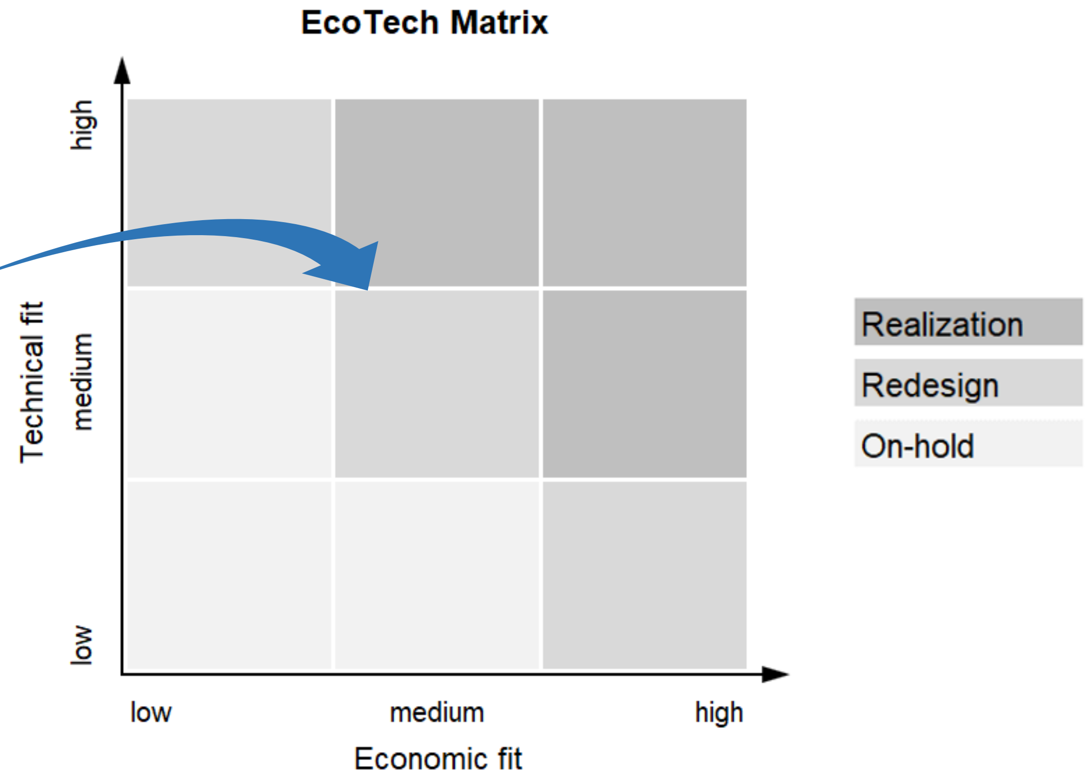
Source: m.esa.int, 2019

Part Screening

Preparation	High-Level Suitability		Detailed evaluation		Part production
Know-how	Technical fit	Economic fit	Application	Business case	Prototype



Source: morf3d, 2019



Source: Additive Minds, 2019, Workshop

Realization

- **< 1%** of stock list
- Direct realization of existing design

Redesign

- **20-30%** of stock list
- Redesign required for economic efficiency

On-hold

- **70-80%** of stock list
- Further evaluation after certain period due to technical progress

Part Screening

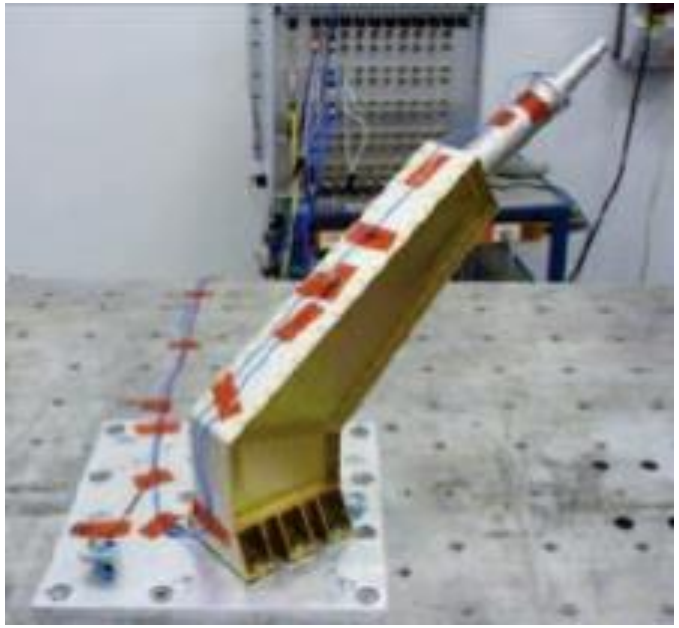
Preparation	High-Level Suitability		Detailed evaluation		Part production
Know-how	Technical fit	Economic fit	Application	Business case	Prototype

- **Size** — 380 x 360 x 180
- **Material** — Aluminium
- **Quality requirements** — Medium

Additional information

- Conventional design hard to manufacture
- Antenna has important function, but redundancy makes it less critical

Technical fit — Medium



Source: morf3d, 2019

Part Screening

Preparation | High-Level Suitability | Detailed evaluation | Part production

Know-how → Technical fit → **Economic fit** → Application → Business case → Prototype

Complexity

- **Geometric complexity:** medium
- **Manufacturing complexity:** high

  - More than 20 single parts
  - Many welding operations
  - High effort for inspection

AM cost per part Estimation

Build time per part	**60 h**
Machine cost per hour	60 €
Machine cost per part	**3,600 €**
Material per job	2.08 kg
Material price per kg	80 €
Material cost per part	**166.40 €**
Total cost per part	**3,766.40 €**

Value add

AM could be used to solve pain points and therefore add value to the application

Pain points satellite:

- High **costs**
- Long **lead time**
- Heavy **weight**

Part Screening

Preparation	High-Level Suitability		Detailed evaluation		Part production
Know-how	Technical fit	Economic fit	Application	Business case	Prototype

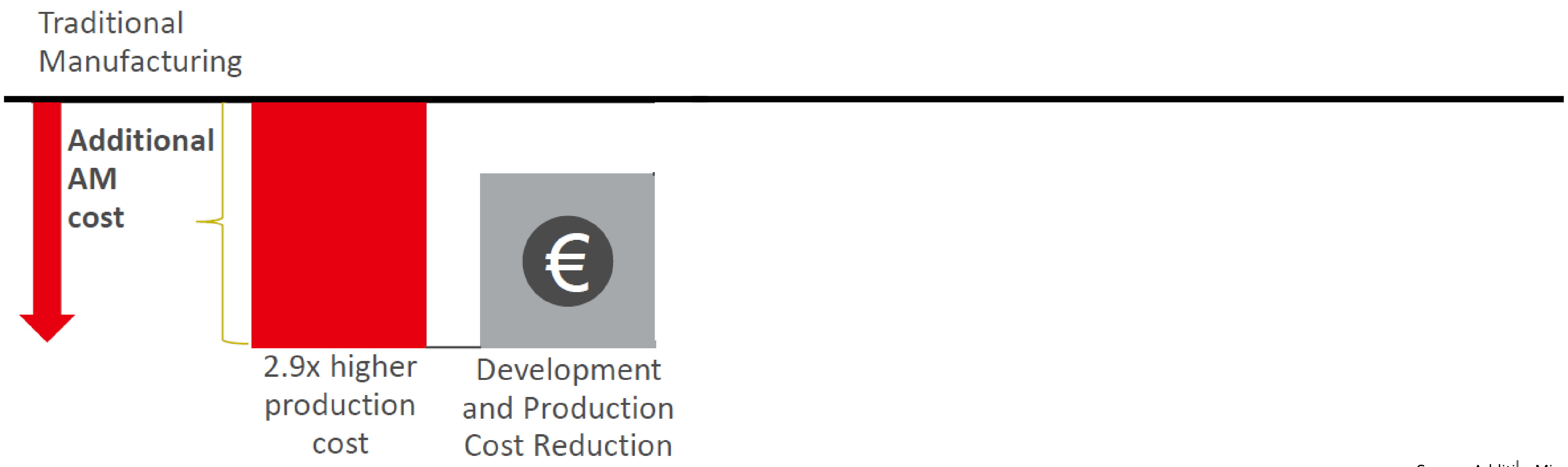
Conventional costs: 1,300€
AM cost estimation: 3,766€

Source: Additive Minds, 2019, Workshop

Part Screening

Preparation	High-Level Suitability		Detailed evaluation		Part production
Know-how	Technical fit	**Economic fit**	Application	Business case	Prototype

Conventional costs: 1,300€
AM cost estimation: 3,766€



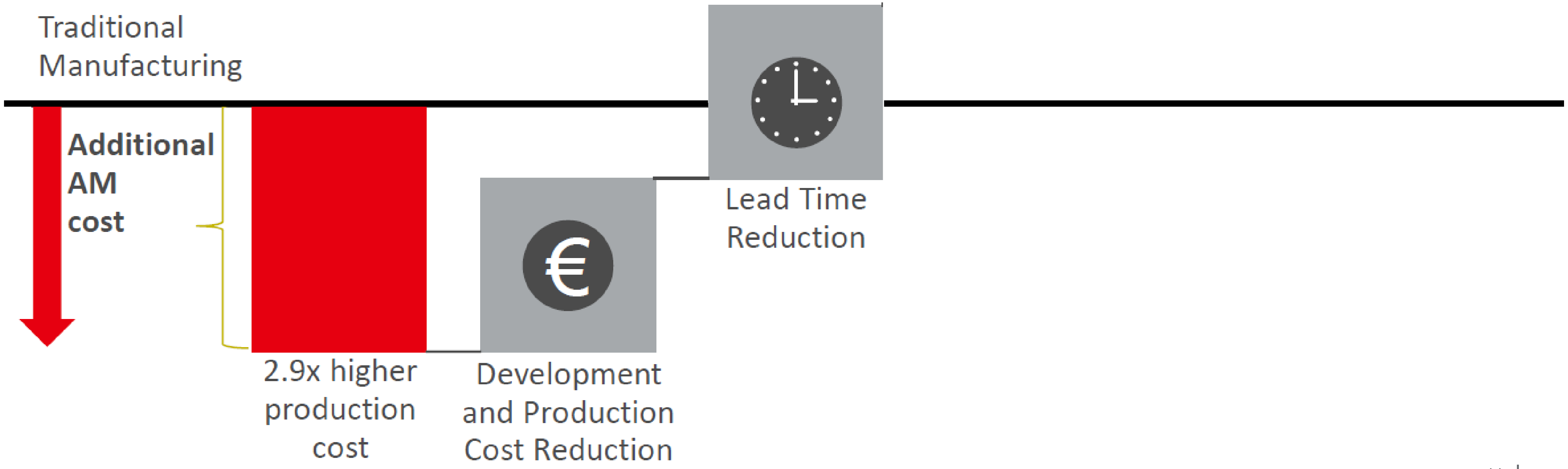
Source: Additive Minds, 2019, Workshop

Part Screening

Preparation | High-Level Suitability | Detailed evaluation | Part production

Know-how → Technical fit → **Economic fit** → Application → Business case → Prototype

Conventional costs: 1,300€
AM cost estimation: 3,766€

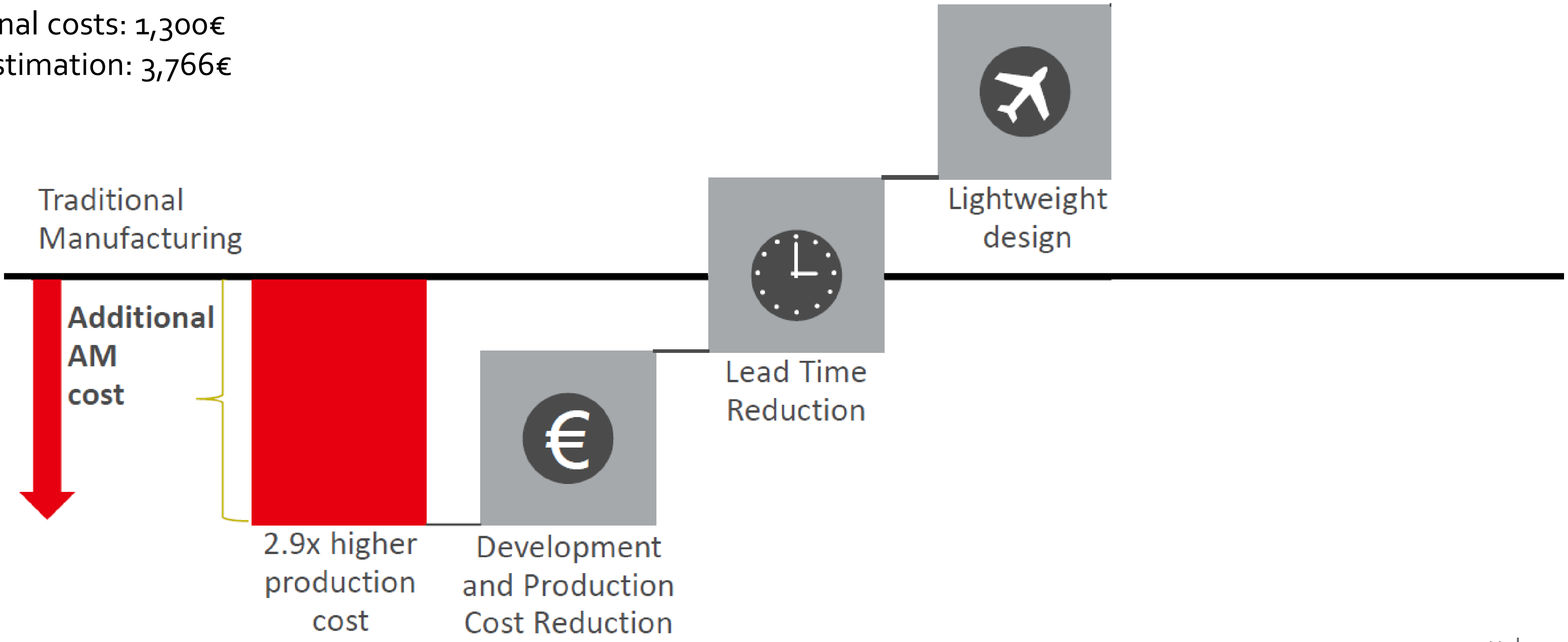


Source: Additive Minds, 2019, Workshop

Part Screening

Preparation	High-Level Suitability		Detailed evaluation		Part production
Know-how	Technical fit	**Economic fit**	Application	Business case	Prototype

Conventional costs: 1,300€
AM cost estimation: 3,766€



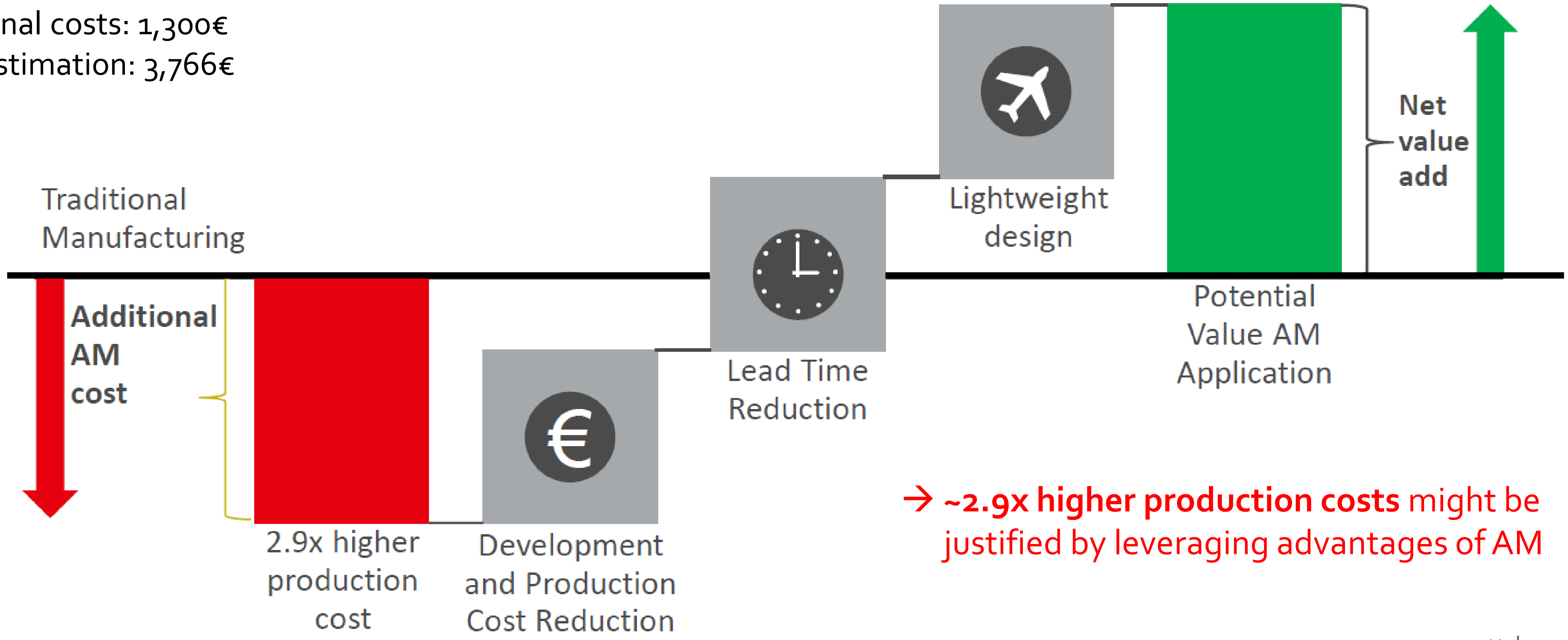
Source: Additive Minds, 2019, Workshop

Part Screening

Preparation | High-Level Suitability | Detailed evaluation | Part production

Know-how → Technical fit → **Economic fit** → Application → Business case → Prototype

Conventional costs: 1,300€
AM cost estimation: 3,766€



→ **~2.9x higher production costs** might be justified by leveraging advantages of AM

Source: Additive Minds, 2019, Workshop

Part Screening

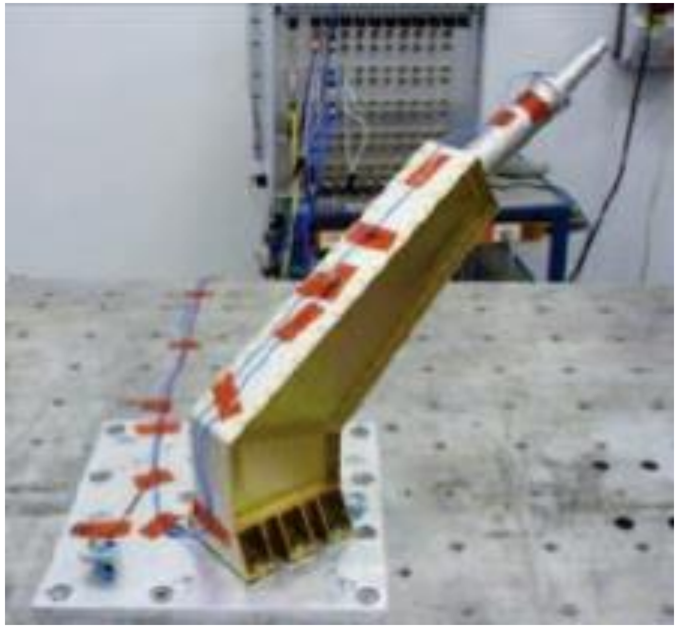
Preparation	High-Level Suitability		Detailed evaluation		Part production
Know-how	Technical fit	Economic fit	Application	Business case	Prototype

- **Complexity** — Medium
- **Costs per part** — ~ 2x conventional
- **Pain points** — High

