Building up the Future
Transformations in Additive Manufacturing

Dr.-Ing. Bernhard Müller
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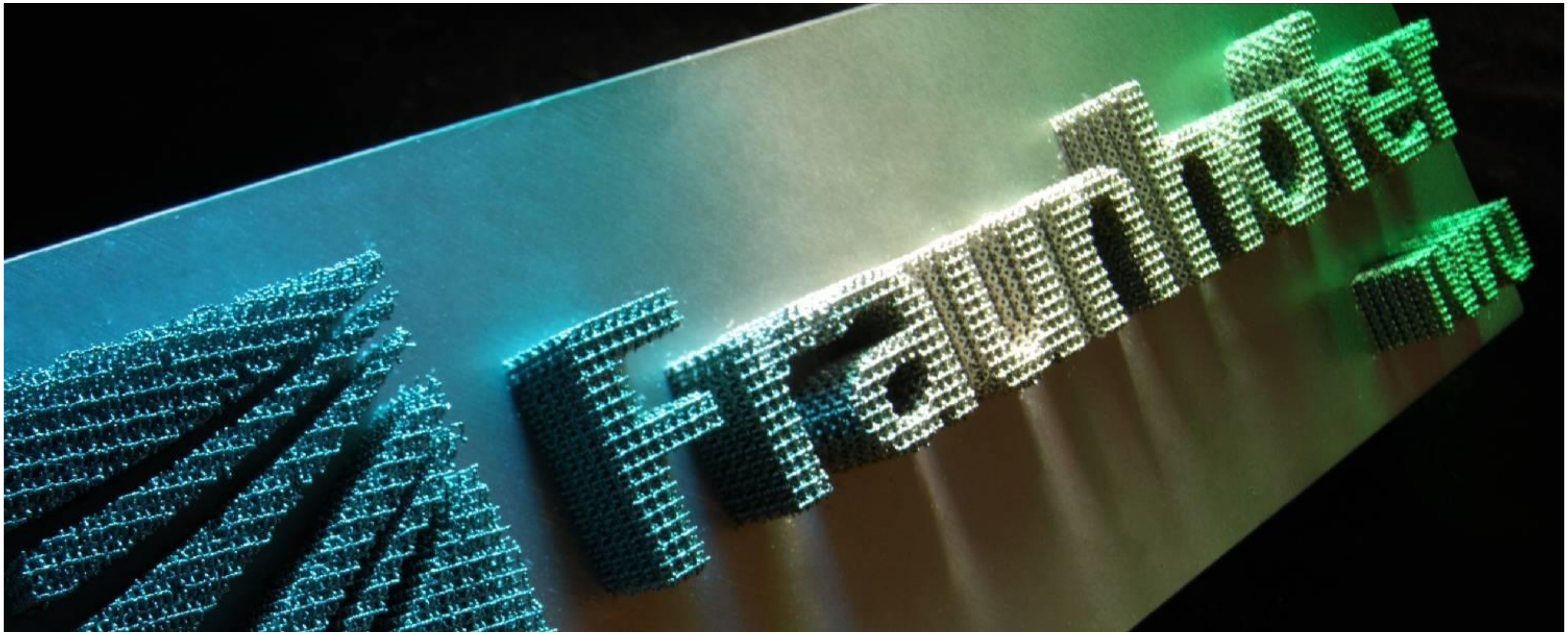
Fraunhofer Institute for Machine Tools and Forming Technology IWU



Manufacturing Leadership Forum Europe, Munich (Germany), June 7-9, 2017

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Agenda

- Introduction
  - The Fraunhofer-Gesellschaft
  - The Fraunhofer IWU
  - Additive Manufacturing at Fraunhofer and at IWU
- Industrial Application Potentials of Additive Manufacturing
  - Light weight design
  - Functionalisation
  - Examples from applied research
- Status quo of industrial application of Additive Manufacturing
  - Medical and dental technology
  - Aerospace
  - Automotive
  - Tool and die making
- Challenges with Additive Manufacturing for series production

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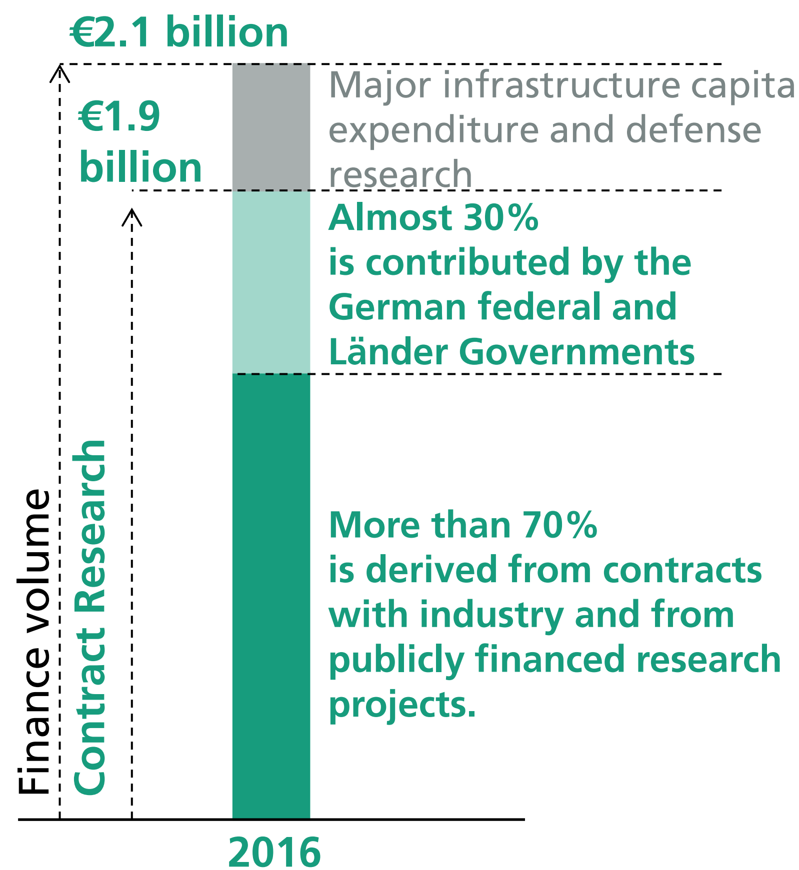
The Fraunhofer-Gesellschaft at a Glance

The Fraunhofer-Gesellschaft undertakes applied research of direct utility to private and public enterprise and of wide benefit to society.