Pain points customer

- More than 20 single components
- Quality issues
- Time to market

Economic fit — Medium

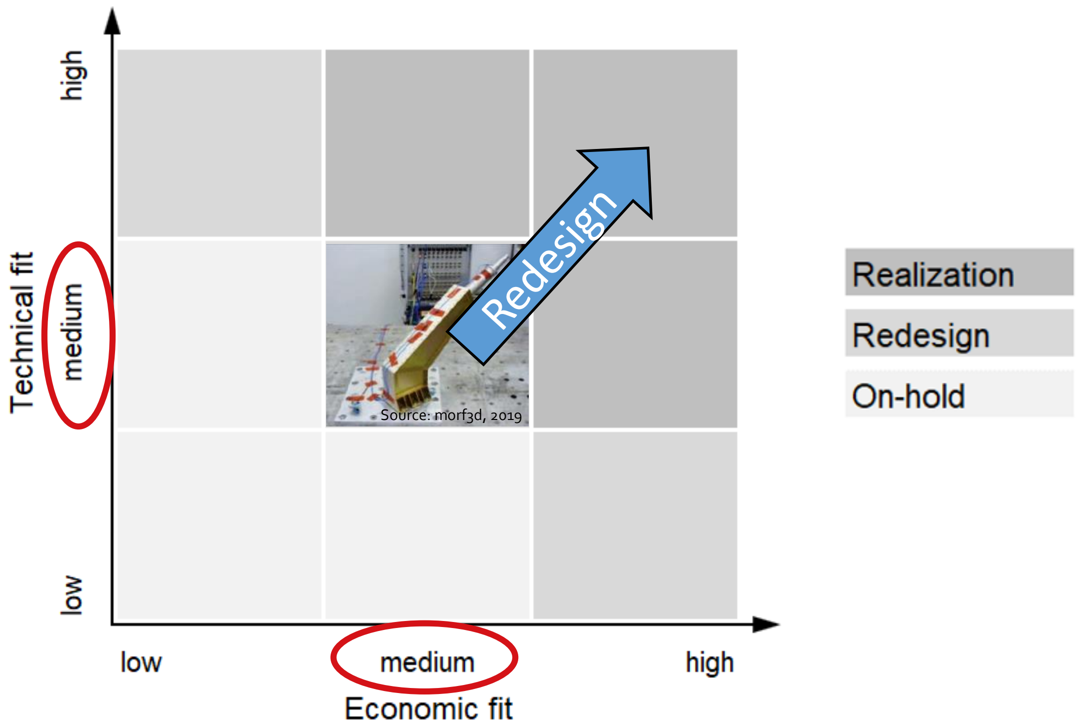


Source: morf3d, 2019

Part Screening

Preparation	High-Level Suitability		Detailed evaluation		Part production
Know-how	Technical fit	Economic fit	Application	Business case	Prototype

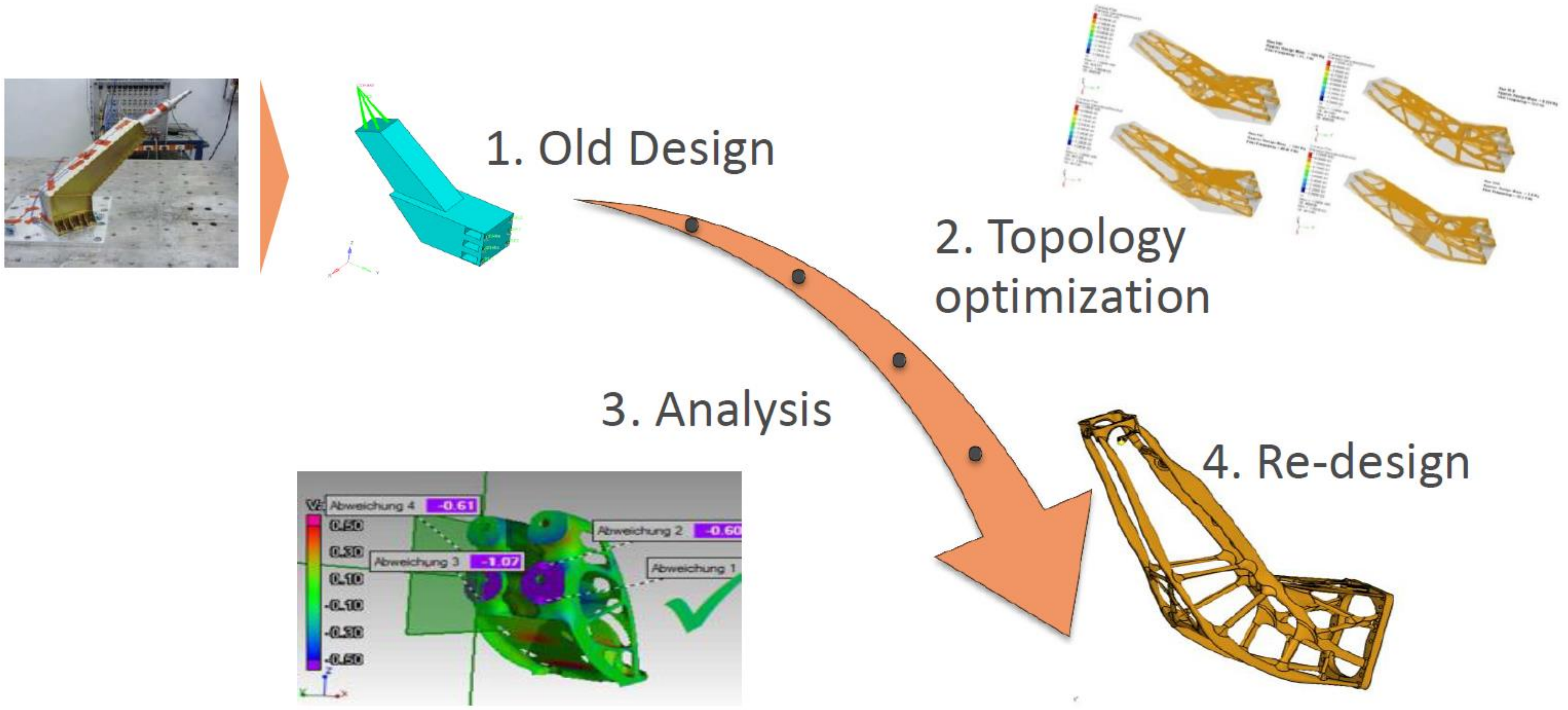
EcoTech Matrix



Source: Additive Minds, 2019, Workshop

Part Screening

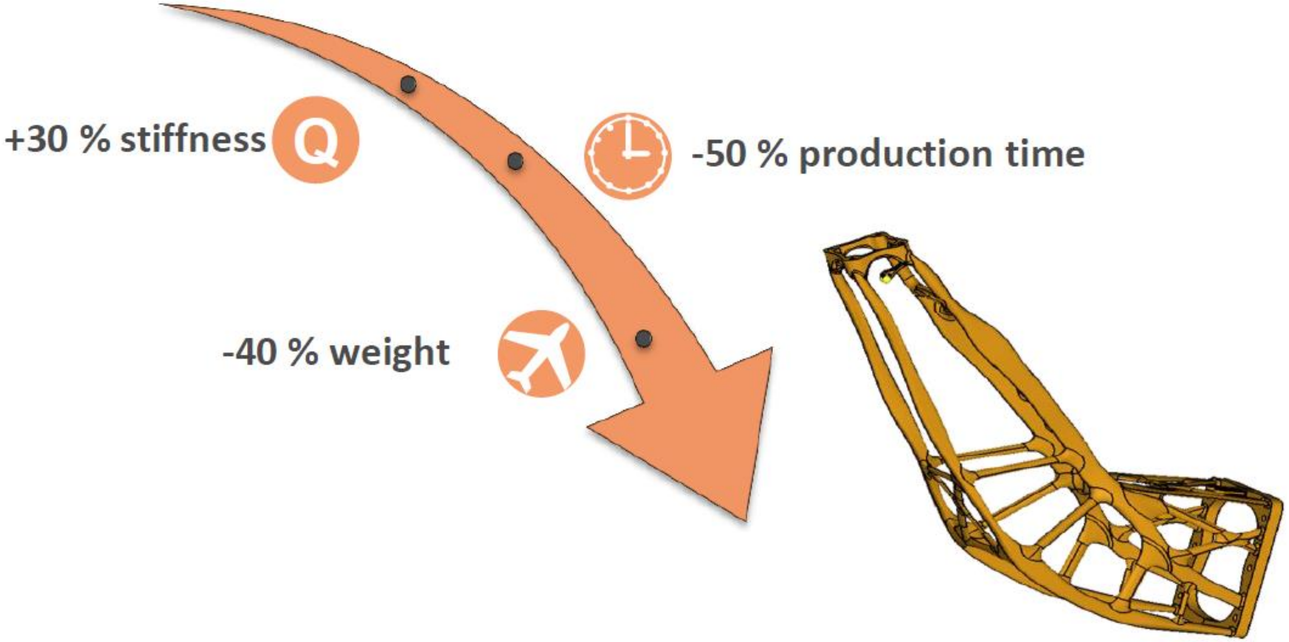
Preparation	High-Level Suitability		Detailed evaluation		Part production
Know-how	Technical fit	Economic fit	Application	Business case	Prototype



Source: Additive Minds, 2019, Workshop

Part Screening

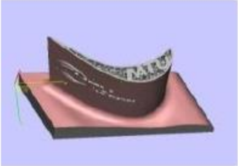
Preparation	High-Level Suitability		Detailed evaluation		Part production
Know-how	Technical fit	Economic fit	Application	**Business case**	Prototype



Source: Additive Minds, 2019, Workshop

Part Screening

Preparation	High-Level Suitability		Detailed evaluation		Part production
Know-how	Technical fit	Economic fit	Application	Business case	Prototype



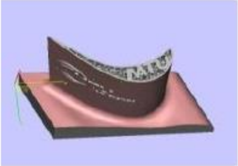
1. Data Preparation

	1. Manual Labor
Time / Material	1h
Cost	50€/h
Total Cost	50€

Source: Additive Minds, 2019, Workshop

Part Screening

Preparation	High-Level Suitability		Detailed evaluation		Part production
Know-how	Technical fit	Economic fit	Application	Business case	Prototype



1. Data Preparation → **2. Additive Manufacturing**

	1. Manual Labor	2. System	2. Material
Time / Material	1h	40h	1.2kg
Cost	50€/h	60€/h	80 €/kg
Total Cost	50€	2,400€	96€

Source: Additive Minds, 2019, Workshop

Part Screening

Preparation | High-Level Suitability | Detailed evaluation | Part production

Know-how → Technical fit → Economic fit → Application → **Business case** → Prototype

1. Data Preparation → 2. Additive Manufacturing → 3. Remove Parts

	1. Manual Labor	2. System	2. Material	3.Manual Labor	3. Band saw
Time / Material	1h	40h	1.2kg	0.5h	0.2h
Cost	50€/h	60€/h	80 €/kg	50€/h	10€/h
Total Cost	50€	2,400€	96€	25€	2€

Source: Additive Minds, 2019, Workshop

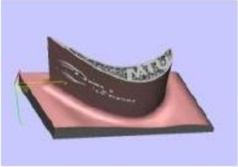
Part Screening

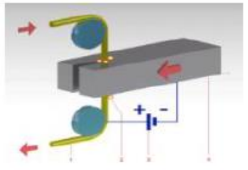
Preparation: Know-how

High-Level Suitability: Technical fit → Economic fit

Detailed evaluation: Application → **Business case**

Part production: Prototype






1. Data Preparation → **2. Additive Manufacturing** → **3. Remove Parts** → **4. Remove Supports**

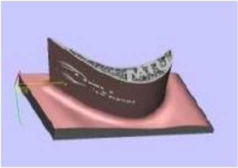
	1. Manual Labor	2. System	2. Material	3.Manual Labor	3. Band saw	4.Manual Labor
Time / Material	1h	40h	1.2kg	0.5h	0.2h	2h
Cost	50€/h	60€/h	80 €/kg	50€/h	10€/h	50€
Total Cost	50€	2,400€	96€	25€	2€	100€

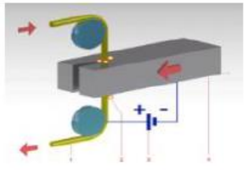
Source: Additive Minds, 2019, Workshop

Part Screening

Preparation | High-Level Suitability | Detailed evaluation | Part production

Know-how → Technical fit → Economic fit → Application → **Business case** → Prototype





1. Data Preparation → **2. Additive Manufacturing** → **3. Remove Parts** → **4. Remove Supports** → **5. Heat Treatment**

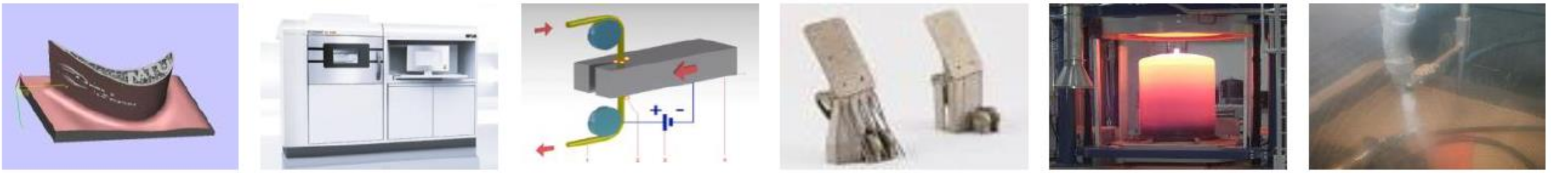
	1. Manual Labor	2. System	2. Material	3.Manual Labor	3. Band saw	4.Manual Labor	5. System
Time / Material	1h	40h	1.2kg	0.5h	0.2h	2h	4h
Cost	50€/h	60€/h	80 €/kg	50€/h	10€/h	50€	20€
Total Cost	50€	2,400€	96€	25€	2€	100€	80€

Source: Additive Minds, 2019, Workshop

Part Screening

Preparation | High-Level Suitability | Detailed evaluation | Part production

Know-how → Technical fit → Economic fit → Application → **Business case** → Prototype



1. Data Preparation → 2. Additive Manufacturing → 3. Remove Parts → 4. Remove Supports → 5. Heat Treatment → 6. Blasting

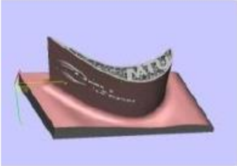
	1. Manual Labor	2. System	2. Material	3.Manual Labor	3. Band saw	4.Manual Labor	5. System	6.Manual Labor
Time / Material	1h	40h	1.2kg	0.5h	0.2h	2h	4h	0.5h
Cost	50€/h	60€/h	80 €/kg	50€/h	10€/h	50€	20€	50€
Total Cost	50€	2,400€	96€	25€	2€	100€	80€	25€

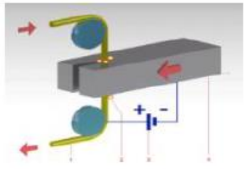
Source: Additive Minds, 2019, Workshop

Part Screening

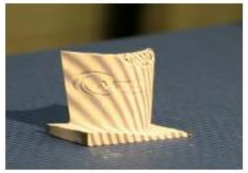
Preparation | High-Level Suitability | Detailed evaluation | Part production

Know-how → Technical fit → Economic fit → Application → **Business case** → Prototype









1. Data Preparation → **2. Additive Manufacturing** → **3. Remove Parts** → **4. Remove Supports** → **5. Heat Treatment** → **6. Blasting** → **7. Inspection**

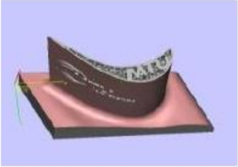
	1. Manual Labor	2. System	2. Material	3.Manual Labor	3. Band saw	4.Manual Labor	5. System	6.Manual Labor	7. System	7.Manual Labor
Time / Material	1h	40h	1.2kg	0.5h	0.2h	2h	4h	0.5h	3 h	3h
Cost	50€/h	60€/h	80 €/kg	50€/h	10€/h	50€	20€	50€	60€	50€
Total Cost	50€	2,400€	96€	25€	2€	100€	80€	25€	180€	150€

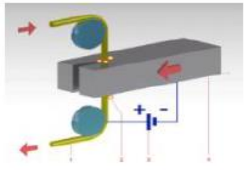
Source: Additive Minds, 2019, Workshop

Part Screening

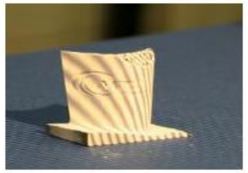
Preparation | High-Level Suitability | Detailed evaluation | Part production

Know-how → Technical fit → Economic fit → Application → **Business case** → Prototype







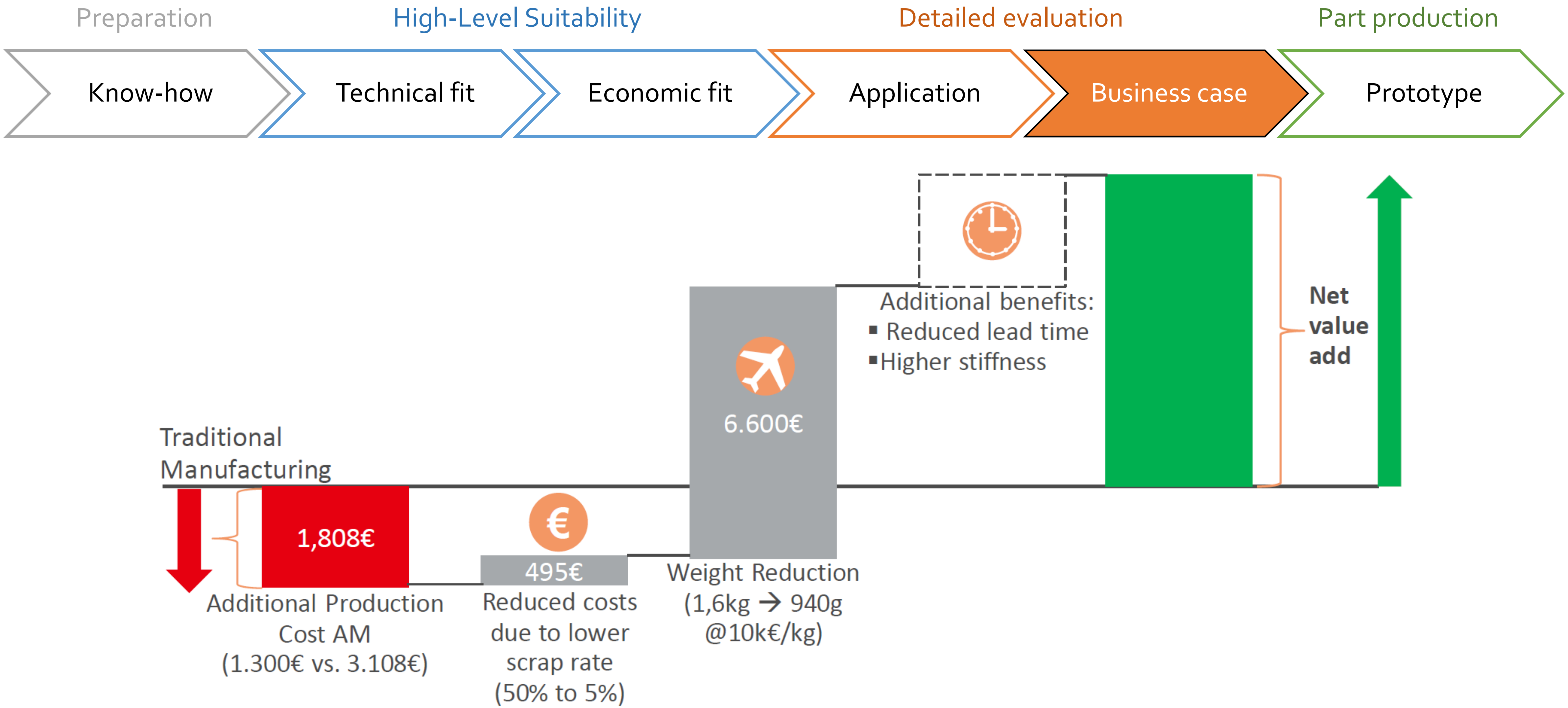


1. Data Preparation → **2. Additive Manufacturing** → **3. Remove Parts** → **4. Remove Supports** → **5. Heat Treatment** → **6. Blasting** → **7. Inspection**

	1. Manual Labor	2. System	2. Material	3.Manual Labor	3. Band saw	4.Manual Labor	5. System	6.Manual Labor	7. System	7.Manual Labor	Total
Time / Material	1h	40h	1.2kg	0.5h	0.2h	2h	4h	0.5h	3 h	3h	55,4h
Cost	50€/h	60€/h	80 €/kg	50€/h	10€/h	50€	20€	50€	60€	50€	
Total Cost	50€	2,400€	96€	25€	2€	100€	80€	25€	180€	150€	3.108€

Source: Additive Minds, 2019, Workshop

Part Screening



Source: Additive Minds, 2019, Workshop

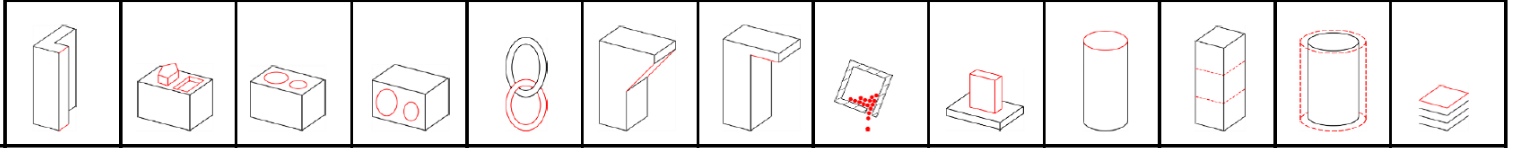
Part Screening

Preparation | High-Level Suitability | Detailed evaluation | Part production

Know-how → Technical fit → Economic fit → Application → Business case → Prototype

Part design

- CAD Model
- **Design rules**

	Wall Thickness	Embossed and engraved details	Vertical Holes	Horizontal Holes	Interlocking parts clearance	Overhangs	Un-supported edges	Powder removal holes	Min. feature size	Min. Pin diameter	Aspect Ratio	Machining offset	Layer Thickness
													
Polymer (PA2200)	~0,5	+/- 1 mm	1,5 mm	1,5 mm	~0,5 mm			~10 mm	~0,5 mm	>0,8			60 – 180 µm
Metal (Ti64)	> 0,4 mm	+/- 0,5 mm	> 2 mm	< 8 mm		45°	~ 1mm	~2mm	120 µm	> 1mm	8:1	~0,5 mm	20 – 90 µm

Source: Additive Minds, 2019, Workshop

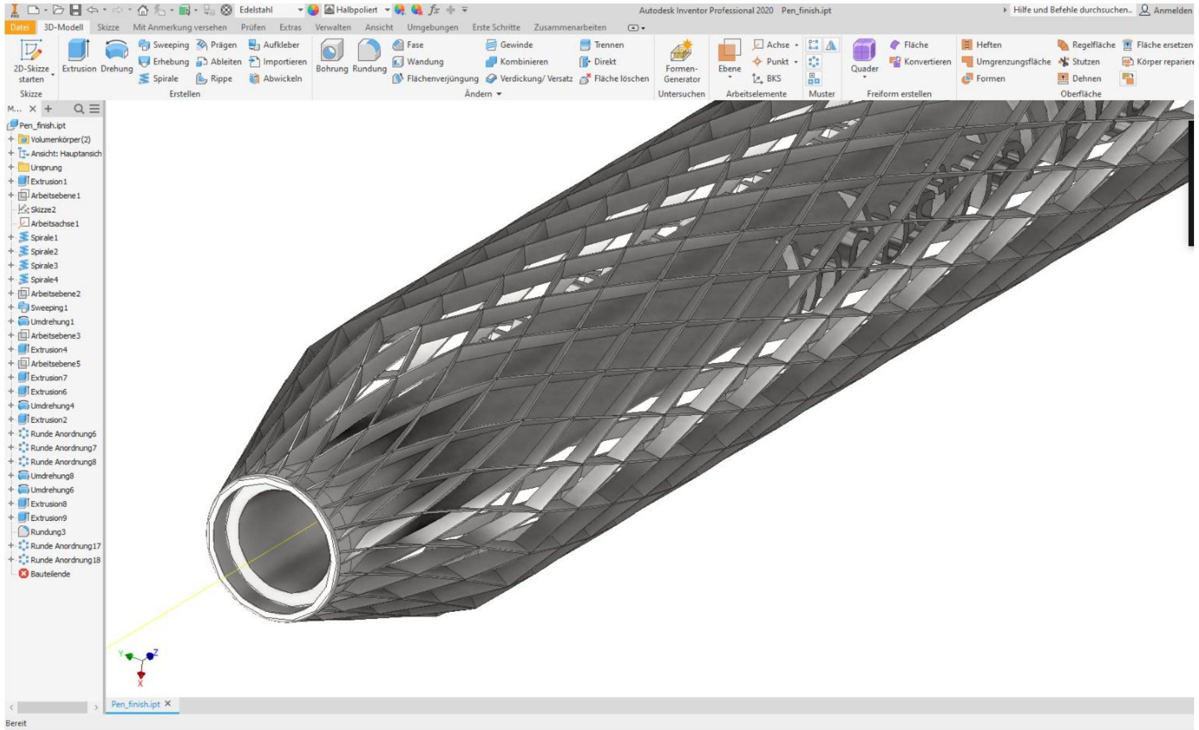
Part Screening

Preparation | High-Level Suitability | Detailed evaluation | Part production

Know-how → Technical fit → Economic fit → Application → Business case → Prototype

Part design

- **CAD Model**
- Design rules

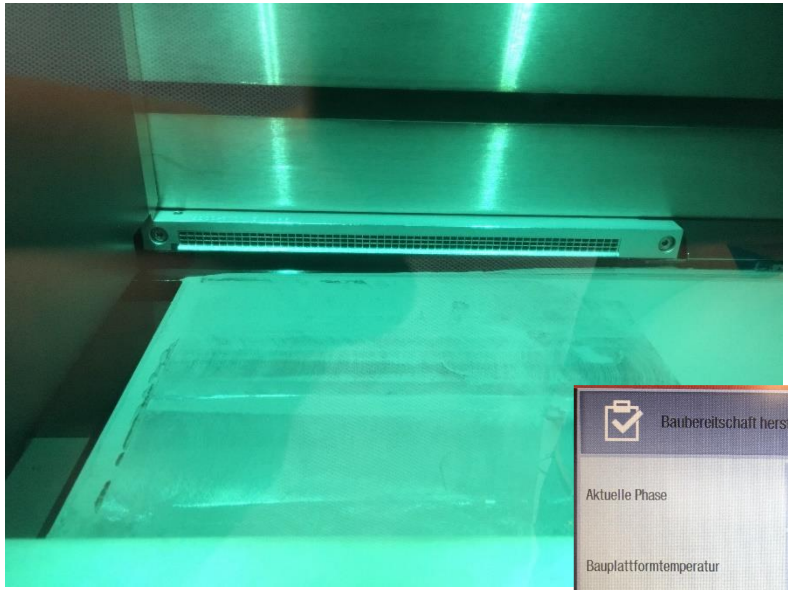


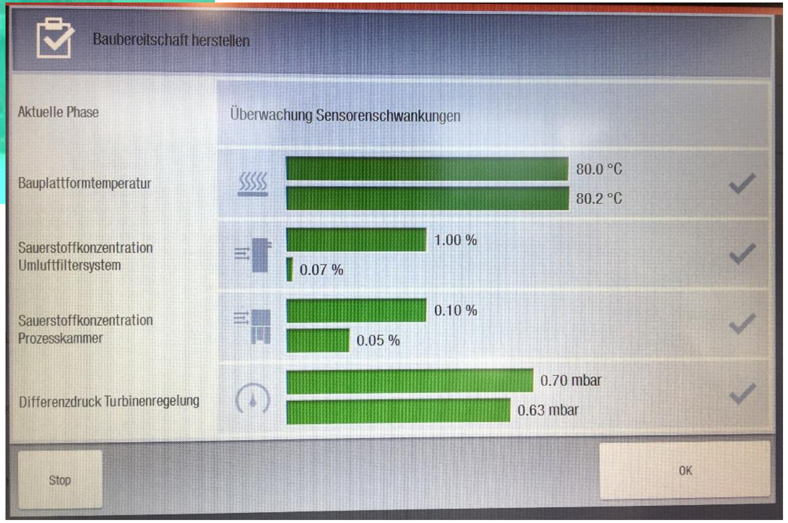
Part Screening

Preparation	High-Level Suitability		Detailed evaluation		Part production
Know-how	Technical fit	Economic fit	Application	Business case	Prototype

Part design
- CAD Model
- Design rules

Preprocessing
- **Setup of printing system**
- Part orientation
- Support structures





Part Screening

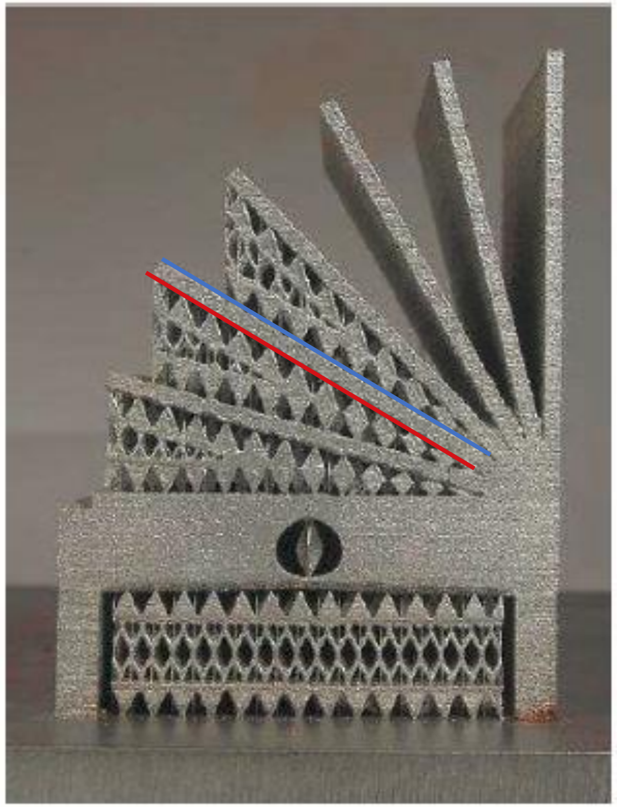
Preparation	High-Level Suitability		Detailed evaluation		Part production
Know-how	Technical fit	Economic fit	Application	Business case	Prototype

Part design
- CAD Model
- Design rules

Preprocessing
- Setup of printing system
- **Part orientation**
- Support structures

Upskin

Downskin



Source: Additive Minds, 2019, Workshop

Part Screening

Preparation | High-Level Suitability | Detailed evaluation | Part production

Know-how → Technical fit → Economic fit → Application → Business case → Prototype

Part design
- CAD Model
- Design rules

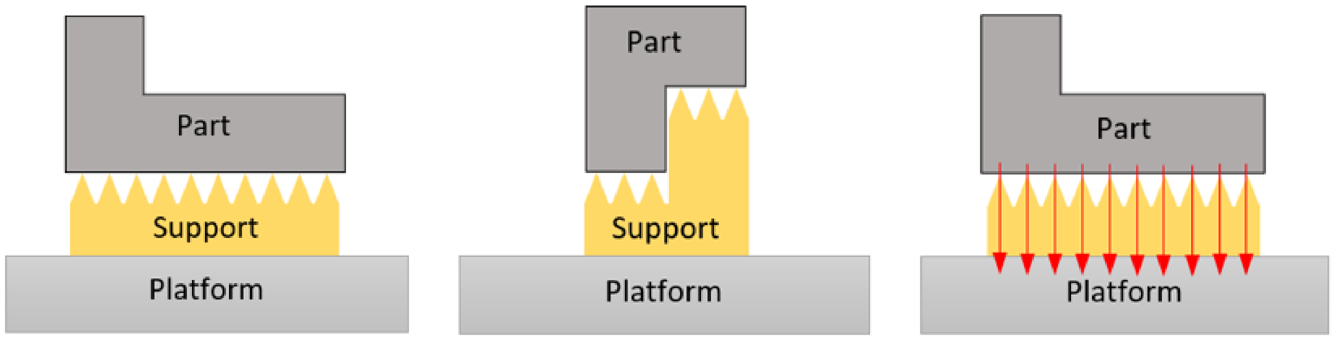
Preprocessing
- Setup of printing system
- Part orientation
- **Support structures**

→ The purpose of support structure is to…

... attach part to platform

... support steep angles/overhangs

... conduct heat away

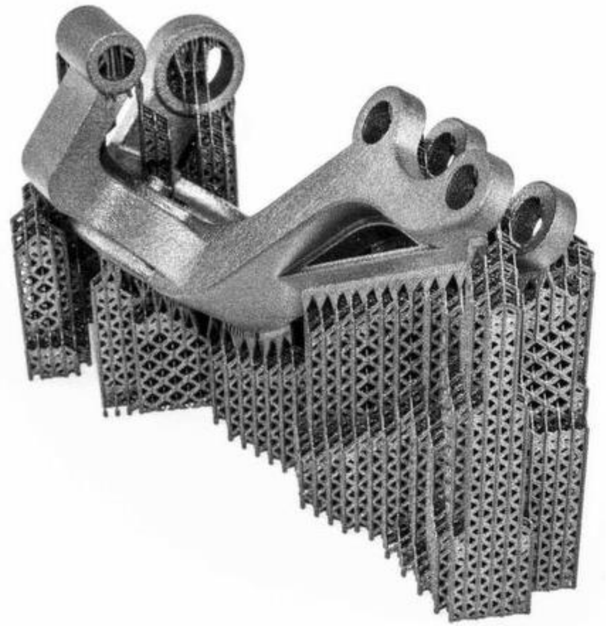


Part Screening

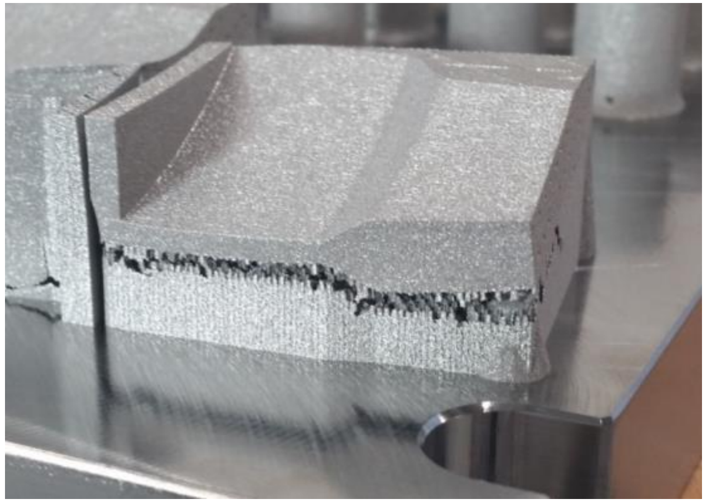
Preparation	High-Level Suitability		Detailed evaluation		Part production
Know-how	Technical fit	Economic fit	Application	Business case	Prototype

Part design
- CAD Model
- Design rules

Preprocessing
- Setup of printing system
- Part orientation
- **Support structures**



Source: konstruktionspraxis.vogel.de, 2019



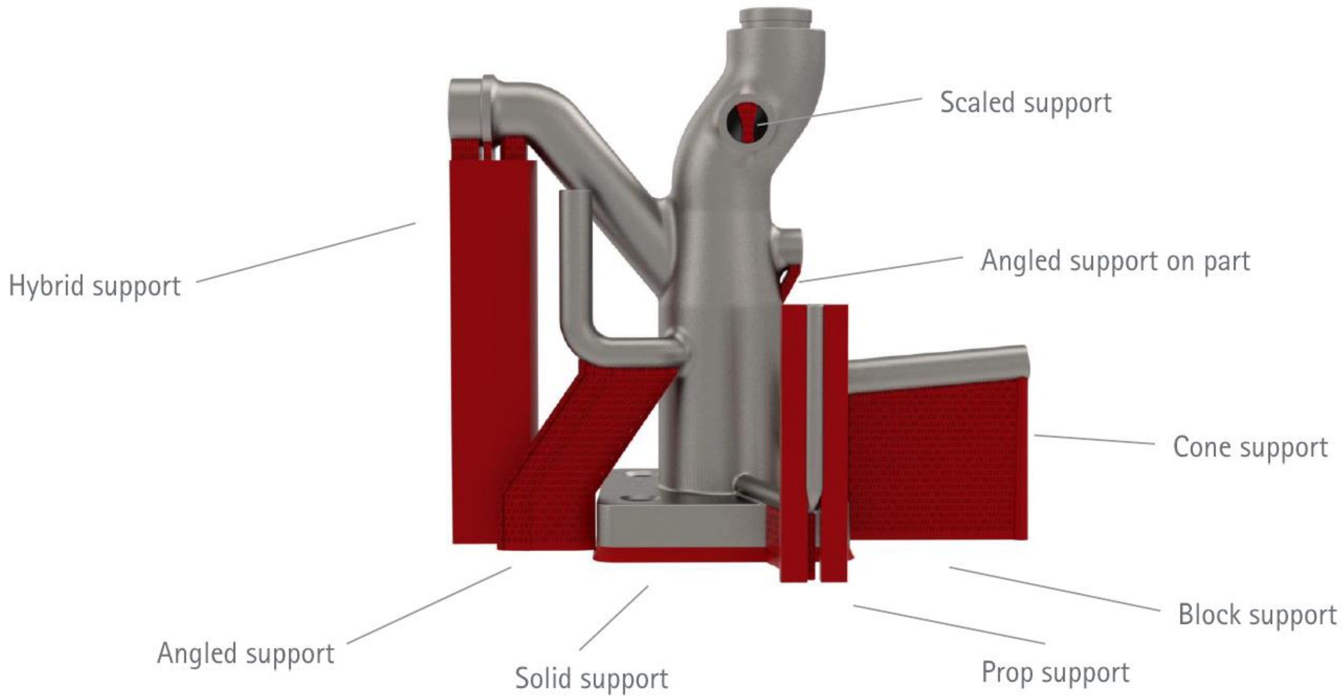
Source: Additive Minds, 2019, Workshop

Part Screening

Preparation	High-Level Suitability		Detailed evaluation		Part production
Know-how	Technical fit	Economic fit	Application	Business case	Prototype

Part design
- CAD Model
- Design rules

Preprocessing
- Setup of printing system
- Part orientation
- **Support structures**



Source: Additive Minds, 2019, Workshop

Part Screening

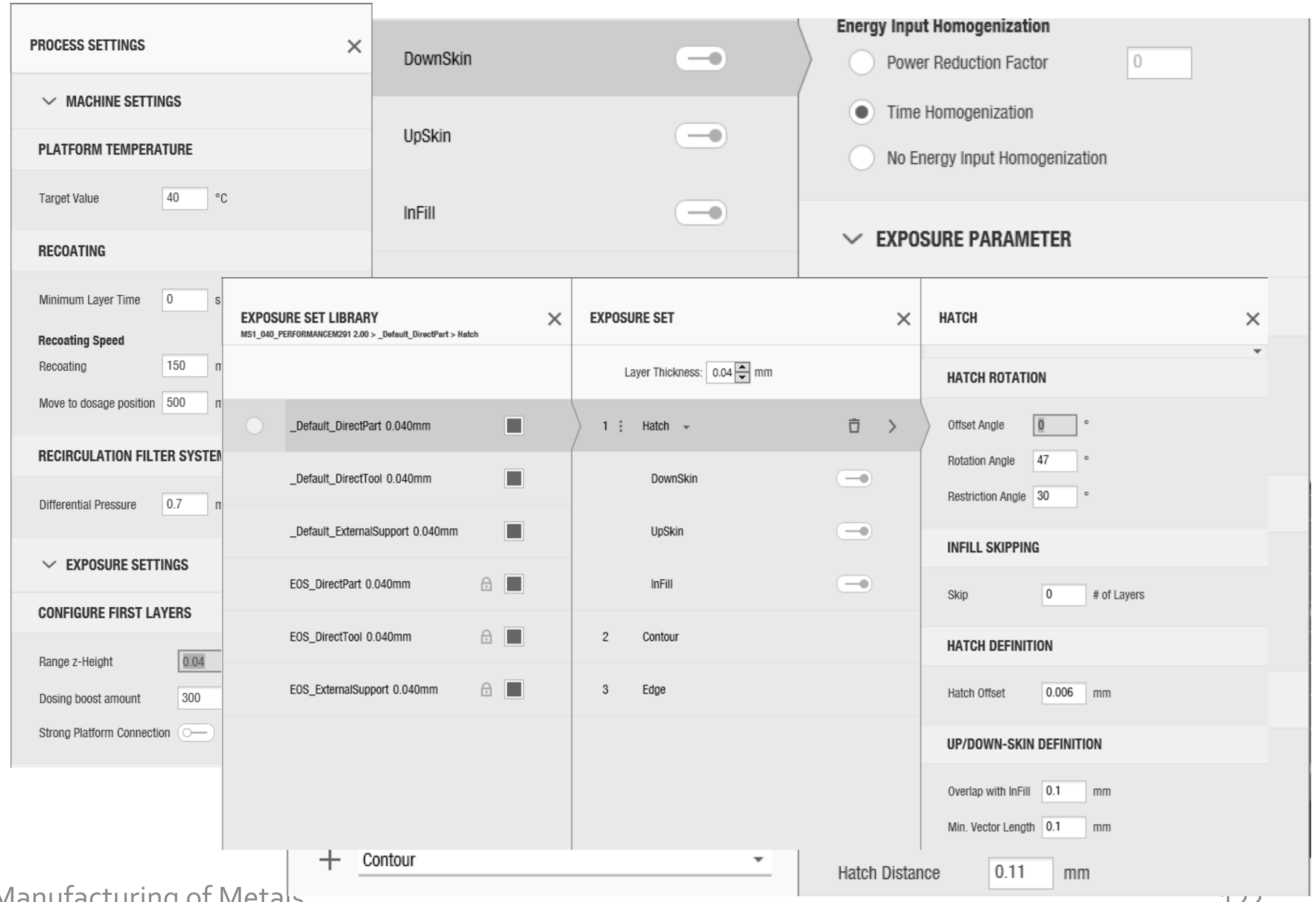
Preparation | High-Level Suitability | Detailed evaluation | Part production