24,500 staff

69 institutes and research units



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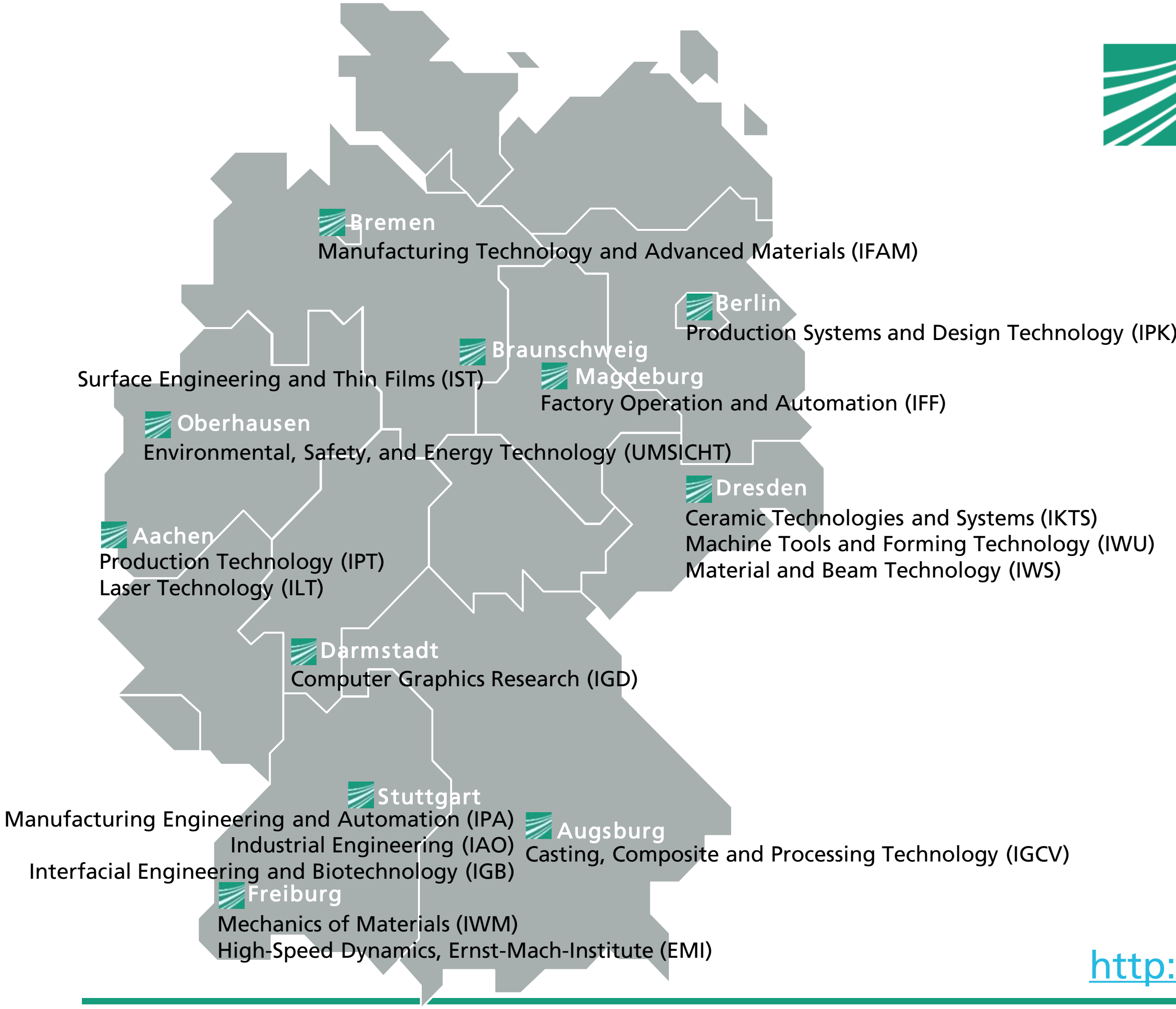
Additive Manufacturing at Fraunhofer

One topic – seventeen institutes – one alliance



Fraunhofer GENERATIV

Fraunhofer Additive Manufacturing Alliance
Spokesman:
Dr.-Ing. Bernhard Mueller

Office:
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Nöthnitzer Straße 44,
01187 Dresden (Germany)
http://www.generativ.fraunhofer.de

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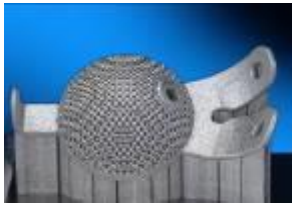
Fraunhofer Additive Manufacturing Alliance
Research areas

- **Engineering**
  to invent and design new products and develop suitable process chains

- **Materials**
  to adapt new materials

- **Technologies**
  to achieve (cost-)efficient processes

- **Quality**
  to control and ensure manufacturing reproducibility and product quality



Fraunhofer IWU

The Fraunhofer IWU in Profile

- founded in 1991
- about 620 employees
- €41.5 million annual budget
- locations in **Chemnitz**, Dresden and Zittau

Research under the heading “Resource-efficient Production“

Scientific fields

- Mechatronics and lightweight structures
- Machine tools, production systems and machining
- Forming technology and joining

Additive Manufacturing at Fraunhofer IWU
Equipment

Metal

Laser Beam Melting

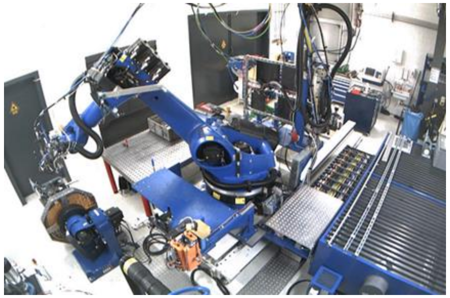
Concept Laser M2 Cusing, IWU Dresden

Realizer SLM 100, IWU Dresden

SLM Solutions SLM 250HL, TU Chemnitz (SLK)

Laser / plasma / arc deposition welding

Laser deposition welding DepositionLine + TruDisk 6002 (Trumpf), IWU Chemnitz



MAG / plasma welding equipment Phoenix 500 coldarc, TransPuls Synergie 5000 CMT, Tetrix 400, IWU Chemnitz

Polymers

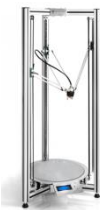
3D-Printing

ZPrinter 310 + Zprinter 450 (3D Systems / Z Corp.), TU Chemnitz (IWP, RP-Labor)

Fused Layer Modeling (FLM/FDM)

FORTUS 900mc (Stratasys), IWU Zittau

Dimension SST 1200es (Stratasys), TU Chemnitz (IWP, RP-Labor)



Delta Tower

Cube X (3D Systems), IWU Chemnitz

Selective Laser Sintering (SLS)

sPro™60 HD-HS High Speed SLS® Center (3D Systems) IWU Zittau

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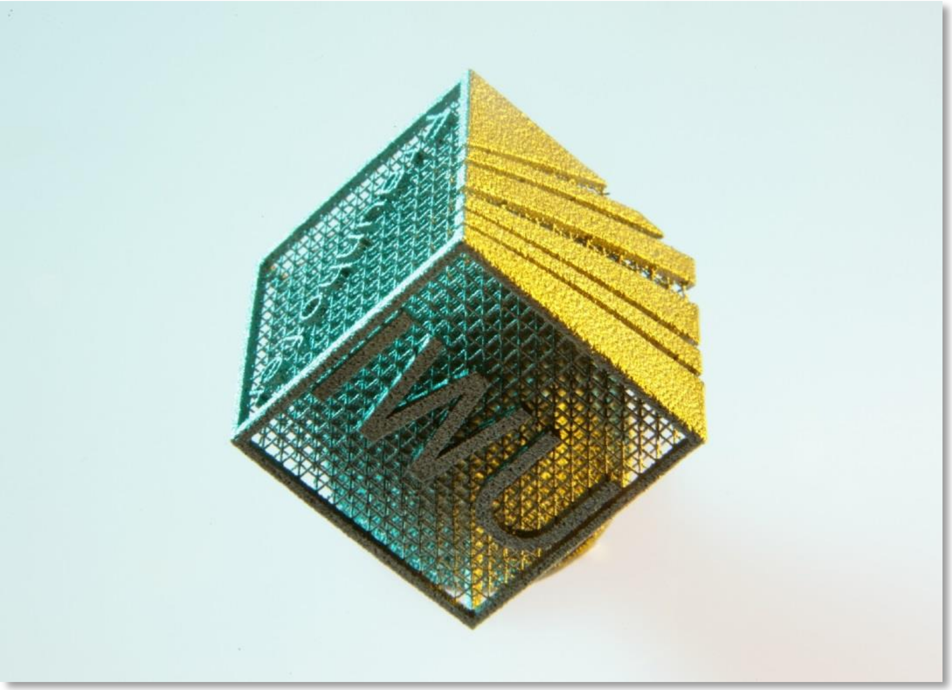
Industrial Application Potentials



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Industrial Application Potentials of Additive Manufacturing

- **Lightweight Design**
  - → omit all volume/mass without function (biomimicry, topology optimisation)
  - → miniaturisation/downsizing
  - → lattice structures
- **Freedom of design**
  - → design to function
  - → manufacturing the impossible
  - → individualisation/flexibilisation
- **Functionalisation**
  - → geometrical
  - → in terms of material
  - → integrative

Added value in product or equipment

- → enhanced efficiency
- → conserved ressources
- → increased performance
- → completely new product features