Know-how → Technical fit → Economic fit → Application → Business case → Prototype

Part design
- CAD Model
- Design rules

Preprocessing
- Setup of printing system
- Part orientation
- Support structures

Printjob
- **Process parameters**
- Load file – start job



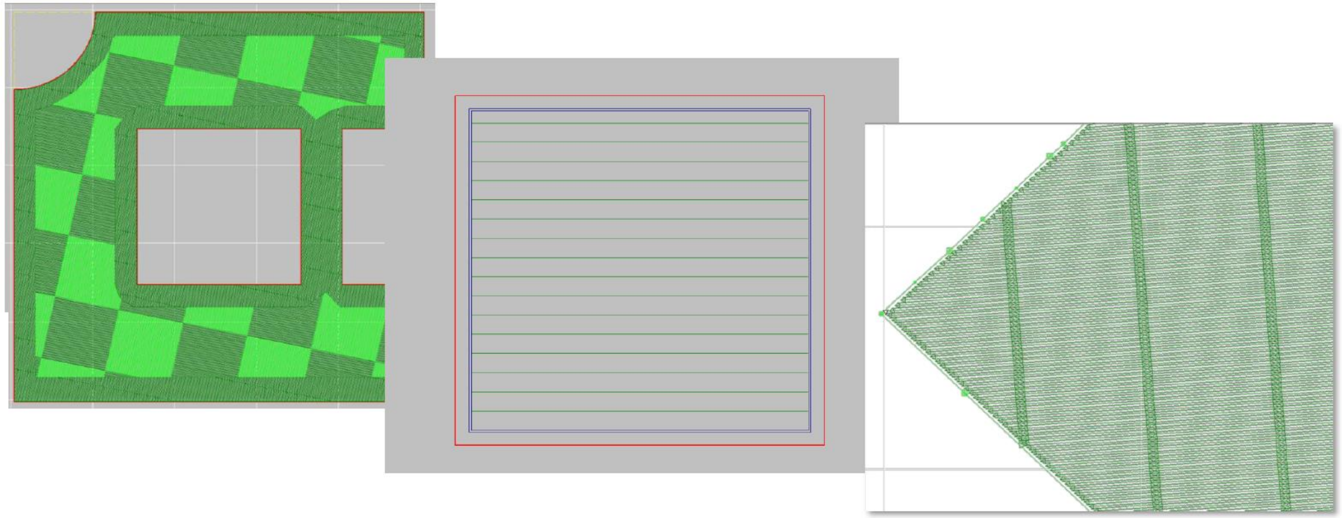
Part Screening

Part design
- CAD Model
- Design rules

Preprocessing
- Setup of printing system
- Part orientation
- Support structures

Printjob
- **Process parameters**
- Load file – start job

Laser strategies:



Source: Additive Minds, 2019, Workshop

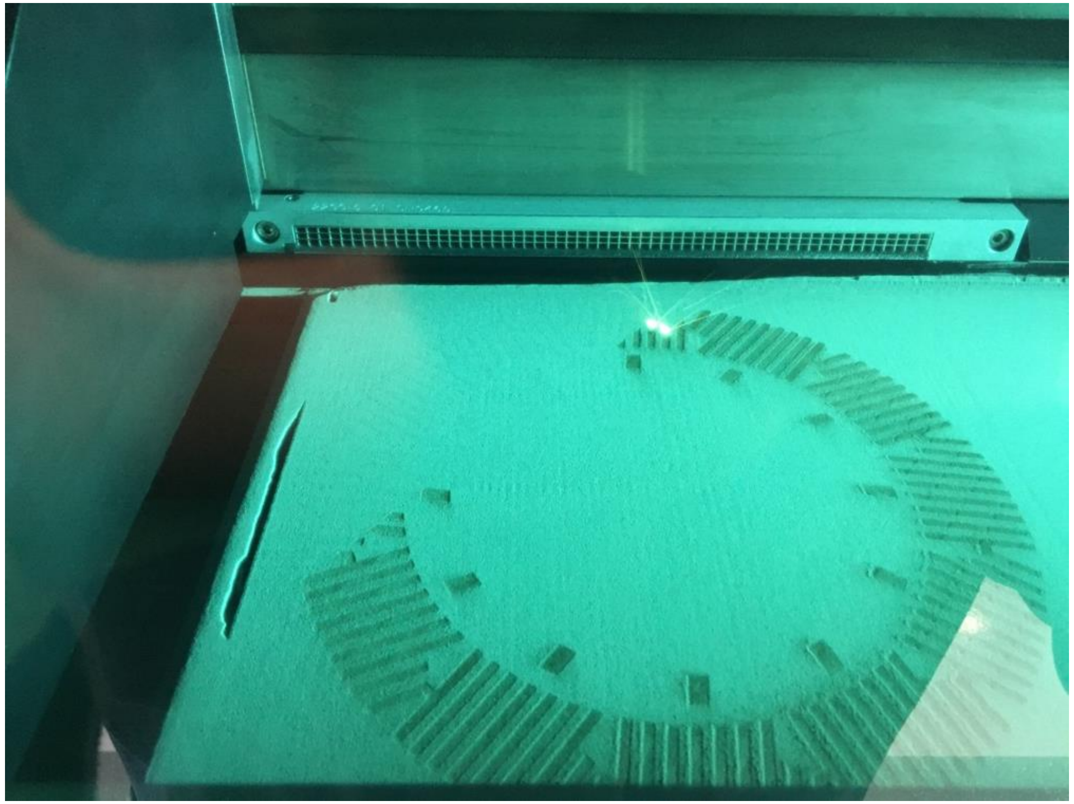
Part Screening

Preparation	High-Level Suitability		Detailed evaluation		Part production
Know-how	Technical fit	Economic fit	Application	Business case	Prototype

Part design
- CAD Model
- Design rules

Preprocessing
- Setup of printing system
- Part orientation
- Support structures

Printjob
- Process parameters
- **Load file – start job**



Part Screening

Preparation	High-Level Suitability		Detailed evaluation		Part production
Know-how	Technical fit	Economic fit	Application	Business case	Prototype

Part design
- CAD Model
- Design rules

Preprocessing
- Setup of printing system
- Part orientation
- Support structures

Printjob
- Process parameters
- Load file – start job

Postprocessing
- **Thermal treatment**
- Mechanical treatment

Source: rohde-online.net, 2019

Part Screening

Preparation | High-Level Suitability | Detailed evaluation | Part production

Know-how → Technical fit → Economic fit → Application → Business case → Prototype

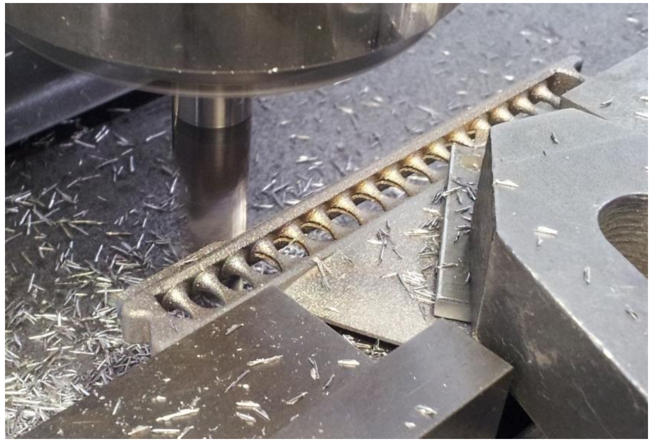
Part design
- CAD Model
- Design rules

Preprocessing
- Setup of printing system
- Part orientation
- Support structures

Printjob
- Process parameters
- Load file – start job

Postprocessing
- Thermal treatment
- **Mechanical treatment**

Source: Additive Minds, 2019, Workshop



Source: Additive Minds, 2019, Workshop

Part Screening

Preparation	High-Level Suitability		Detailed evaluation		Part production
Know-how	Technical fit	Economic fit	Application	Business case	Prototype

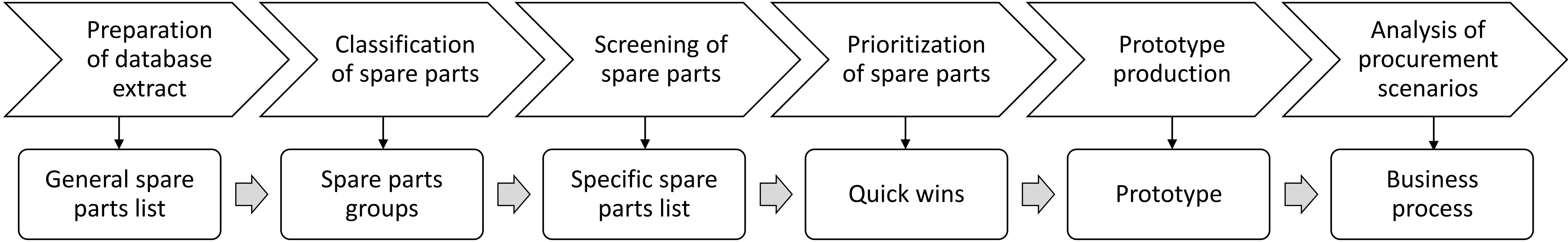
Iterative process!

Part design	• CAD Model • Design rules
Preprocessing	• Setup of printing system • Part orientation • Support structures
Printjob	• Process parameters • Load file – start job
Postprocessing	• Thermal treatment • Mechanical treatment
Analysis	• **Dimensional inspection** • **Functional test**

Case study

ECONOMIC FEASIBILITY STUDY OF THREE-DIMENSIONAL PRINTING PROCESSES WITHIN THE FIELD OF SPARE PARTS PROCUREMENT

Case study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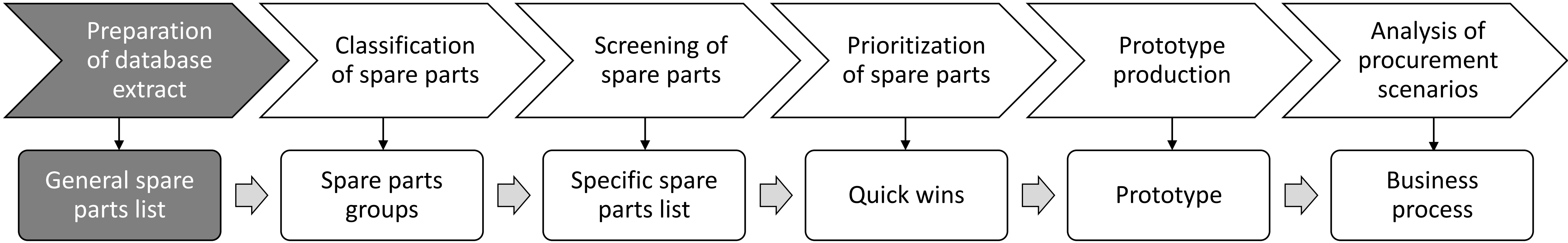
Prioritization of spare parts
Prototype production
Analysis of procurement scenarios
General spare parts list
Spare parts groups
Specific spare parts list
Quick wins
Prototype
Business process

Case study



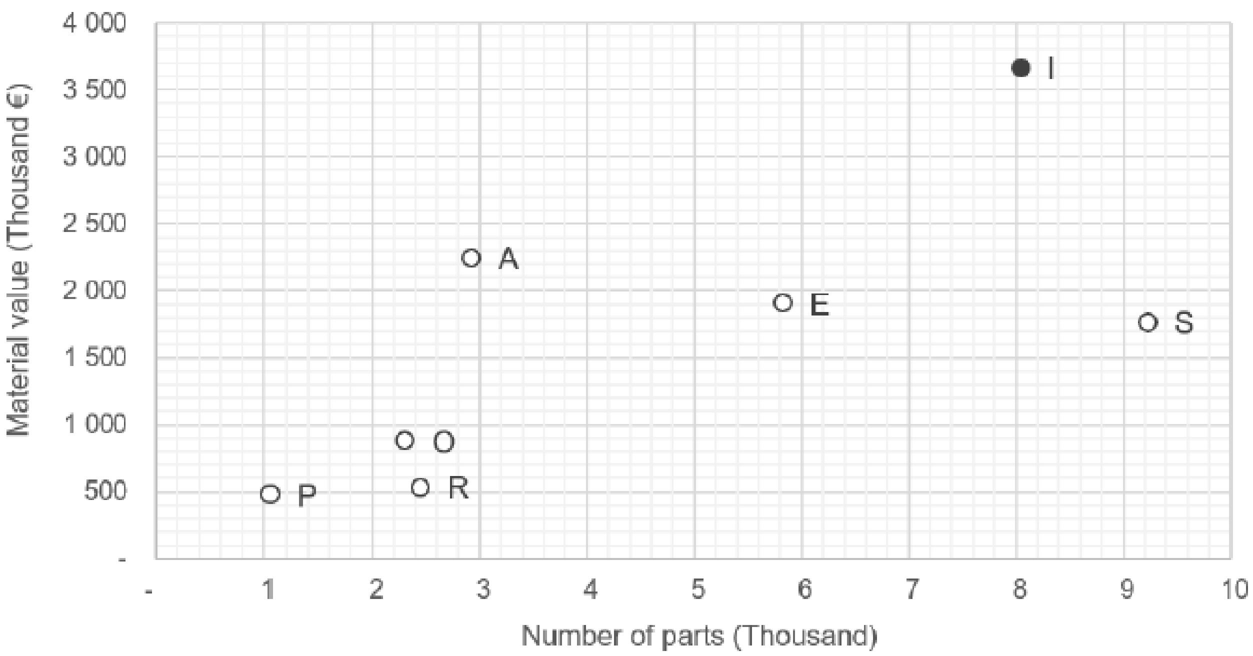
Source: sap.com, 2019

Case study

Preparation of database extract → Classification of spare parts → Screening of spare parts → Prioritization of spare parts → Prototype production → Analysis of procurement scenarios

General spare parts list → Spare parts groups → Specific spare parts list → Quick wins → Prototype → Business process

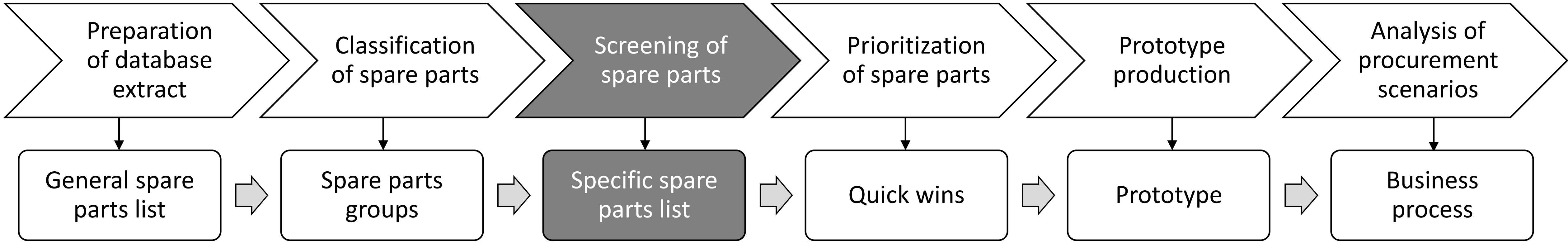
Spare parts groups



Spare parts groups

S	Standard parts
R	Raw materials
P	Pressurized parts
I	Individual parts
E	Electrical components
A	Assembly groups
O	Other materials

Case study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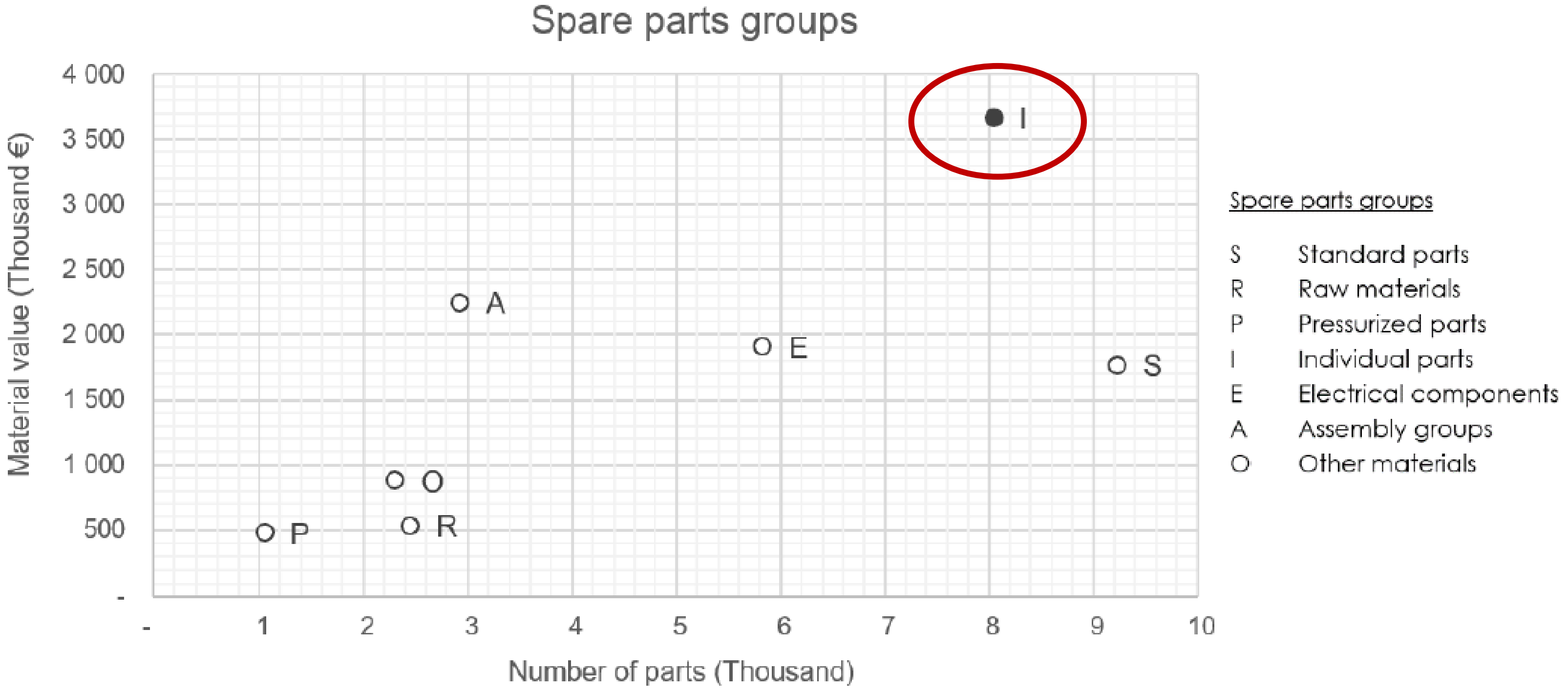
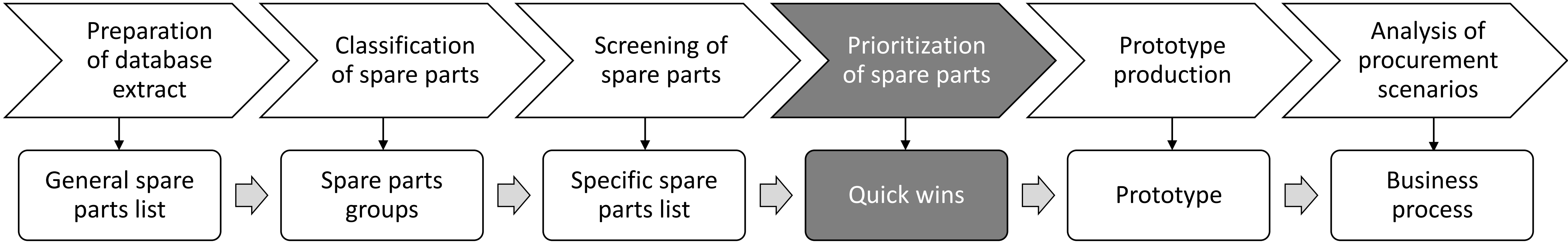
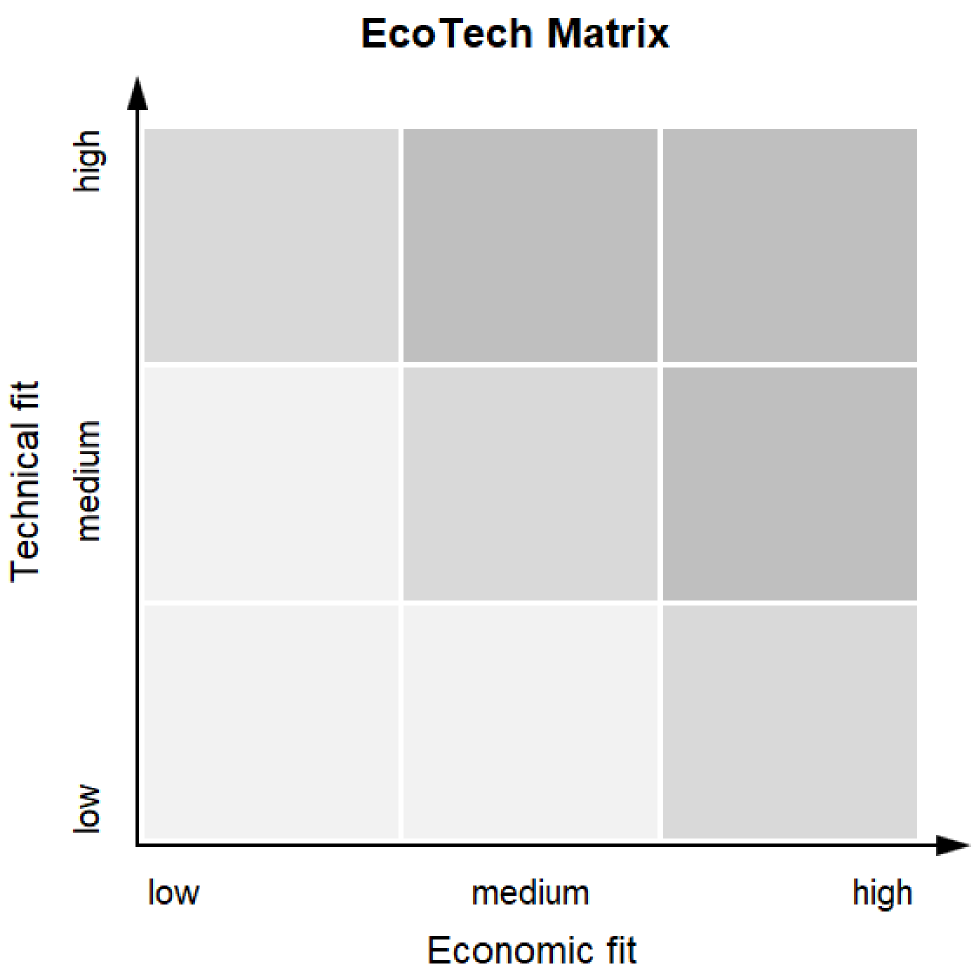

Spare parts groups
Material value (Thousand €)
4 000
3 500
3 000
2 500
2 000
1 500
1 000
500
-
Number of parts (Thousand)
1
2
3
4
5
6
7
8
9
10
A
E
S
I
O
R
P
Spare parts groups
S Standard parts
R Raw materials
P Pressurized parts
I Individual parts
E Electrical components
A Assembly groups
O Other materials

Case study



Source: Additive Minds, 2019, Workshop

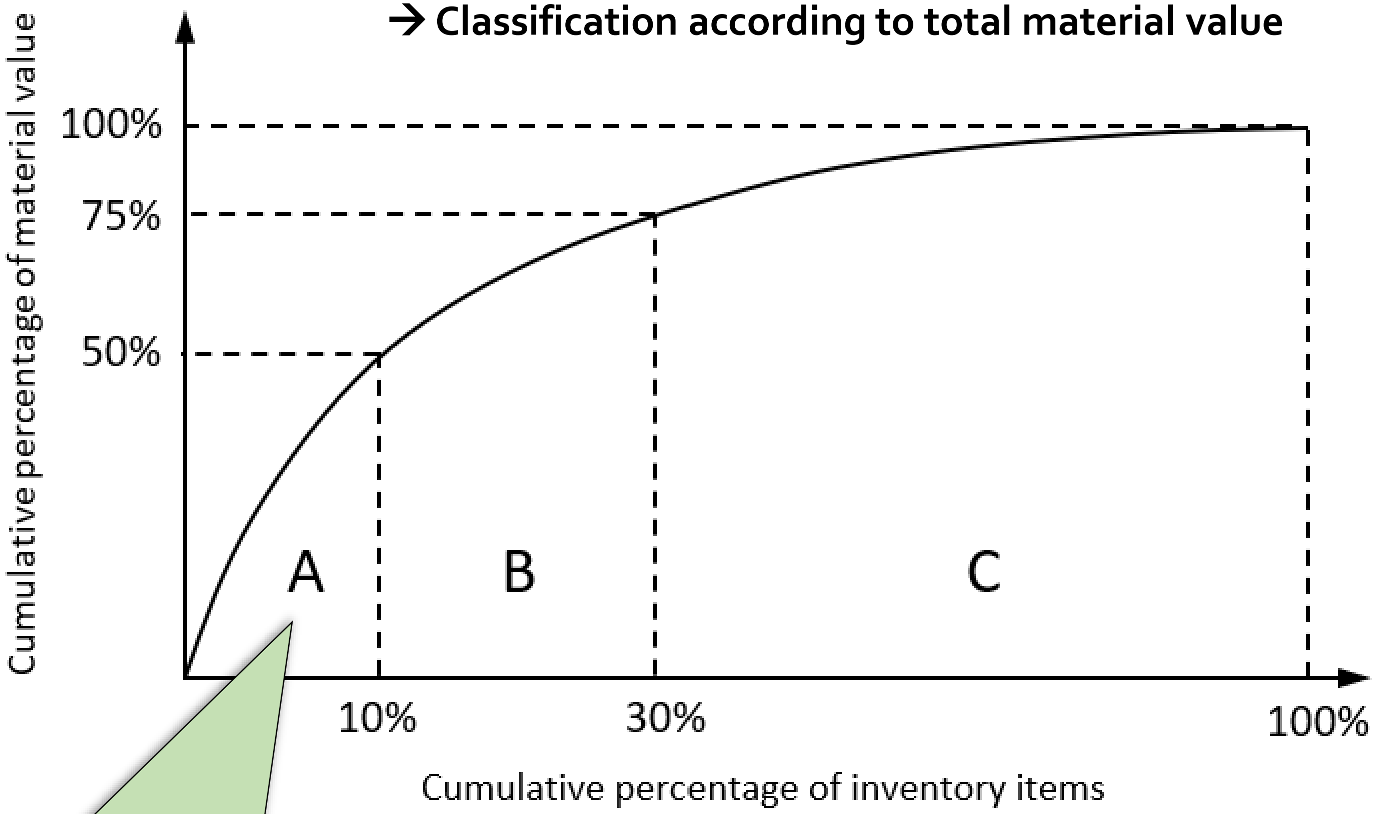
AM Suitability	Value-oriented	Consumption-based	Mixed form
EcoTech Matrix	ABC Analysis	XYZ Analysis	ABC-XYZ Analysis



Source: Additive Minds, 2019, Workshop

AM Suitability → EcoTech Matrix | Value-oriented → **ABC Analysis** | Consumption-based → XYZ Analysis | Mixed form → ABC-XYZ Analysis

→ Classification according to total material value



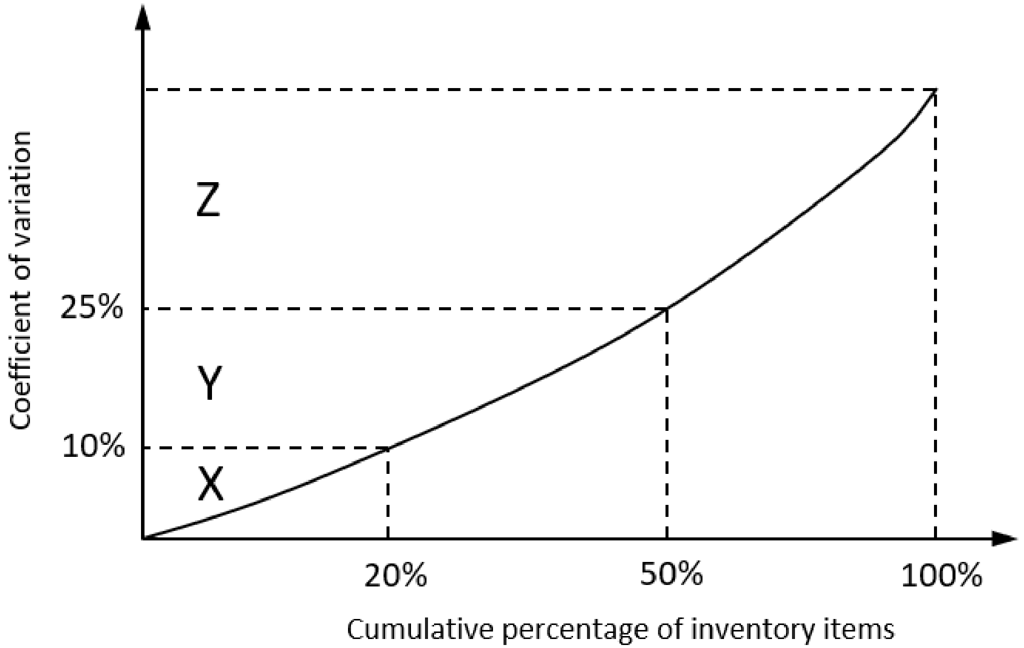
Few materials make up a high proportion of the total consumption

→ Borders can be individually specified by the enterprises

	A	B	C
Realization	Real. A	Real. B	Real. C
Redesign	Red. A	Red. B	Red. C
On-hold	On. A	On. B	On. C

AM Suitability → EcoTech Matrix | Value-oriented → ABC Analysis | Consumption-based → **XYZ Analysis** | Mixed form → ABC-XYZ Analysis

→ Classification according to consumption



X-Parts: Regular consumption
→ high forecast quality

Y-Parts: Variation of consumption
→ medium forecast quality

Z-Parts: Unregular consumption
→ low forecast quality

$$Coeffizient = \frac{\sigma\ (standard\ deviation)}{\bar{X}\ (mean)}$$

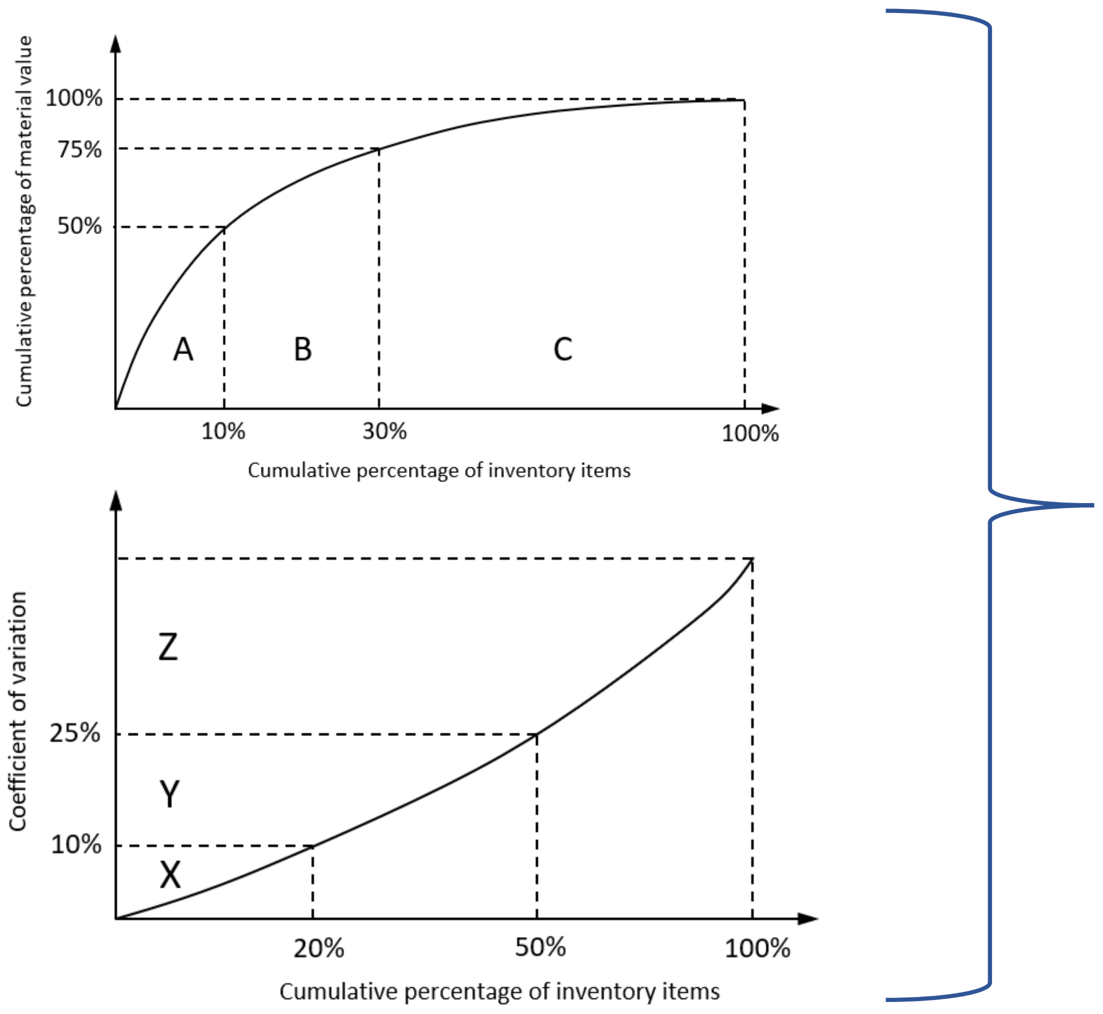
Source: Heiserich, Otto-Ernst; Helbig Klaus; Ullmann, Werner; Logistik – Eine praxisorientierte Einführung – Page 115

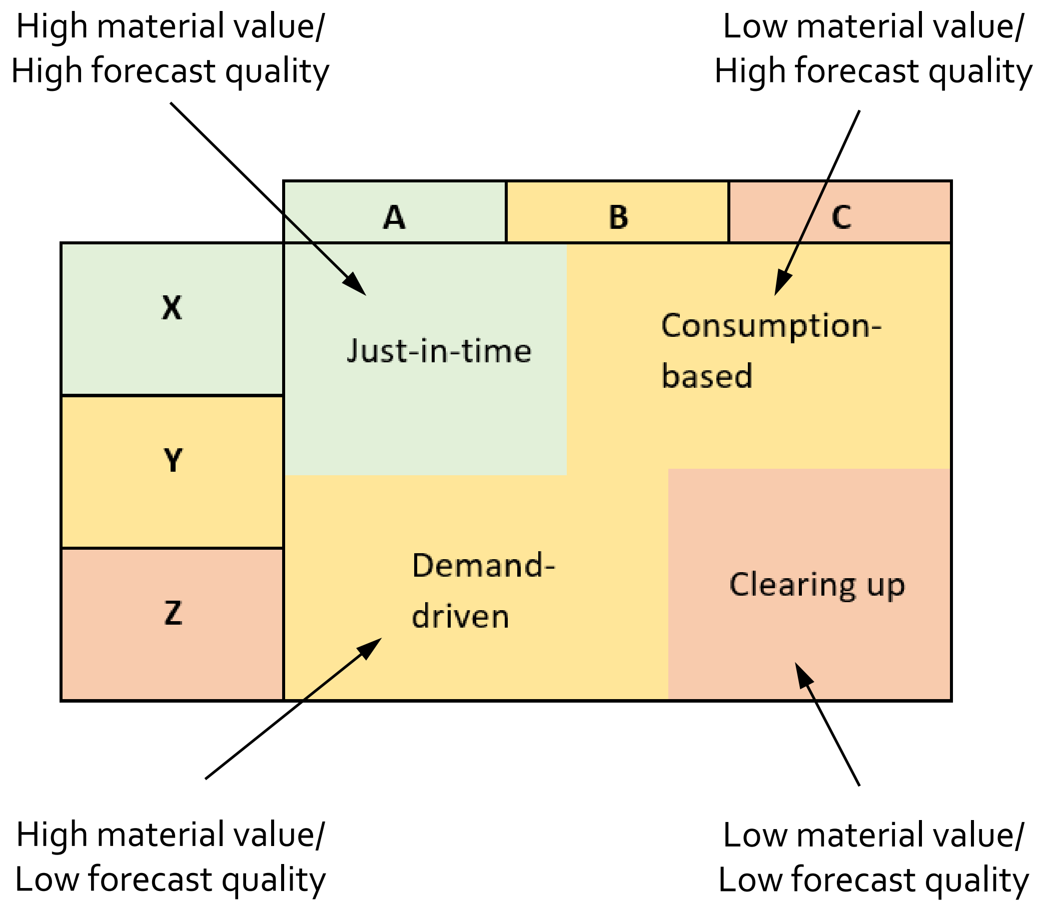
Period	Part 1	Part 2	Part 3
1	9	34	55
2	11	40	65
3	12	36	61
4	11	46	70
Standard deviation	**0,96**	**5,29**	**33**
Mean	**10,75**	**39**	**46,75**
Coefficient	**9%**	**14%**	**71%**

X $\leq 10\%$ | Y $\leq 25\%$ | Z $> 25\%$

AM Suitability | Value-oriented | Consumption-based | Mixed form

EcoTech Matrix → ABC Analysis → XYZ Analysis → **ABC-XYZ Analysis**





AM Suitability	Value-oriented	Consumption-based	Mixed form
EcoTech Matrix	ABC Analysis	XYZ Analysis	ABC-XYZ Analysis

Realization

	A	B	C
X	Real. AX	Real. BX	Real. CX
Y	Real. AY	Real. BY	Real. CY
Z	Real. AZ	Real. BZ	Real. CZ

Redesign

	A	B	C
X	Real. AX	Real. BX	Real. CX
Y	Real. AY	Real. BY	Real. CY
Z	Real. AZ	Real. BZ	Real. CZ

On-hold

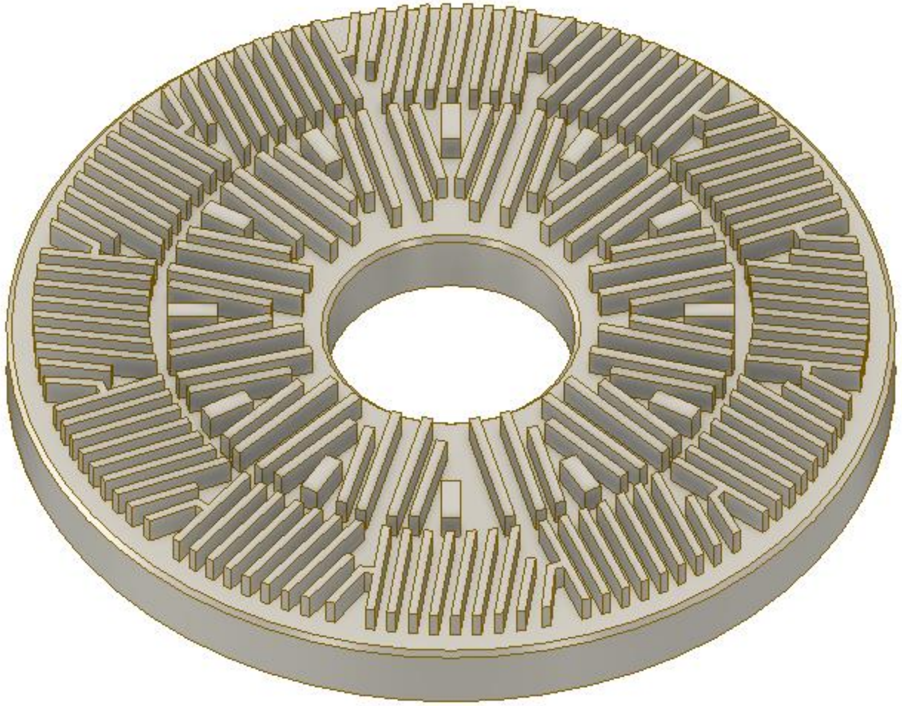
	A	B	C
X	Real. AX	Real. BX	Real. CX
Y	Real. AY	Real. BY	Real. CY
Z	Real. AZ	Real. BZ	Real. CZ

Sequence of processing →

→ **This approach requires a precise stock list including relevant data!**
(material, size, weight, price, delivery time, consumption per perios, etc.)