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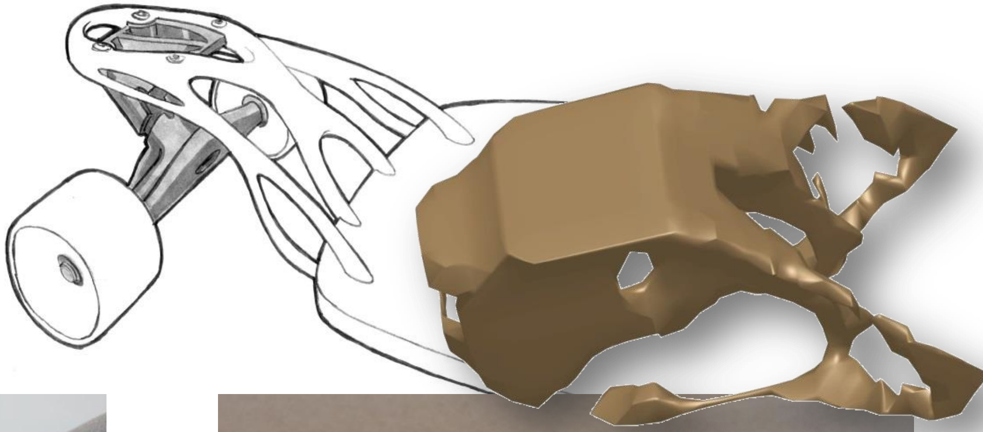
Industrial Application Potentials of Additive Manufacturing

Lightweight Design through Topology Optimisation

- ✓ improved functionality
- ✓ optimised stress distribution
- ✓ weight reduction (up to 30 %)
- ✓ ressource efficiency



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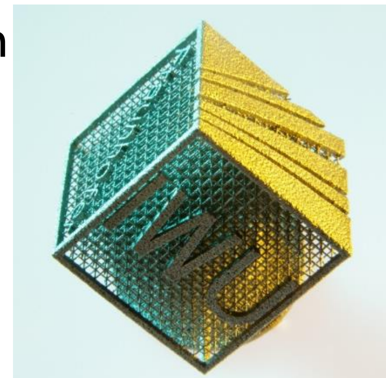
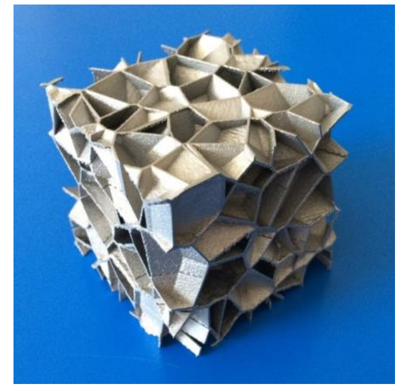
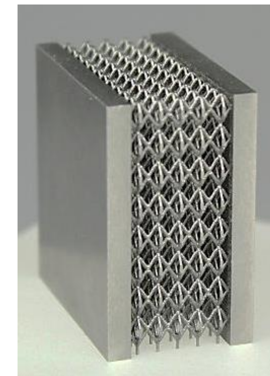
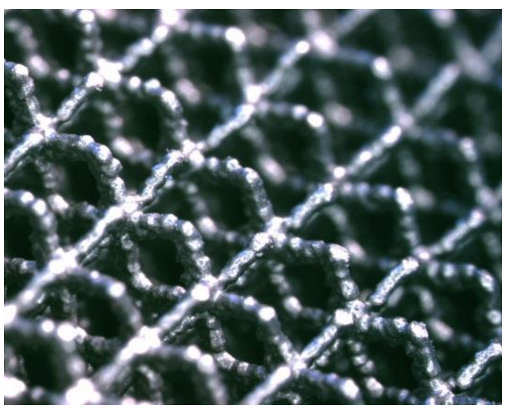
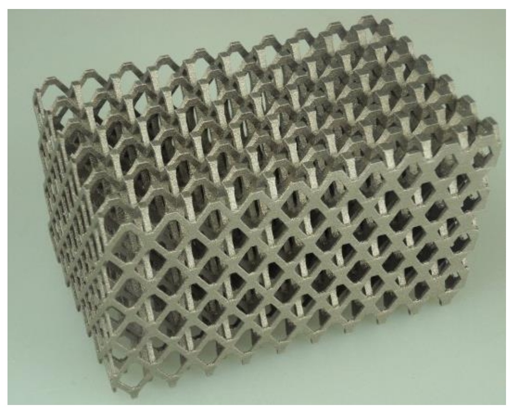
Industrial Application Potentials of Additive Manufacturing
Lightweight Design through Lattice Structures

Lattice structure integration in parts for specific properties

- ✓ extreme weight reduction
- ✓ graded structures
- ✓ locally varying properties
- ✓ "fit to function"



Need for research:

- ✓ material behaviour
- ✓ mechanical properties
- ✓ stiffness and absorptivity

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Industrial Application Potentials of Additive Manufacturing
Functionalisation

- **geometrical**
  - → functional channels and cavities
    - → temperature management (e.g. conformal cooling)
    - → heat exchangers & coolers
    - → media supply & disposal, e.g. (compressed) air, fluids, drugs, …
- **in terms of material**
  - → high performance materials (e.g. Scalmalloy®, high strength steels, …)
  - → functional materials (smart materials, magnetic materials)
  - → multi-material parts (metal-metal, metal-ceramics, …)
  - → adaptronic parts and products
  - → complex assemblies & products „from one print job“
- **integrative**
  - → integration of functional elements & parts
  - → sensors and actuators
  - → electrical/electronic function

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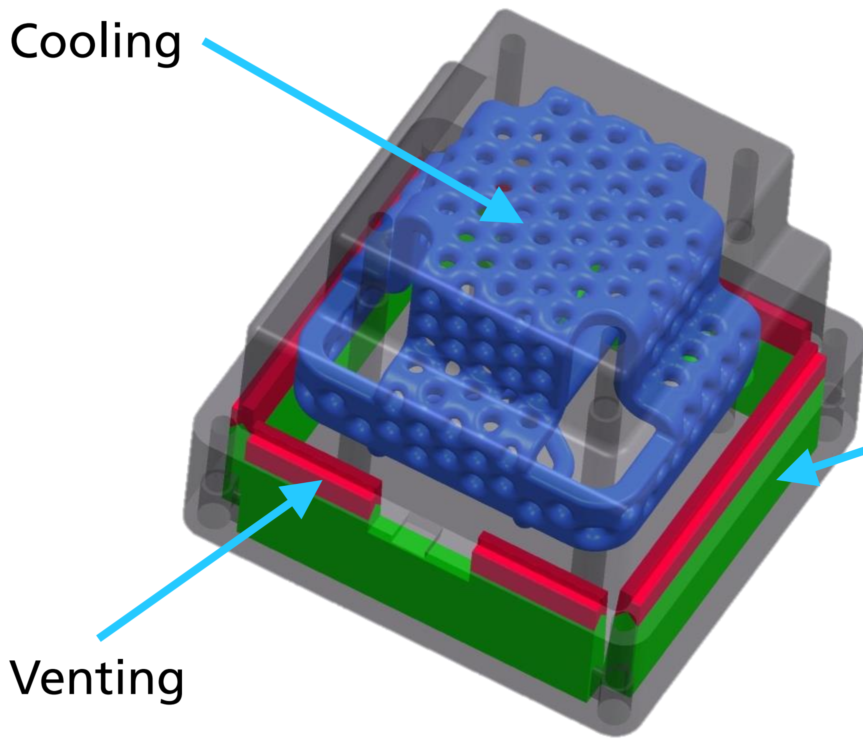
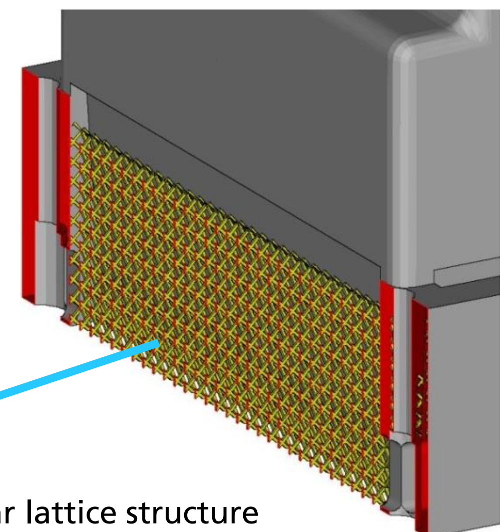
Industrial Application Potentials of Additive Manufacturing
Geometrical Functionalisation: Cooling/Venting

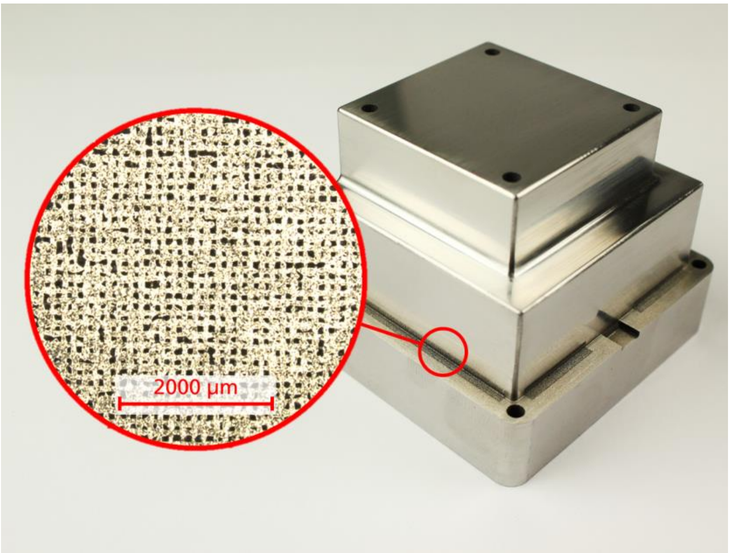
Tooling insert with innovative surface cooling and porous venting structures in **integral design**



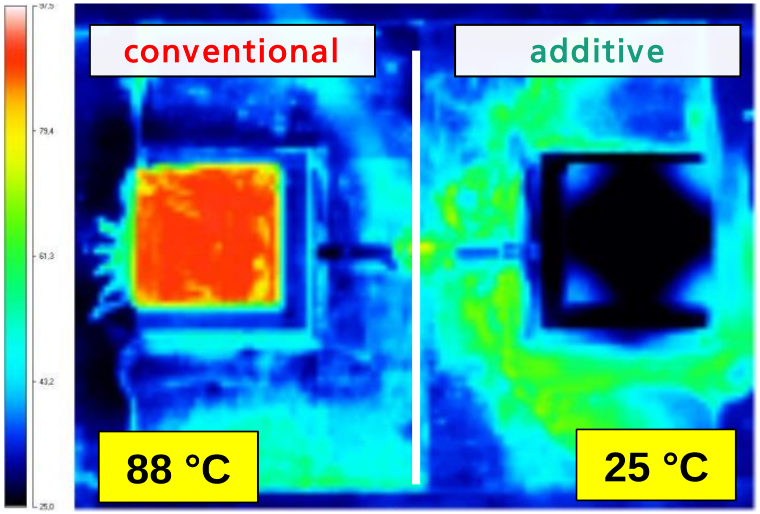


cellular lattice structure
as stiff and stable backing

Industrial Application Potentials of Additive Manufacturing
Geometrical Functionalisation: Cooling/Venting



Additively manufactured tooling insert (demonstrator tooling) with porous venting structure and surface cooling



Thermographic image of pre-heated tool (90 °C) 5 s after switching in the cooling (15 °C) – conventional tooling insert (left), additively manufactured tooling insert (right)

- Reduction of cooling time (holding time) by **33,3%** (from 18 to 12 s)
- Reduction of cycle time by **19,4%** (from 31.4 to 25.3 s)
- Reduced injection time and specific injection pressure by approx. **5 %**

Europäische Union Europa fördert Sachsen. EFRE Europäischer Fonds für regionale Entwicklung

KMS

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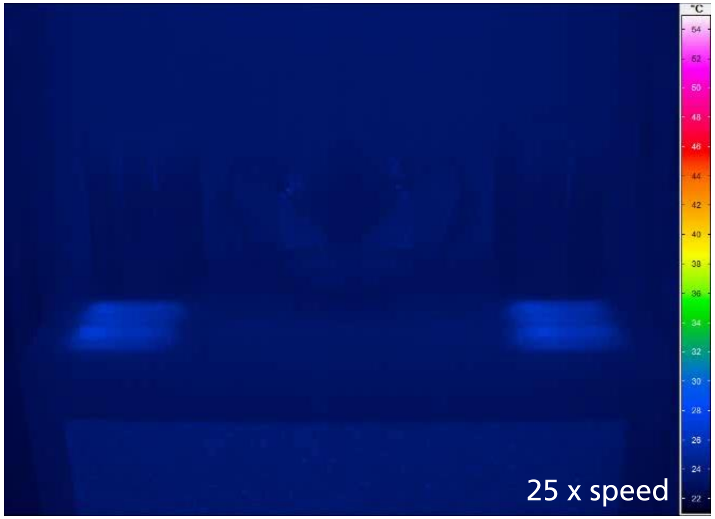
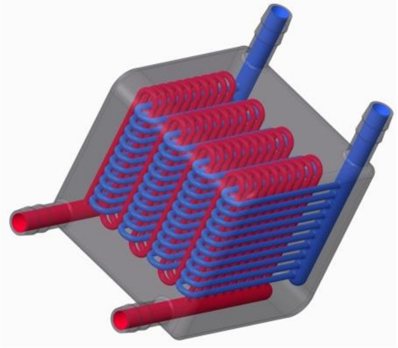
Industrial Application Potentials of Additive Manufacturing

Geometrical Functionalisation: Heat exchangers

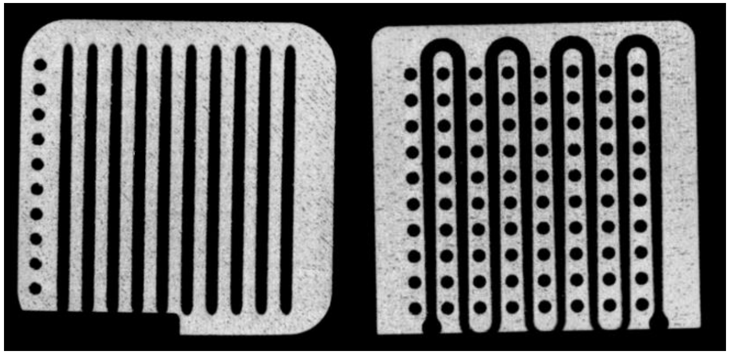
- Development of components and assemblies for thermal management, e.g. power electronics (e-mobility)
- Development of complex components for process engineering





3D CAD model of innovative AM heat exchanger

Additively manufactured innovative heat exchanger



Evaluation / inspection by µCT scan

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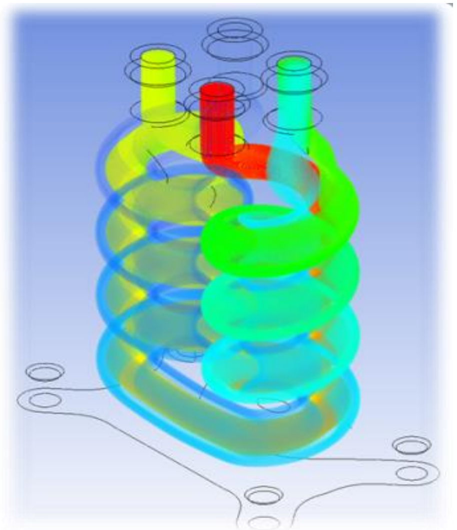
Industrial Application Potentials of Additive Manufacturing