AM Suitability | Value-oriented | Consumption-based | Mixed form

EcoTech Matrix → ABC Analysis → XYZ Analysis → ABC-XYZ Analysis



Single parts: 181

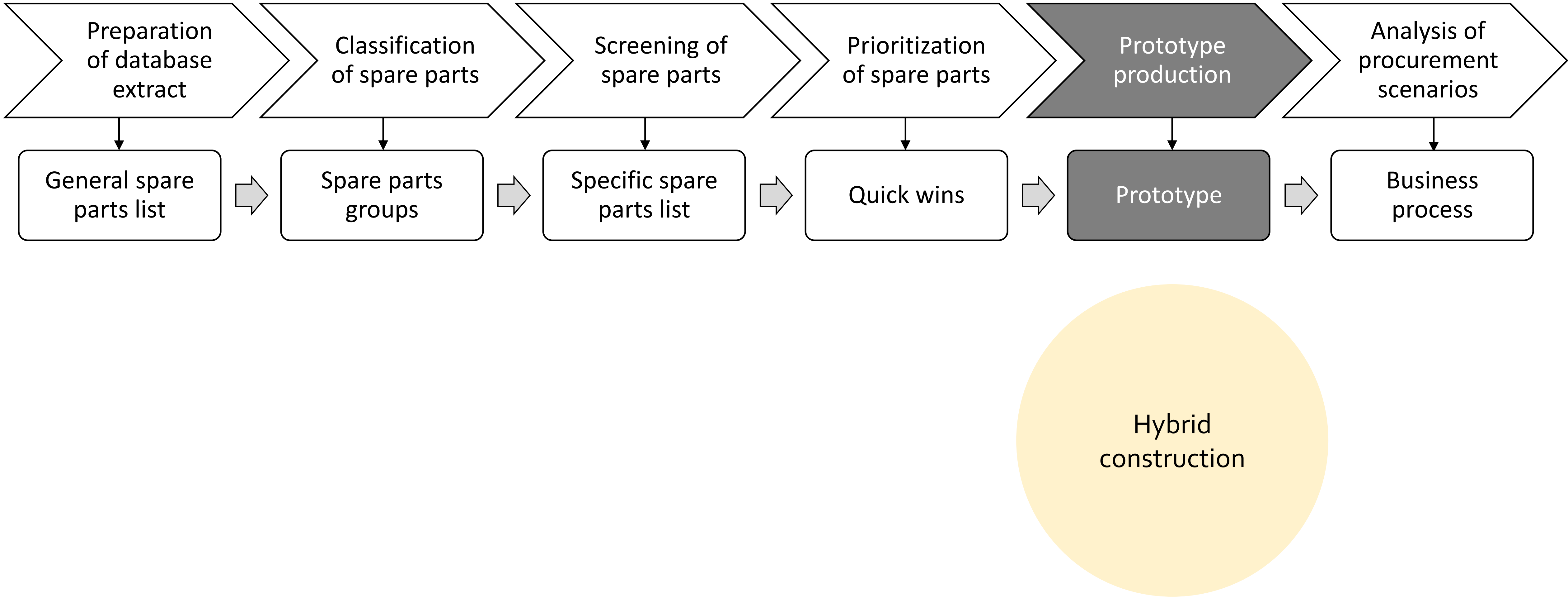
Material: 1.4542 (stainless steel)