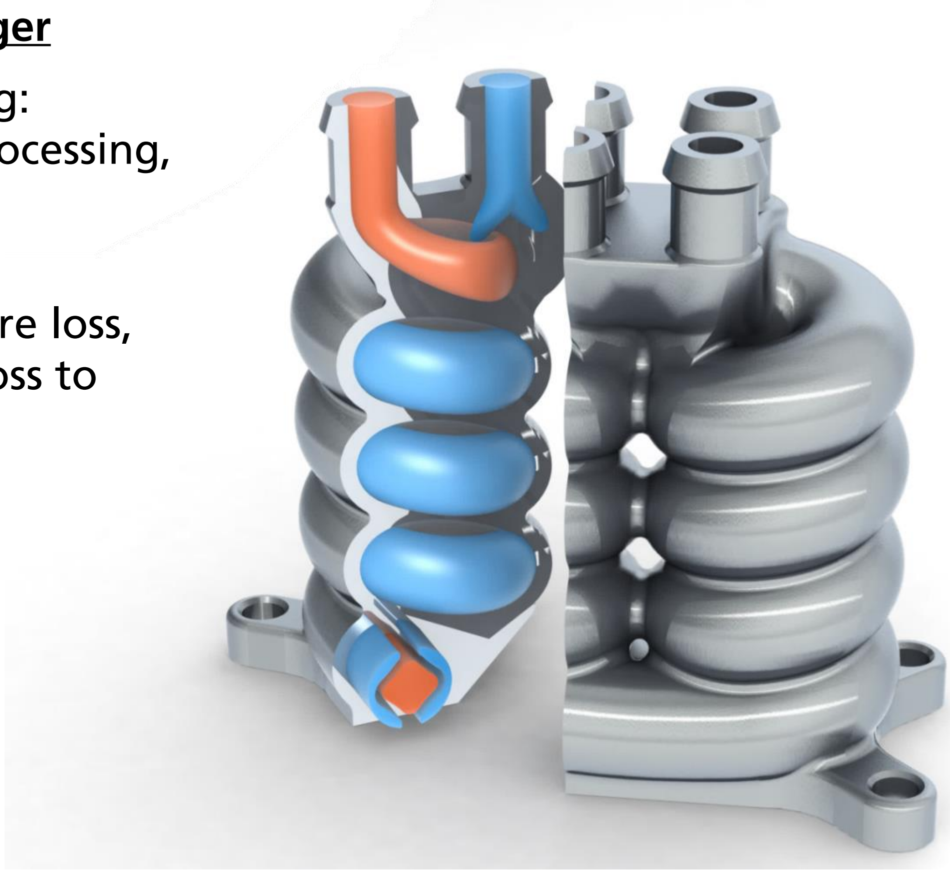
Geometrical Functionalisation: Heat exchangers

<u>Structurally optimized heat exchanger</u>

- Designed for Laser Beam Melting:
  no support structure, no post-processing, flexible design
- Special design features:
  max compact design, low pressure loss, optimal heat transfer, no heat loss to environment



CFD simulation of channels



Design by Kilian Boell

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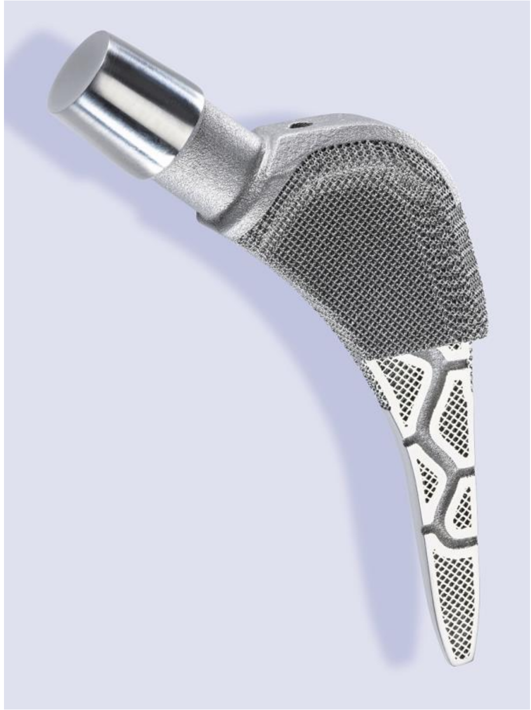
Industrial Application Potentials of Additive Manufacturing
Geometrical Functionalisation: Drug depot

<u>MUGETO® implant with functional channels and cavities</u>

- ✓ Drug depot within the implant for post-surgery treatment

CAD model

Laser beam melted implants on build platform



Finish-machined implant

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Industrial Application Potentials of Additive Manufacturing

Range of materials (Laser Beam Melting)

Material	Condition	Tensile strength R_m [MPa]	Yield strength $R_{p0,2}$ [MPa]	Elonga-tion A [%]	Hardness	Modulus of elasticity [GPa]
Tool steel [1] 1.2709 X3NiCoMoTi 18 9 5	heat treated (490 °C)	2,040 - 2,180	1,870 - 1,940	3 - 5	54 - 56 [HRC]	
Tool steel (stainless) Corrax®	heat treated (525 °C)	1,700	1,600	> 2	48 - 50 [HRC]	
stainless steel 1.4404 X2CrNiMo 17-12-2	as build	640	500	> 15	20 [HRC]	
Titanium [4] 3.7165 TiAl6V4	heat treated	950 - 1,250	800 - 1,100	10 - 20	32 - 36 [HRC]	
Aluminium [2] 3.2381 AlSi10Mg	as build annealed T6 heat treated	353 - 482 221 - 260 281 - 320	210 - 295 126 - 160 222 - 262	2 - 7 10 - 18 5 - 10	95 - 119 [HB] 63 - 74 [HB] 85 - 101 [HB]	67 - 78 57 - 73 69 - 80
Inconel 718 [3] 2.4668 NiCr19NbMo	as build annealed T6 heat treated	929 - 1,308 896 - 1,080 1,334 - 1,545	583 - 945 549 - 922 924 - 1,278	20.2 - 32.7 31.9 - 42.2 6.6 - 19.4	280 - 395 [HV 10] 273 - 320 [HV 10] 453 - 485 [HV 10]	128 - 232 142 - 257 149 - 242

More available Materials : CoCr, 17-4 PH, AlSi12, Hastelloy X

Characteristic values acc. to:

[1] VDI 3405 sheet 2
[2] VDI 3405 sheet 2.1
[3] VDI 3405 sheet 2.2
[4] VDI 3405 sheet 2.4 in prep.

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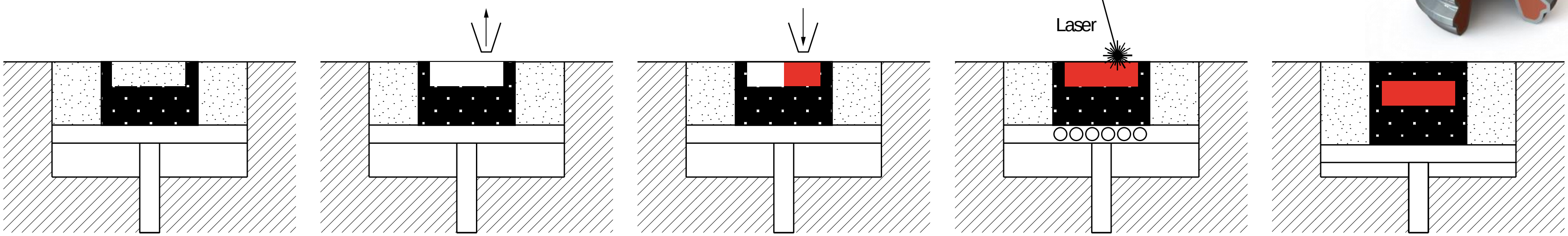
Industrial Application Potentials of Additive Manufacturing

Functionalisation in terms of material: Multi-material

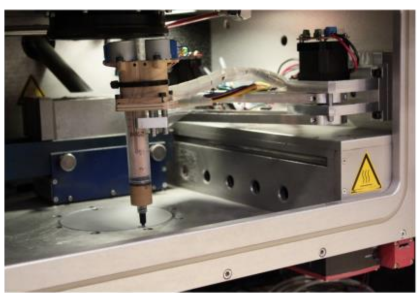
Combination of Laser Beam Melting with Dispensing of Paste



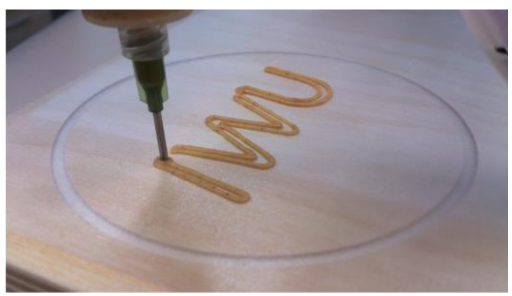
producing a cavity in LBM process | removing powder in the cavity | Inserting pasty secondary component with dispenser | thermal curing of the paste | proceeding the LBM process

layer thickness of copper paste
Top: 0.25 mm, Bottom: 0.75 mm

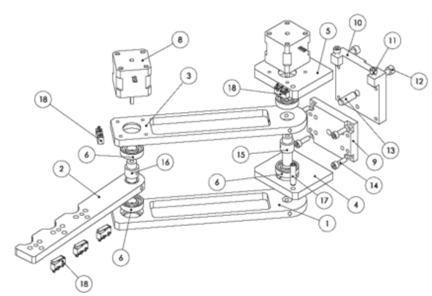
- utilisation of industrial screen printing pastes
- equipment set-up at IWU (integration in Realizer SLM 100)



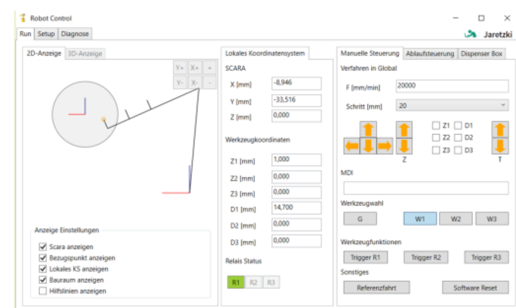
Realizer SLM 100 – process chamber with first dispenser system prototype



successful printing test, considering the visco-elastic behavior of paste



robot arm – exploded view drawing



custom control software

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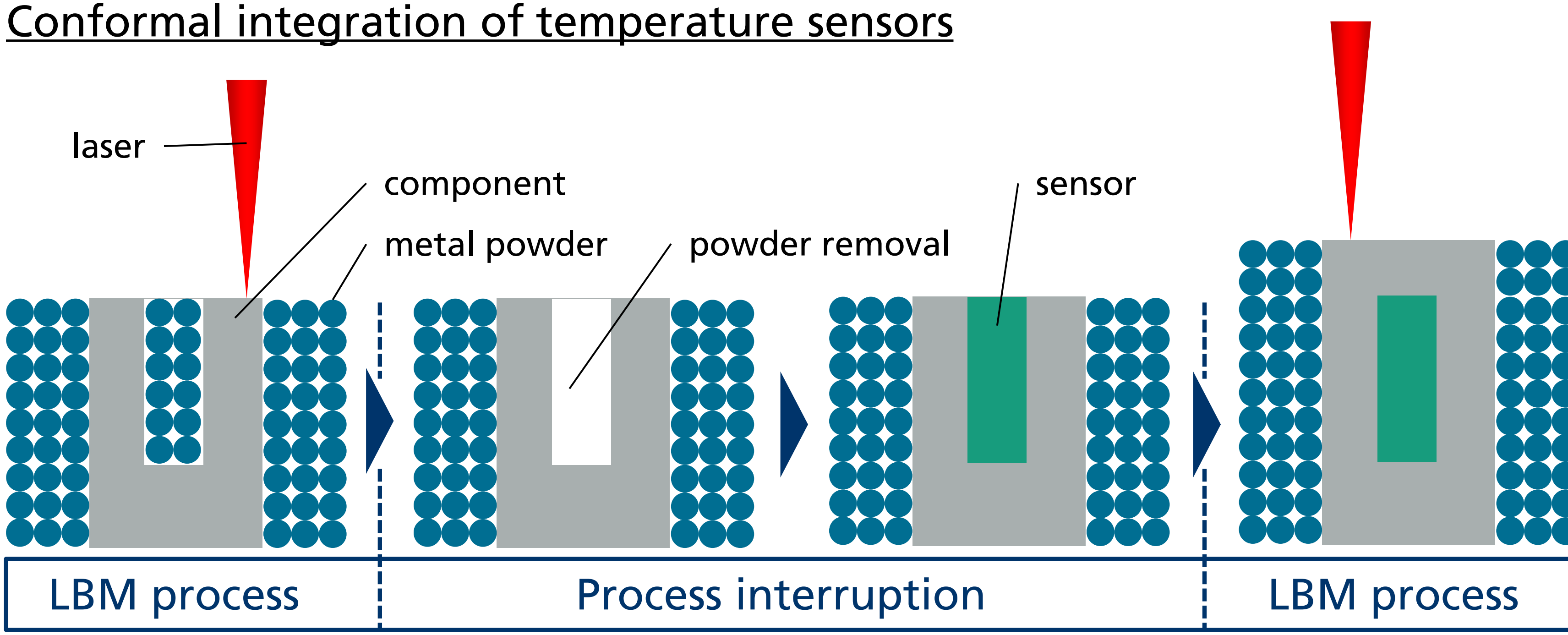
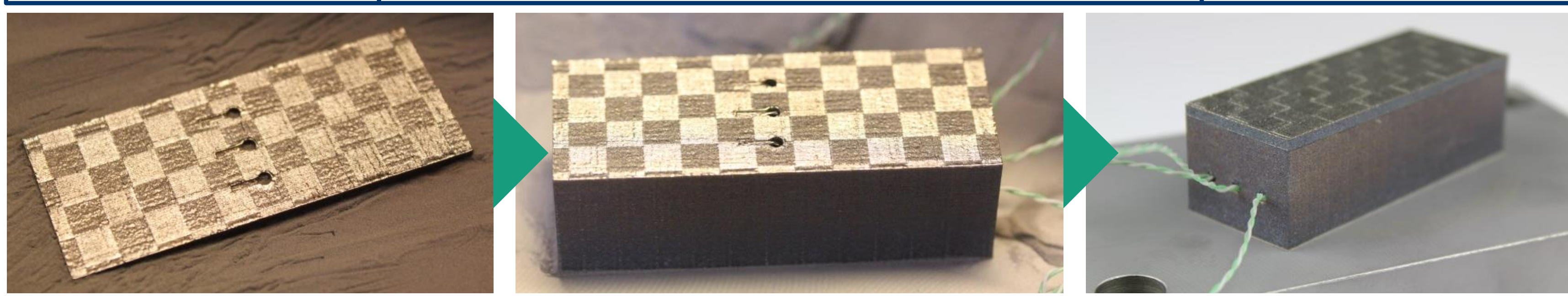
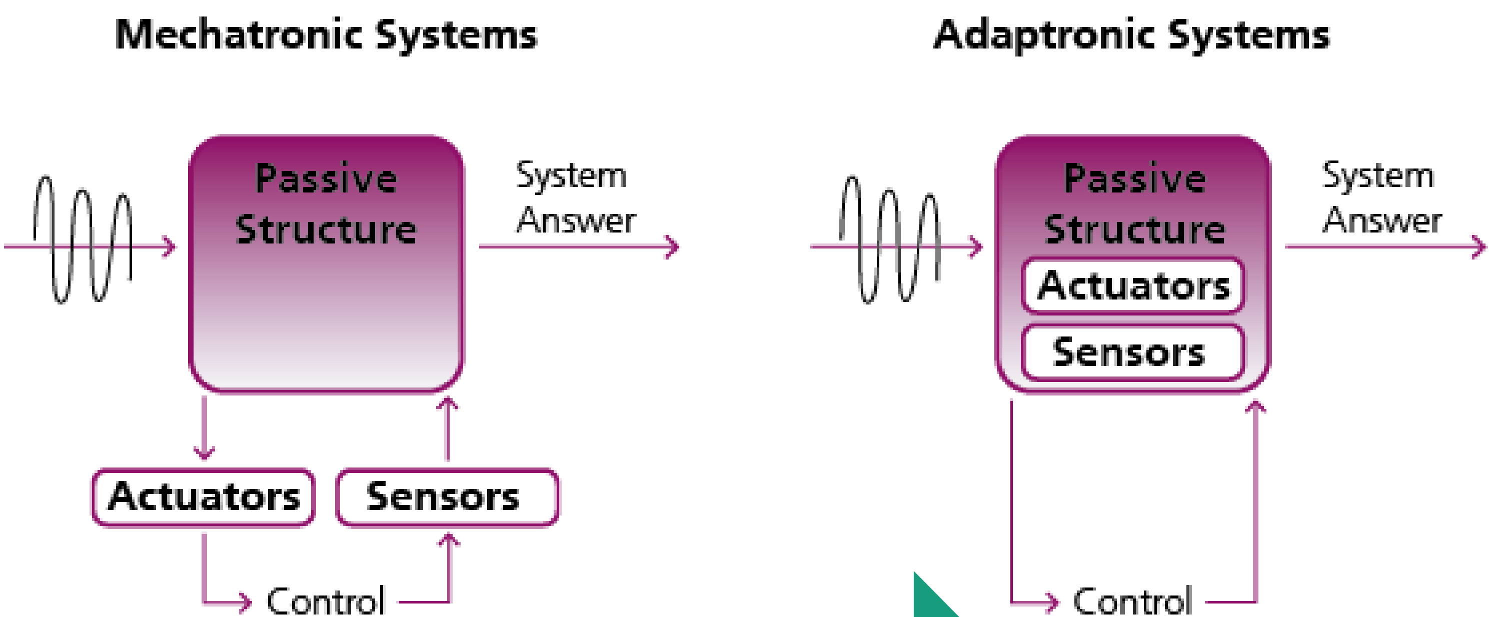
Industrial Application Potentials of Additive Manufacturing
Integrative Functionalisation: Sensor/actuator integration