Hardness: 40 HRC

Procurement costs: 1,500 €

Dependence on supplier -> very high

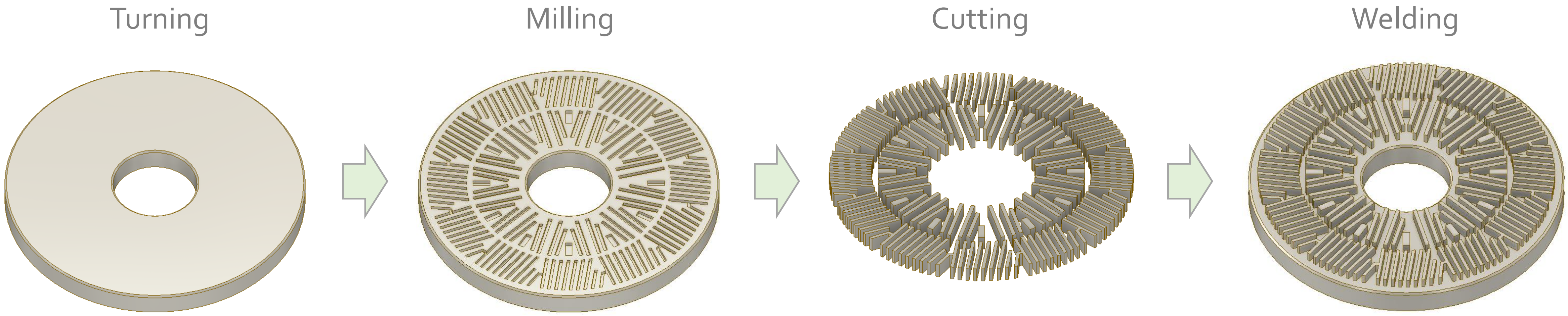
Case study



Source: Additive Minds, 2019, Workshop

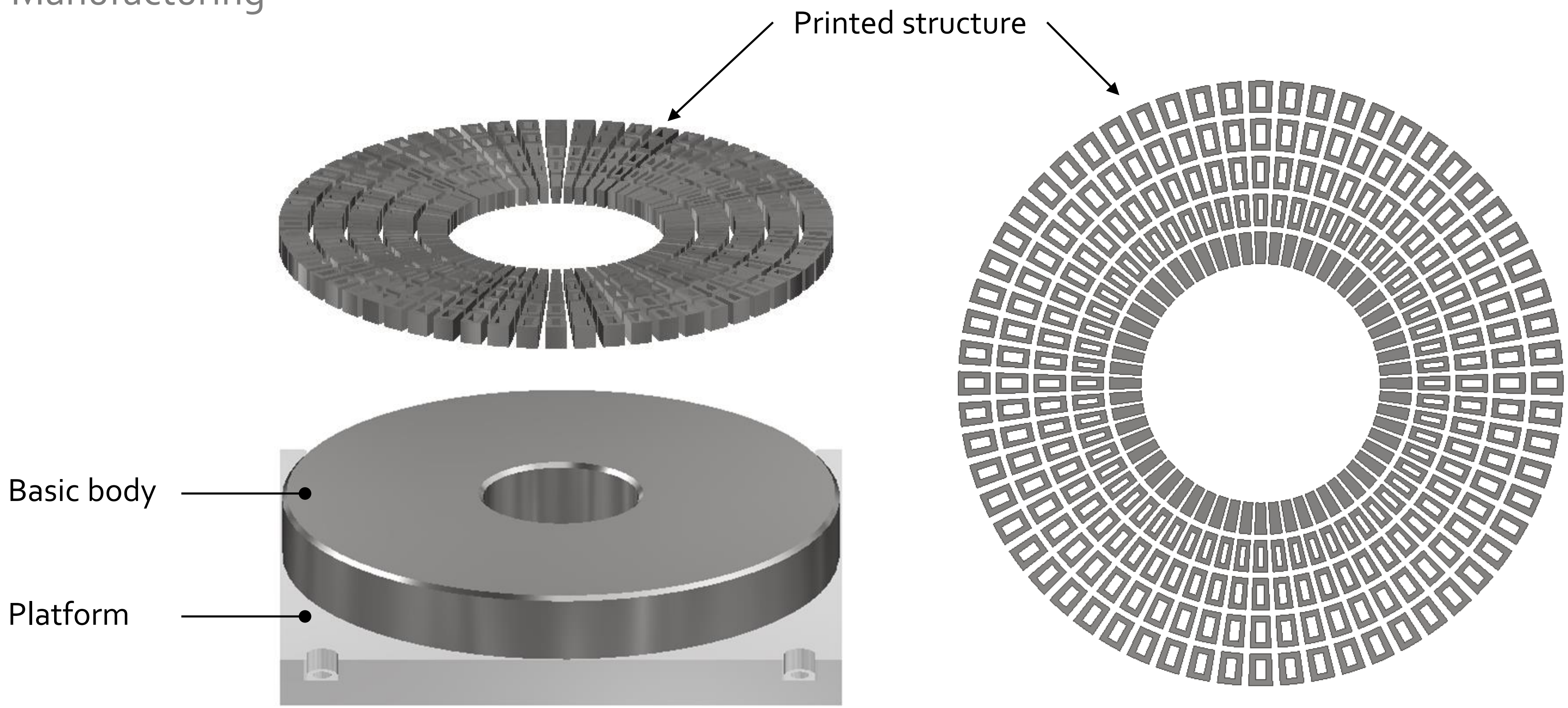
Case study

Conventional Manufacturing



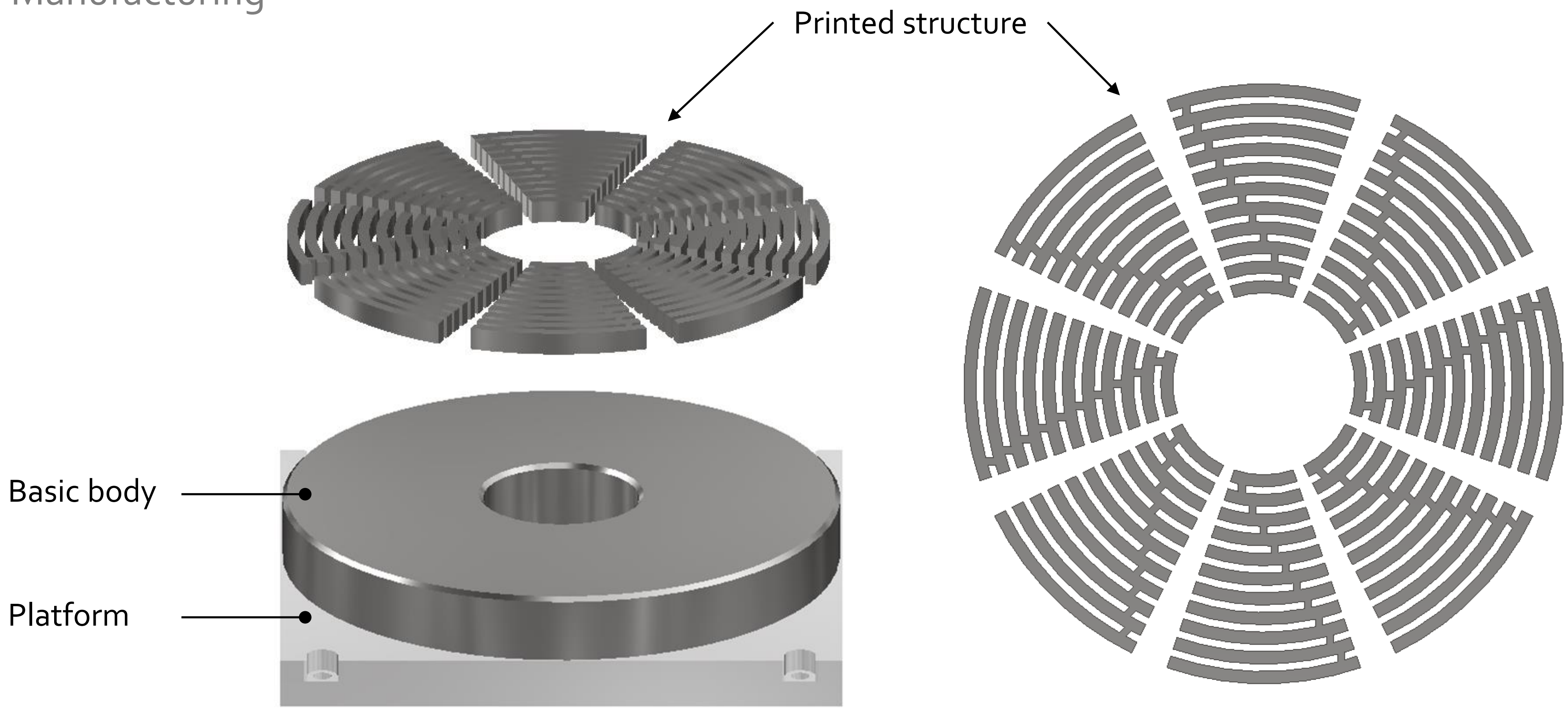
Case study

Additive Manufacturing



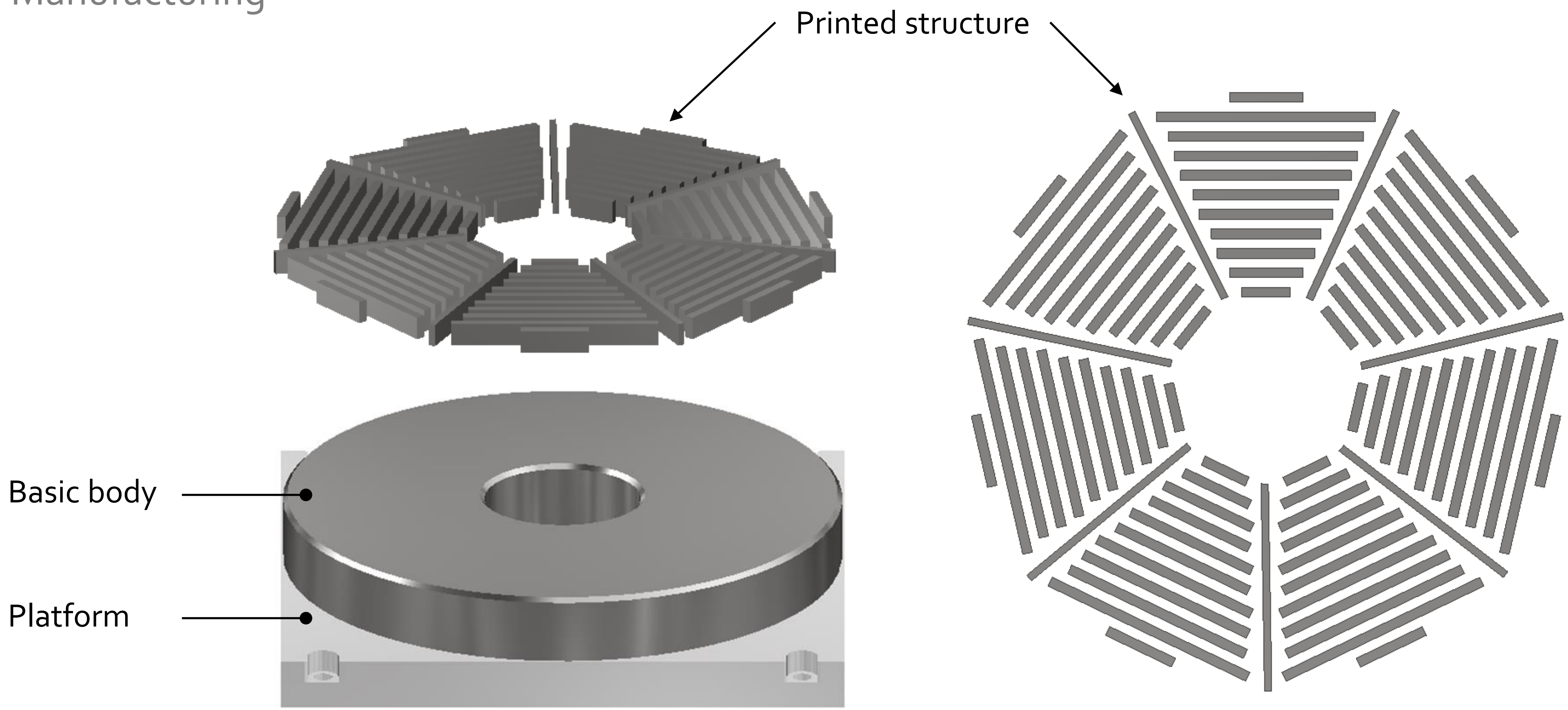
Case study

Additive Manufacturing



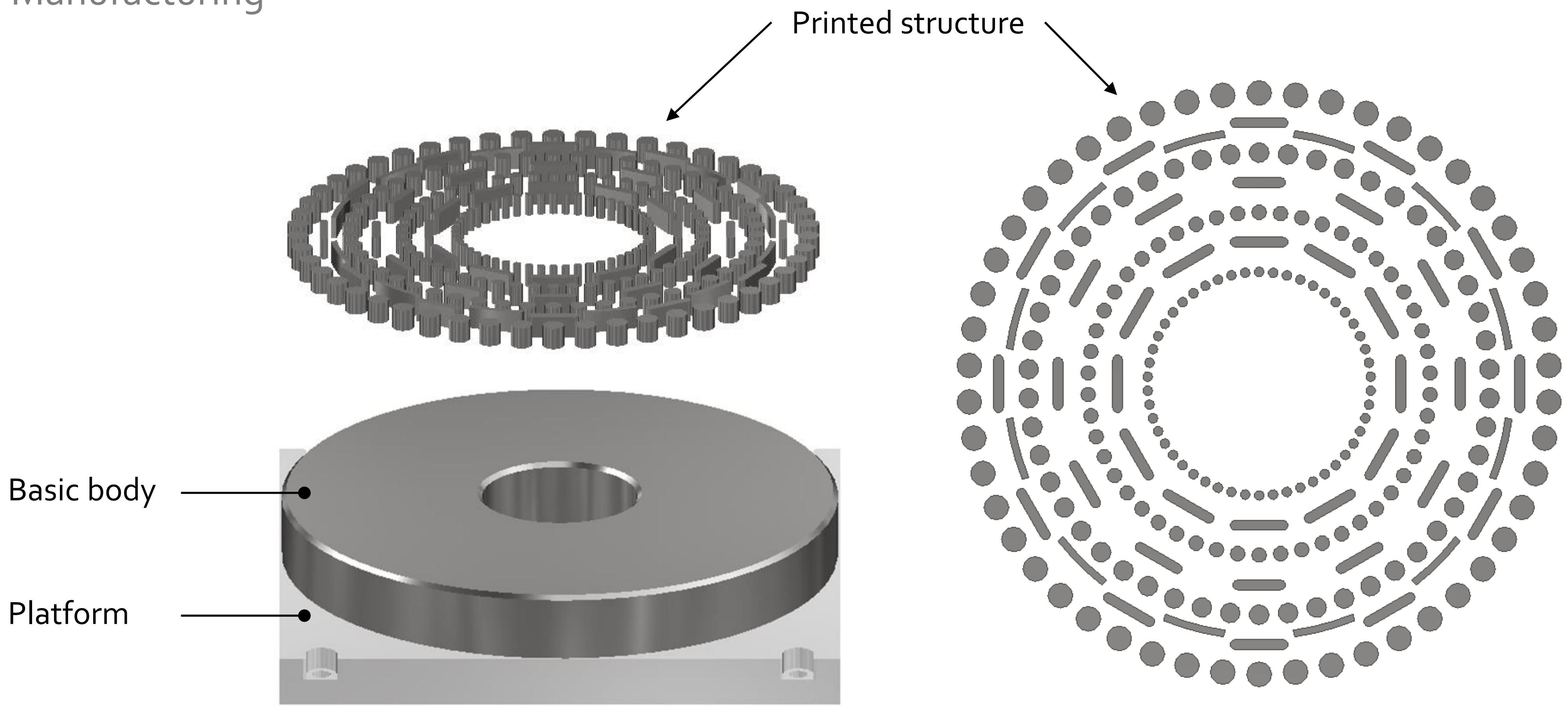
Case study

Additive Manufacturing



Case study

Additive Manufacturing



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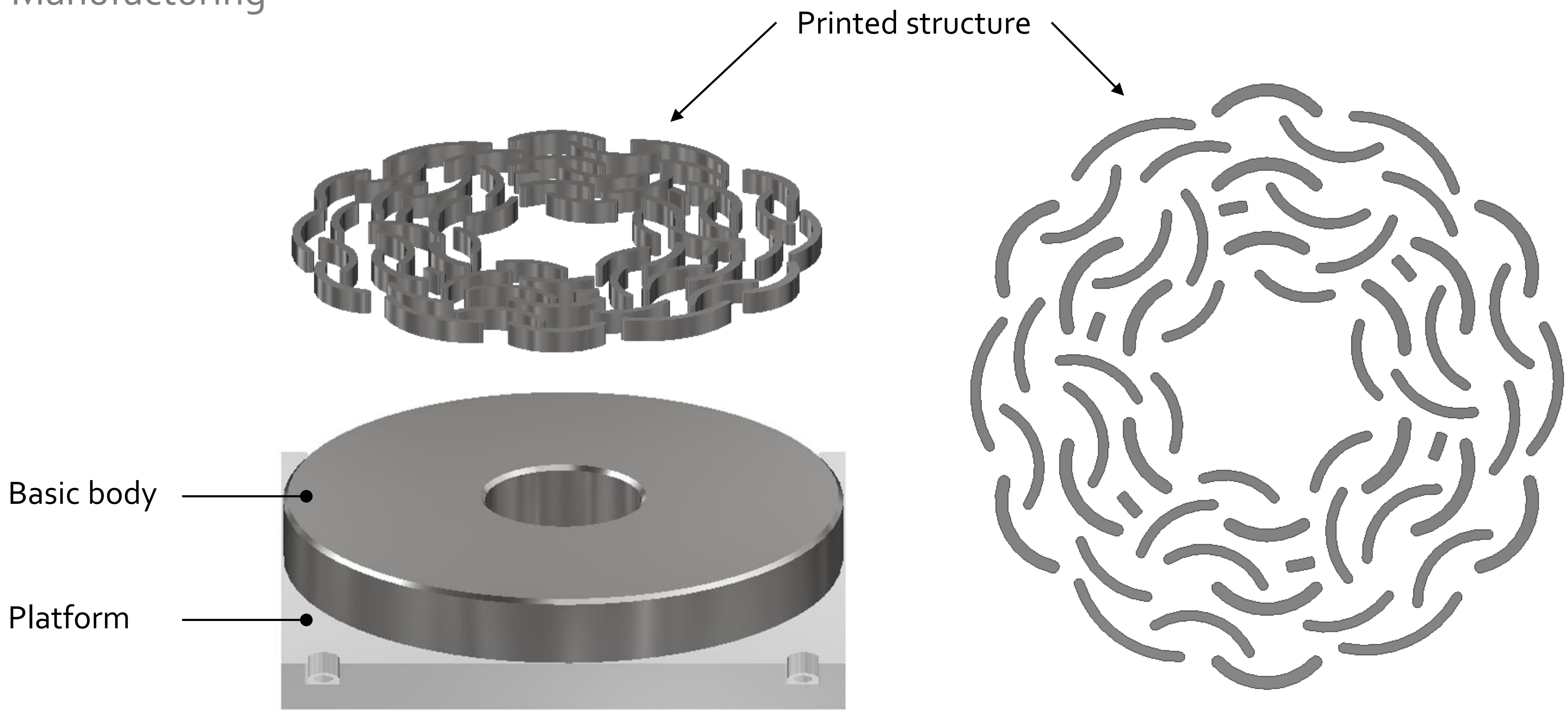
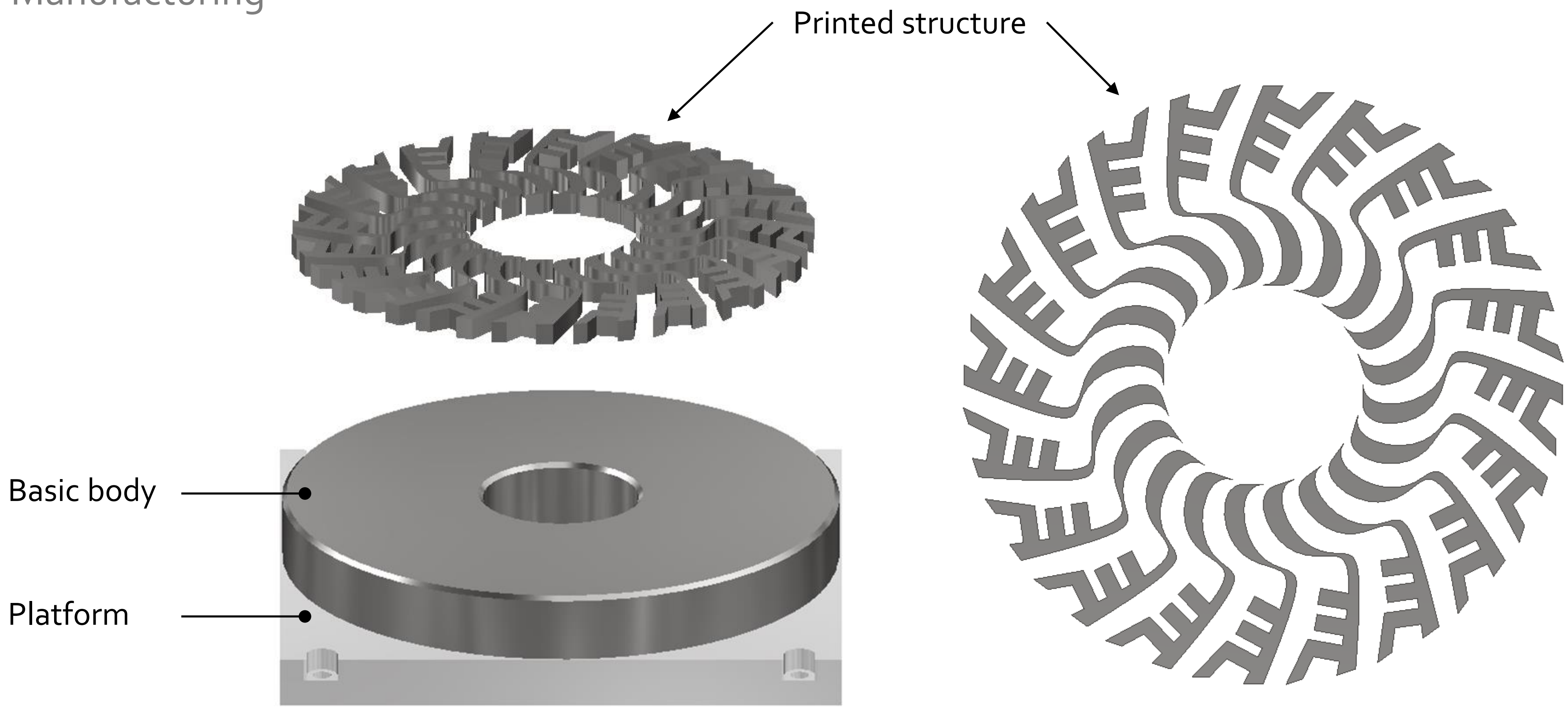
Additive Manufacturing

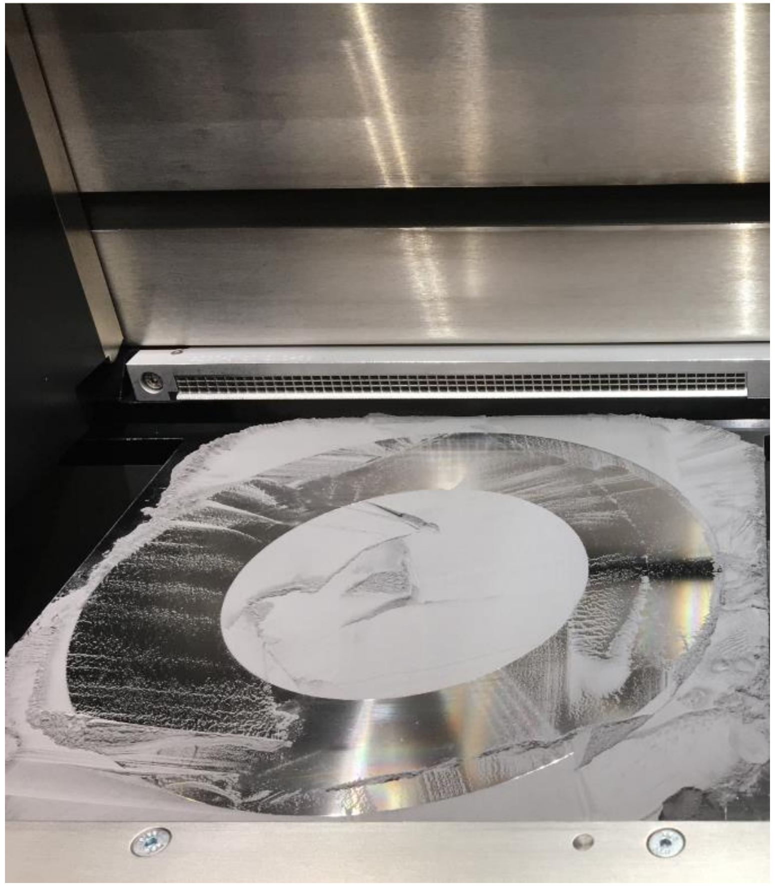


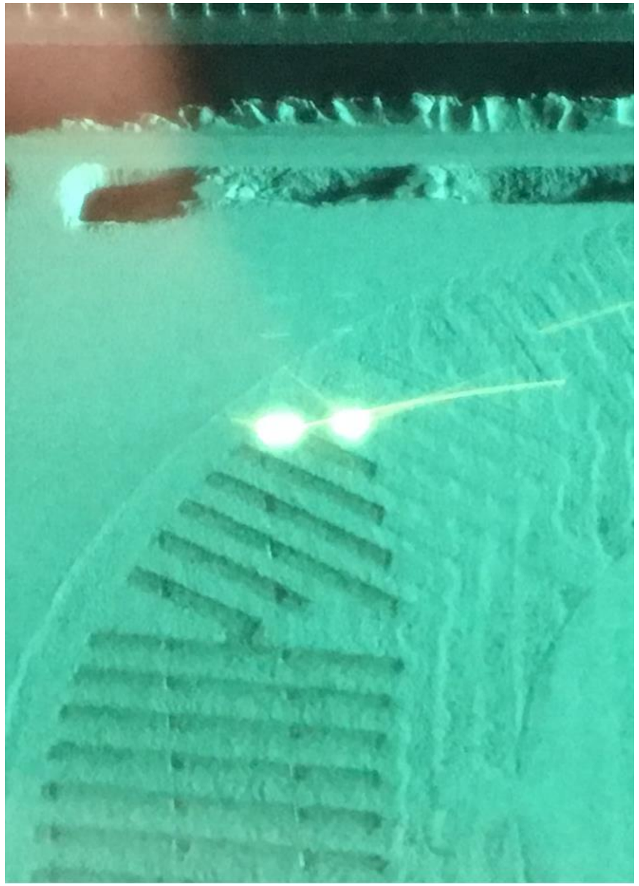
Case study

Additive Manufacturing



Case study





Case study

Conclusion

Cost reduction: **53%**

Reduction of production time: **94%**

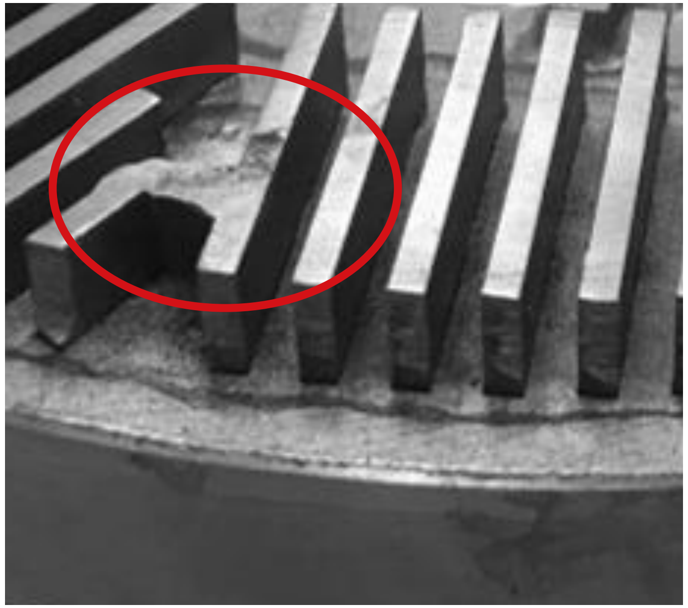
No dependence on supplier!

Process development

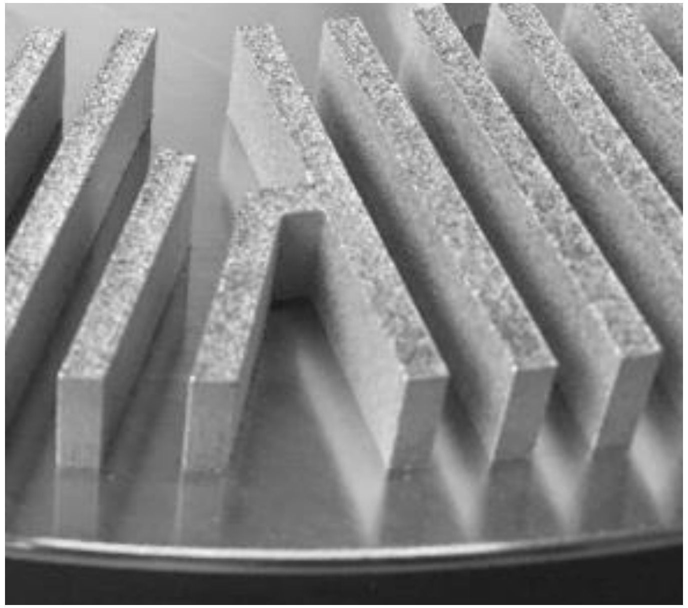
Improvement of part Quality:

- Homogeneous structure
- Measurement accuracy
- Optical appearance

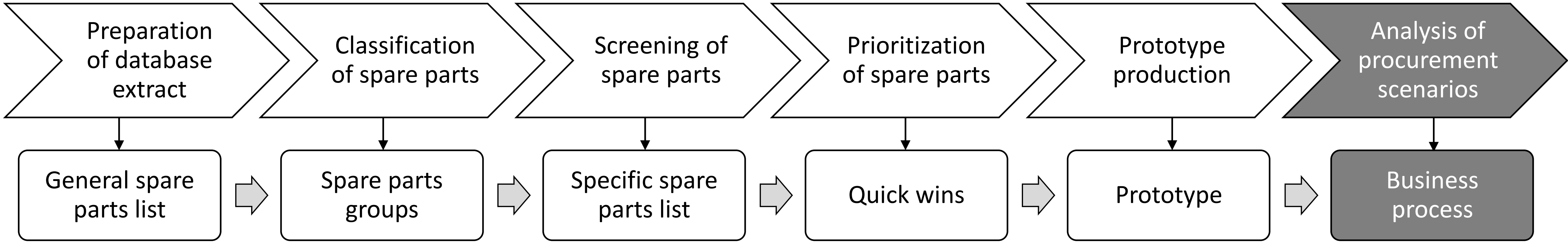
Conventional part



AM part



Case study



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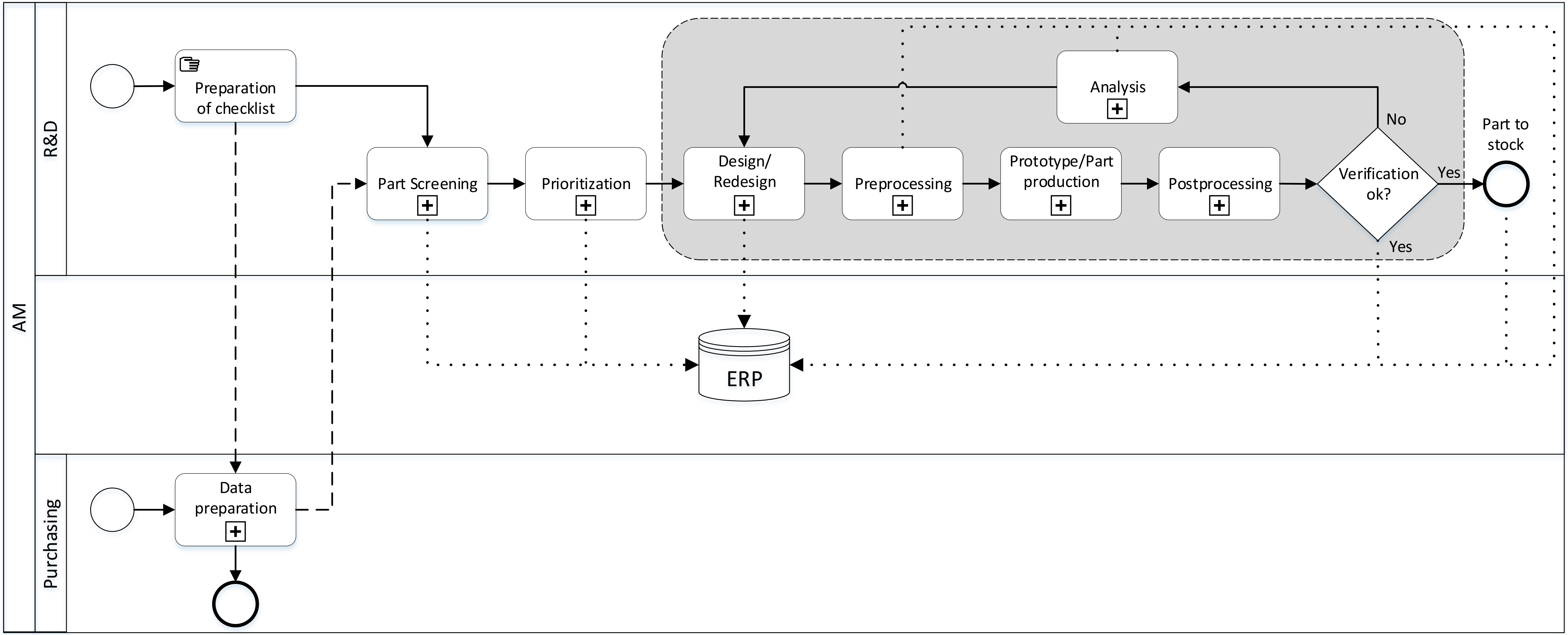
Case study

Process/part development

- In-house production
- Outsourcing



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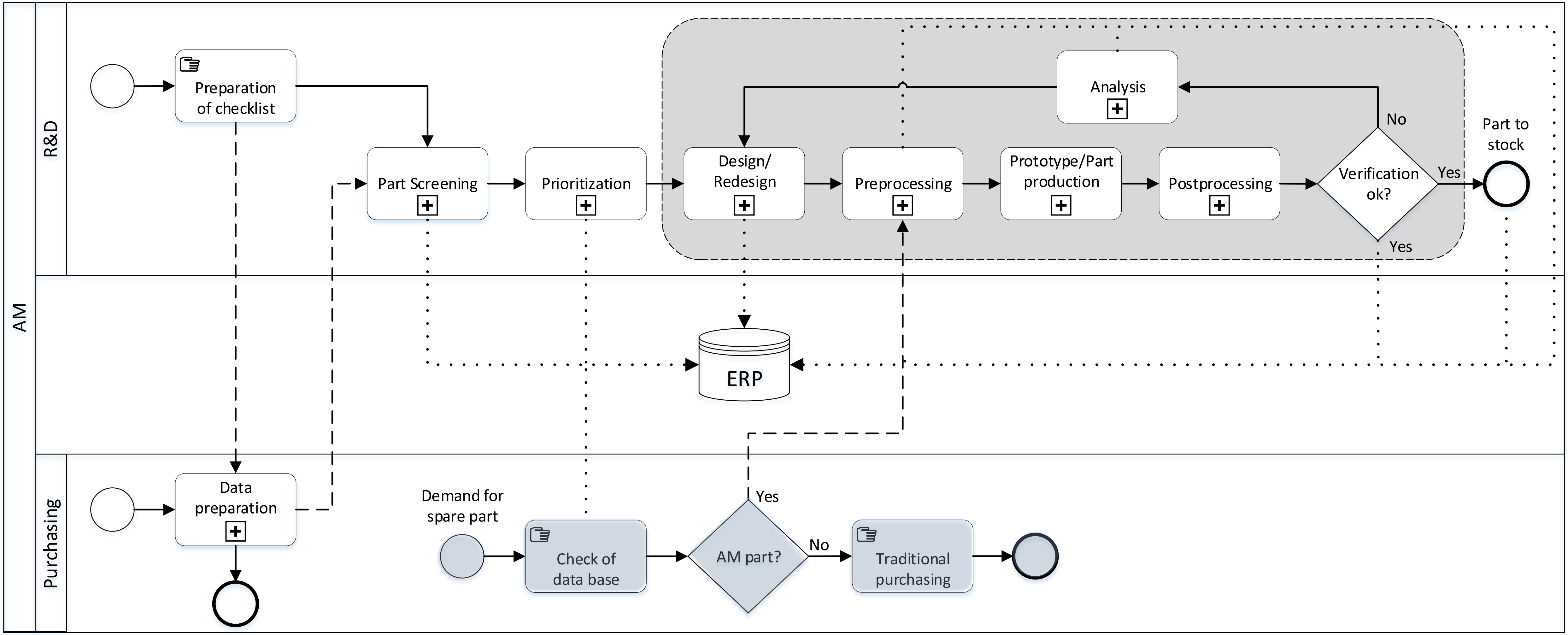
Case study

- In-house production
- Outsourcing



Fulfilment of demand

Postprocessing

Postprocessing

Unpacking of printjob → Thermal treatments → Mechanical treatments

Postprocessing

Unpacking of printjob → Thermal treatments → Mechanical treatments

The removal of the printed job is a critical step that affects:

- Turnaround time
- Part Quality
- Powder quality
- Powder losses

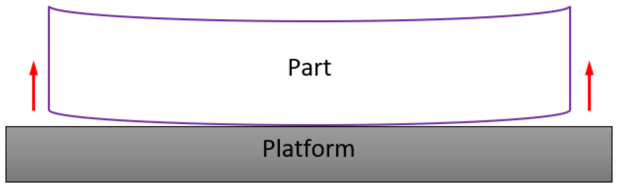
Finished printjob | Powder removal | Dismantling of platform | Removal of plattform

Source: Additive Minds, 2019, Workshop

Postprocessing

Unpacking of printjob → **Thermal treatments** → Mechanical treatments

Thermal treatment is often required for:
- Stress reduction
- Hardening



Methods:
- Electric furnace (air/protective gas box)
- Vacuum furnace
- HIP (Hot Isostatic Pressing)

Source: rohde-online.net, 2019

→ Stress relief annealing is sometimes necessary to reduce internal stresses in the parts/platform due to uneven laser exposure

→ Heat treatment depends on the expected final properties

Material	Heat treatment
EOS MP1	1150°C/ 6h under argon
EOS Ti64	650°C to 800°C/ 3h under Aargon
EOS 1.2709	490°C/ 6h in air
EOS 15.5PH	525°C/ 4h in Air (H1000)
EOS IN718	ASTM5662

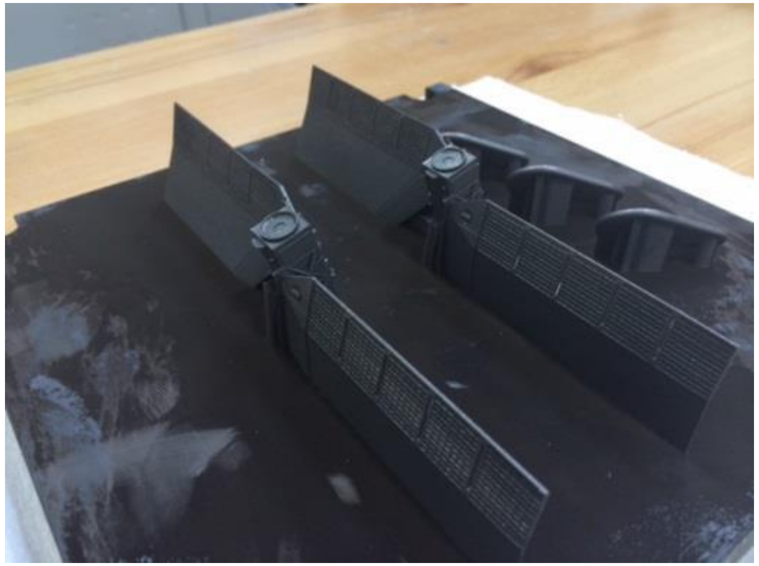
Source: Additive Minds, 2019. Workshop

Postprocessing

Unpacking of printjob → Thermal treatments → Mechanical treatments

- Stress relief annealing/hardening might cause scale and annealing colors
  → removable via blasting
- Inert atmosphere can reduce scale
- Trapped powder must be removed or the heat will cause it to cake

Scale



Source: Additive Minds, 2019, Workshop

Annealing colors

Source: Additive Minds, 2019, Workshop

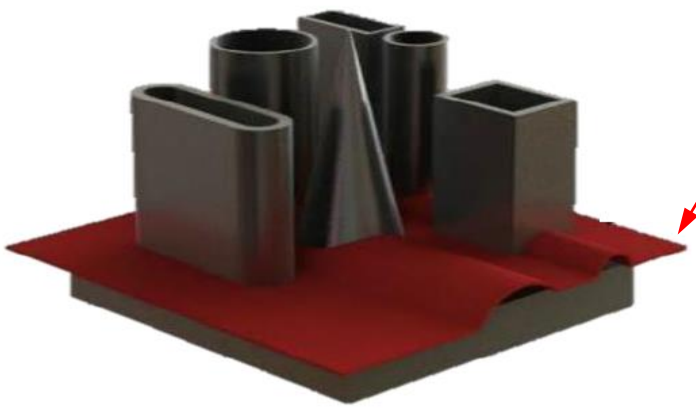
Postprocessing

Unpacking of printjob → Thermal treatments → Mechanical treatments

Wire cutting

- Cut width > 0.5mm
- Typical residues remain on building platform
- Functional surfaces can be generated
- Do not use wire cutting for hollow sections that contain powder (wire gets damaged)
- After machining, the platform can be reused

→ **Wire cutting already has to be considered during the positioning of parts on the platform!**



Source: Additive Minds, 2019, Workshop

Specific wire path along the platform

Different shapes can be realized at once

Source: Additive Minds, 2019, Workshop

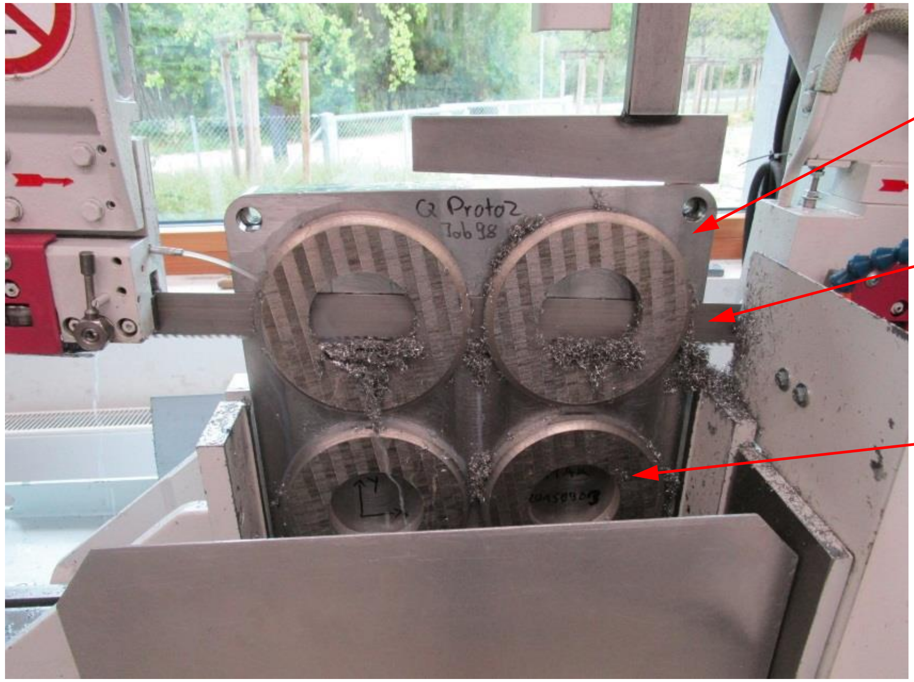
Typical part residues on platform

Postprocessing

Unpacking of printjob → Thermal treatments → Mechanical treatments

Sawing

- Band saw
- Functional surfaces can be generated
- After machining, the platform can be reused
- Once sawn off, the individual parts are post-processed in their own way



Platform (EOS M400)

Saw blade

Individual parts

Source: Additive Minds, 2019, Workshop

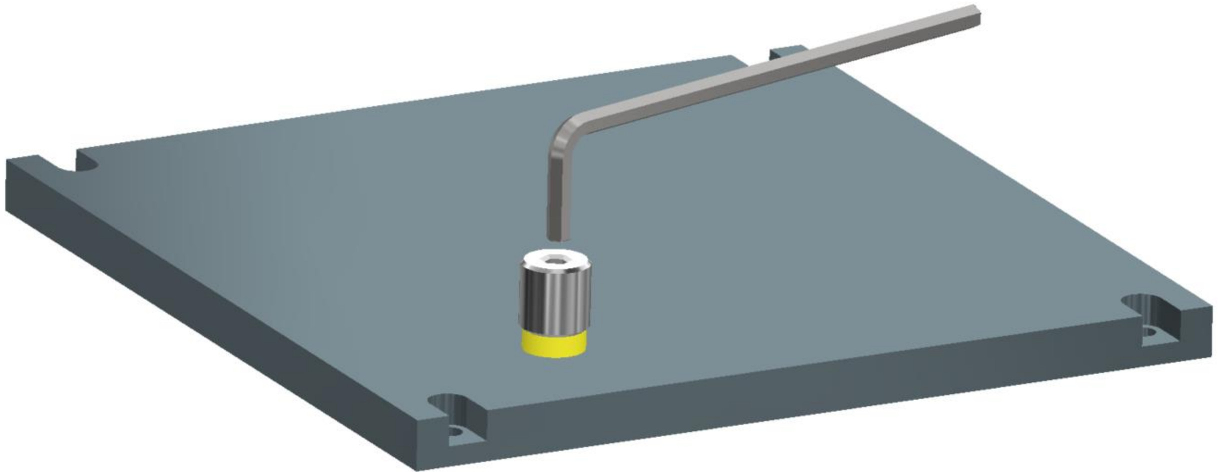
Postprocessing

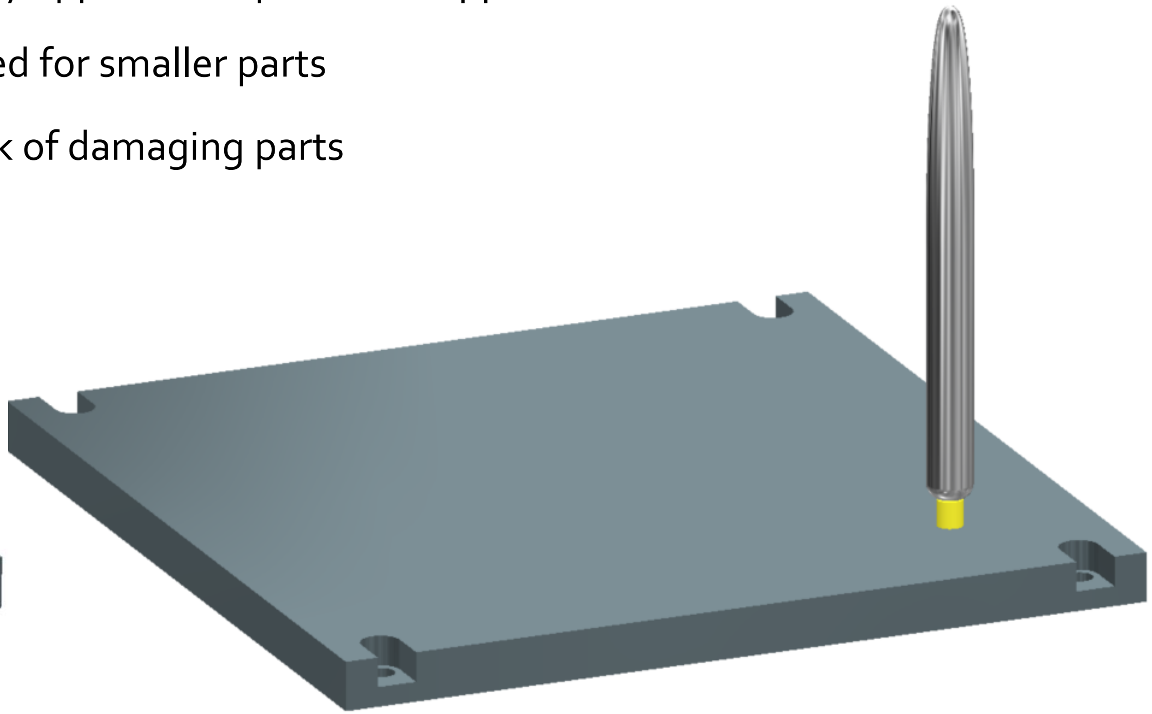
Unpacking of printjob → Thermal treatments → Mechanical treatments

Other methods

- Hammer and chisel
- Rotary tools (e.g. Dremel)
- Separation by hand

- Only applicable if parts are supported
- Used for smaller parts
- Risk of damaging parts





Postprocessing

Unpacking of printjob → Thermal treatments → Mechanical treatments

Support removal

- Separation of support structure from actual part via hand tools (Rotary tools, knippers,...)
- Post-processing effort can be reduced by smart design! (part orientation)

Source: Additive Minds, 2019, Workshop

Source: Additive Minds, 2019, Workshop

Source: Additive Minds, 2019, Workshop

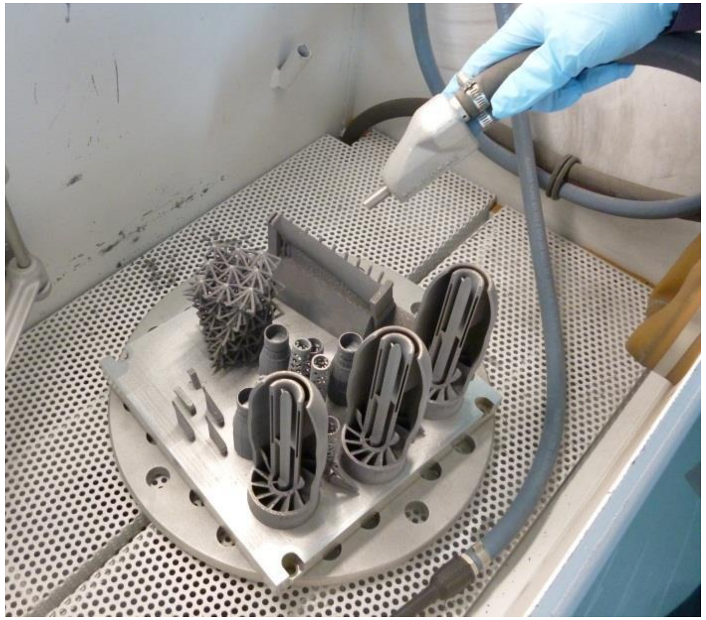
Postprocessing

Unpacking of printjob → Thermal treatments → Mechanical treatments

Blasting

- After removal of support structure
- Cleaning the part from residues
- Homogenous & shiny surface
- Compression of surface possible (e.g. aluminium)

Source: Additive Minds, 2019, Workshop



Source: Additive Minds, 2019, Workshop

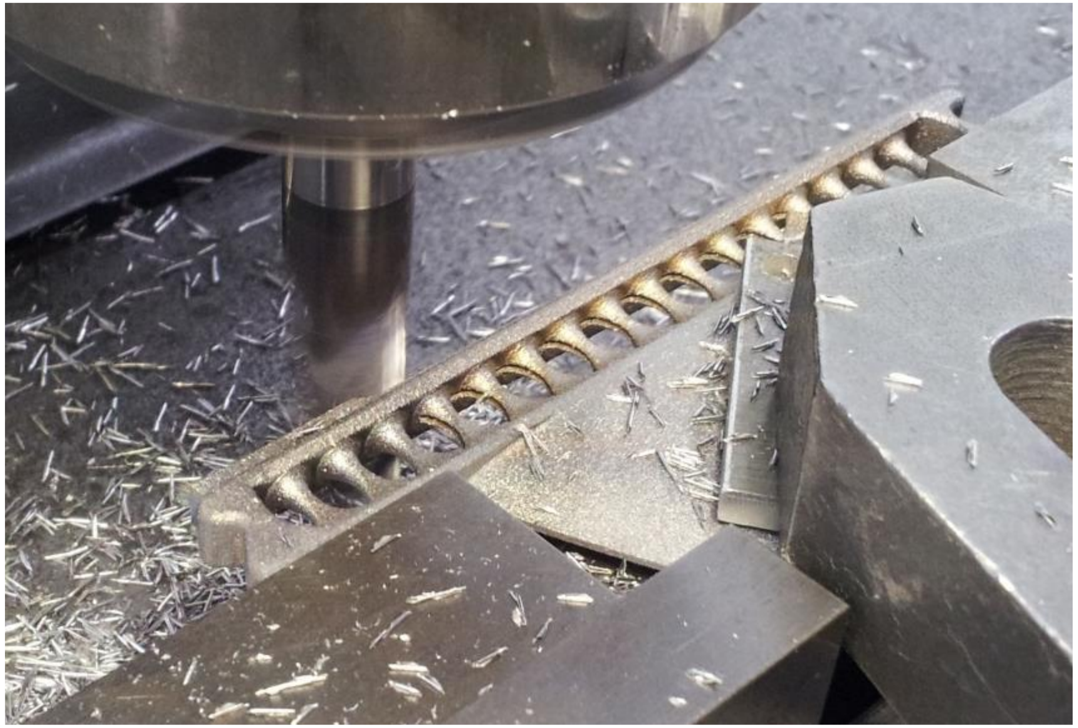
Postprocessing

Unpacking of printjob → Thermal treatments → Mechanical treatments

Machining

- Milling / Drilling
- Especially for functional surfaces (dimensional accuracy)

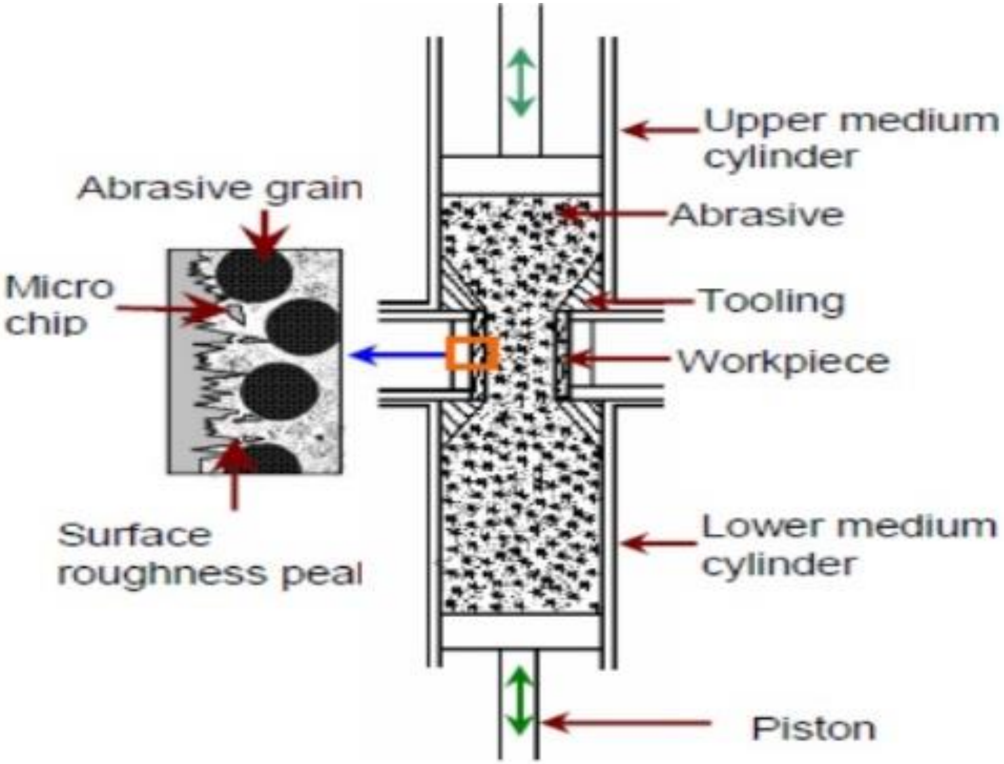
Source: Additive Minds, 2019, Workshop



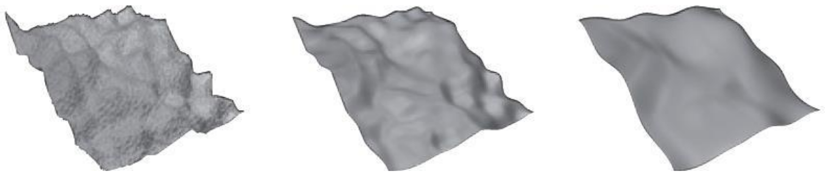
Source: Additive Minds, 2019, Workshop

Unpacking of printjob → Thermal treatments → Mechanical treatments

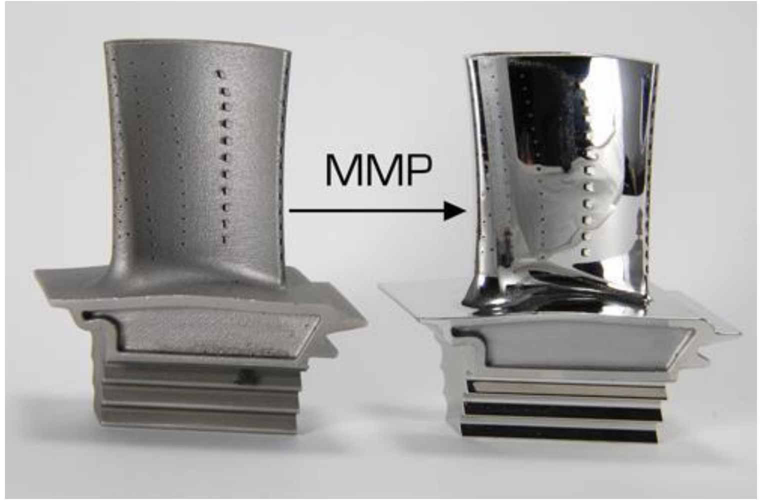
Micro Machining Process (MMP)



Source: slideshare.net, 2019



Source: firstsurface.de, 2019



Source: firstsurface.de, 2019

AMAVIS2

Additive Manufacturing in Agile Virtual Systems for Product Design and Production Process Design

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