Conformal integration of temperature sensors





Industrial Application Potentials of Additive Manufacturing
Integrative Functionalisation: Sensor/actuator integration



Functional consolidation w/ Additive Manufacturing

- ✓ Increased sensitivity
- ✓ Compact design
- ✓ Autonomous control

= Intelligence in mechanical structures

W.-G. Drossel, H. Kunze, A. Bucht, L. Weisheit, and K. Pagel, “Smart³ - Smart Materials for Smart Applications,” Procedia CIRP, vol. 36, 2015, pp. 211-216.

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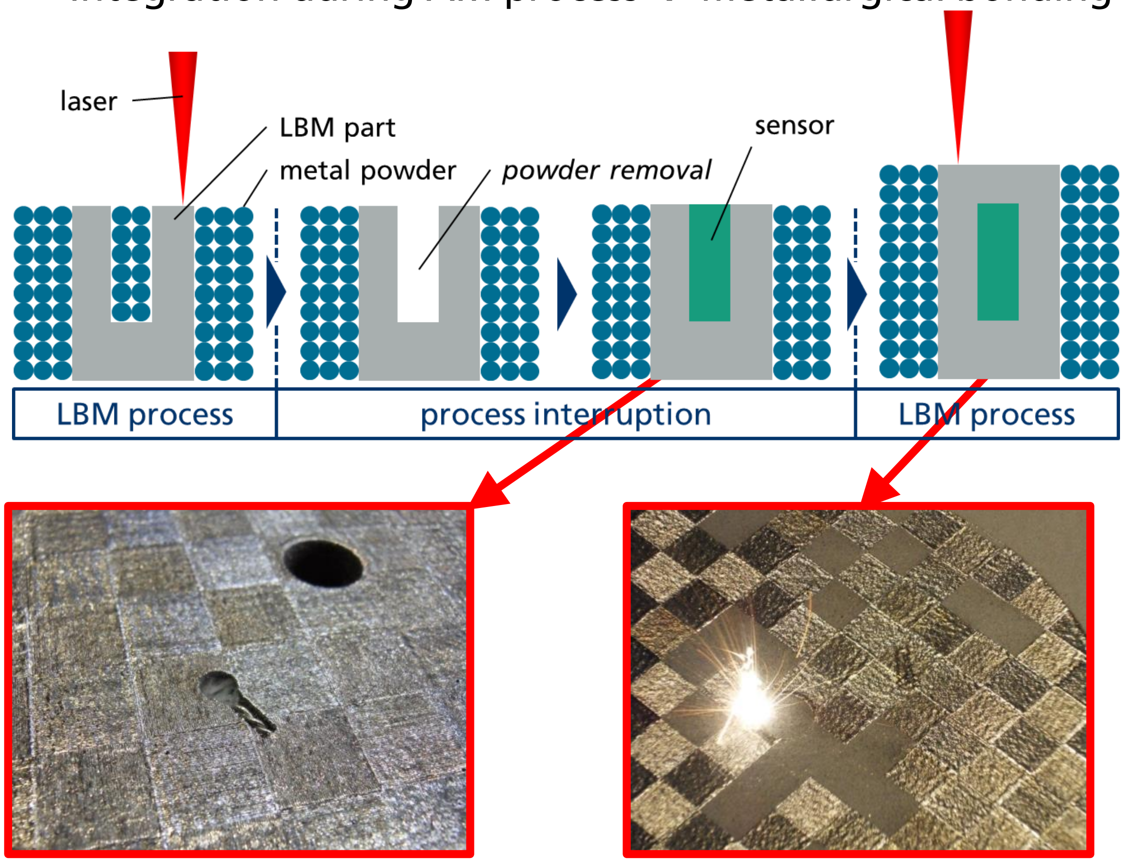
Industrial Application Potentials of Additive Manufacturing

Integrative Functionalisation: Sensor/actuator integration

Approach:

- Integration during AM process → metallurgical bonding for precise real-time measurement



HIPER FORM TOOL

manu net

guti Metallumformung AG

BRAUN CarTec

ringele

inspire irpd institute for rapid product development

Schweizerische Eidgenossenschaft
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Confederazione Svizzera
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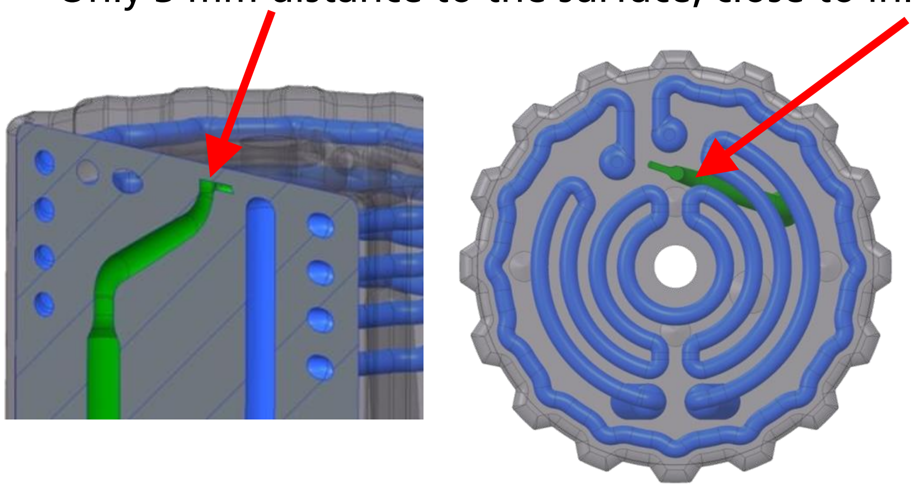
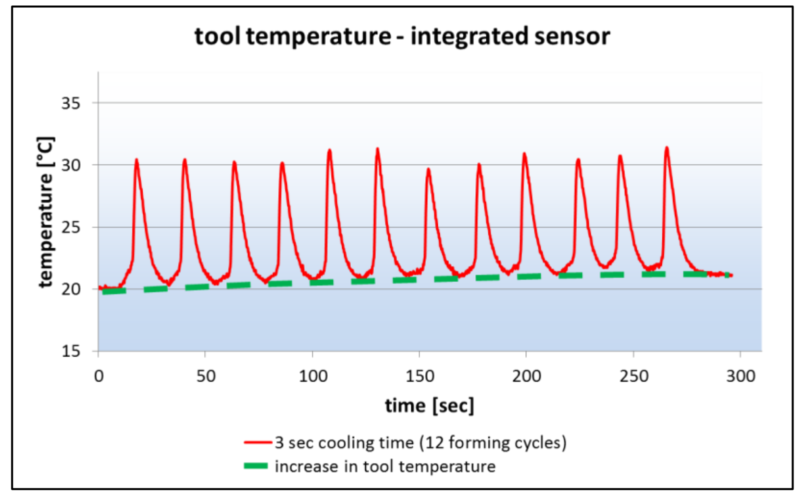
Industrial Application Potentials of Additive Manufacturing
Integrative Functionalisation: Sensor/actuator integration

<u>Approach:</u>

- Integration of a thermocouple into the punch
- Only 3 mm distance to the surface, close to inlet and oulet



Position of the thermocouple within the punch (CAD model)



Temperature profile over 12 forming cycles at 3 seconds holding/cooling time

<u>Results:</u>

- Successful integration of thermocouple in the die → proof of concept
- Significant reduction of cooling/holding time from 10 s to 3 s

Metallumformung AG

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Industrial Application Potentials of Additive Manufacturing
Integrative Functionalisation: Sensor/actuator integration

Implants with integrated shape memory actuators

- ✓ homogeneous and stable fixation of cement-less hip stems
- ✓ improvement of primary stability through optimal load distribution at the implantat-bone interface by means of shape memory actuators

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Status quo
in industrial application

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Status quo in industrial application of Additive Manufacturing
Medical technology: Implant manufacturing

Pioneer applications for series production

Acetabular cups
(source: Arcam AB)

- Manufactured by Electron Beam Melting in titanium
- Trabecular surface structures
- Numbers (as of 2011)
  - > 30,000 manufactured
  - > 10,000 implanted
- Cost benefits!
  - 16 cups (size 48) in 12 h
    → < 50 €/cup
    → conventional tantalum coating already 30 - 60 €/cup

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Status quo in industrial application of Additive Manufacturing
Dental technology: Mass customisation

Pioneer applications for series production

Dental crowns and bridges

- Manufactured by Laser Beam Melting in CoCr
- Numbers (as of 2012):
  - 40 EOS DMLS machines for dental production worldwide
- Cost benefits:
  - up to 450 crowns and bridges in 24 h

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Status quo in industrial application of Additive Manufacturing
Aerospace: Series production

Pioneer applications for series production

Fuel injection nozzle
(source: GE Aviation)

- Manufactured by Laser Beam Melting
- Part of the new GE LEAP jet engine
- 19 nozzles per engine
- By 2020 more than 100,000 parts
- Technical benefits!
  - 25 percent lighter
  - Once 18 parts → with AM one
  - 5 times more durable due to an improved cooling system

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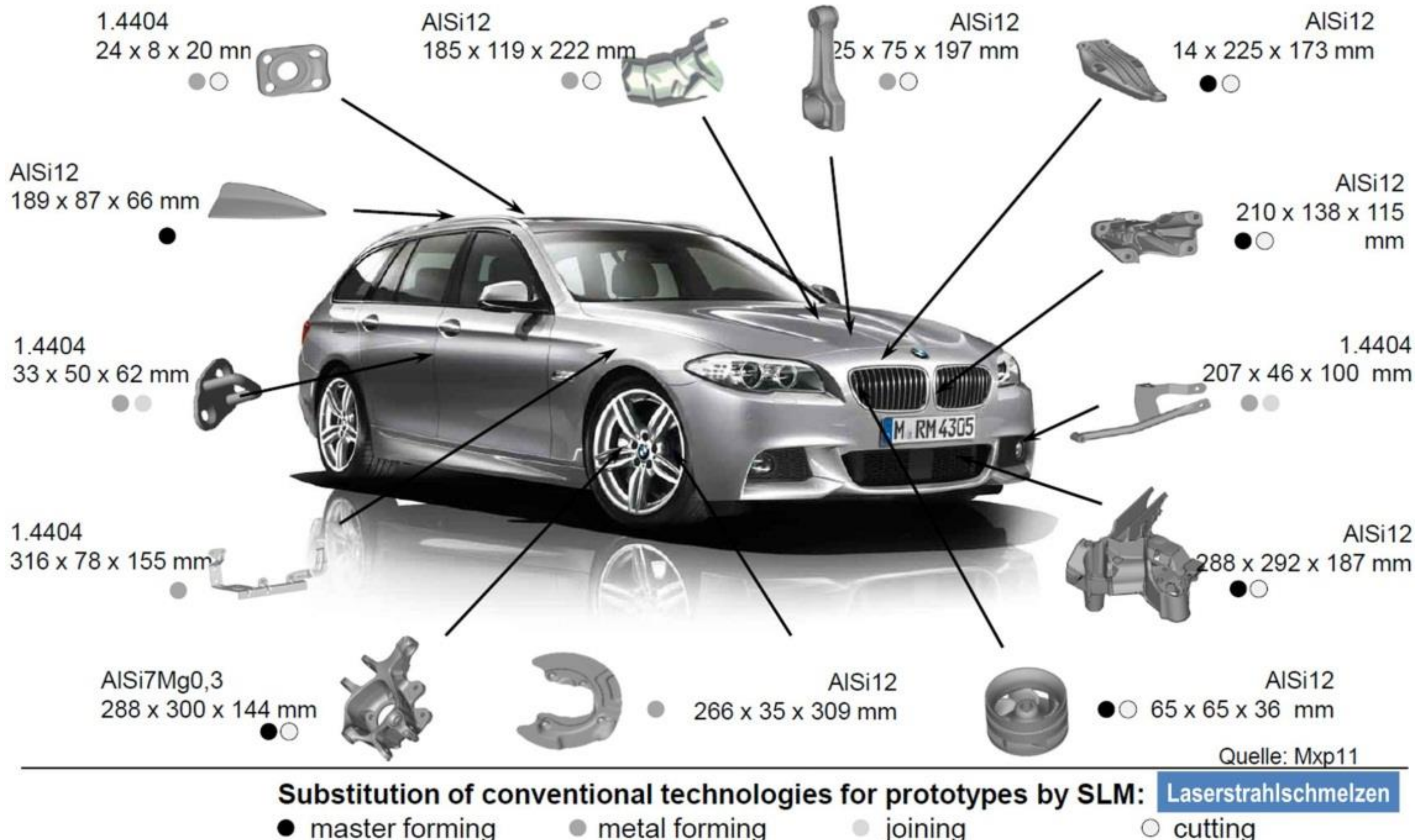
Status quo in industrial application of Additive Manufacturing
Automotive: Product development



(source: BMW AG)

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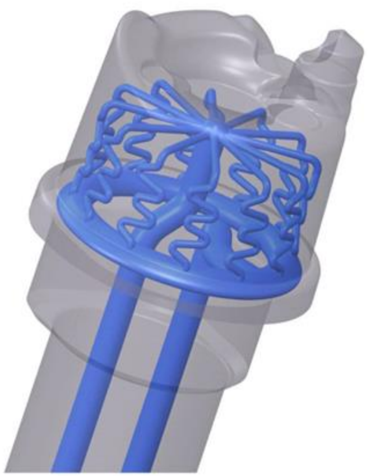
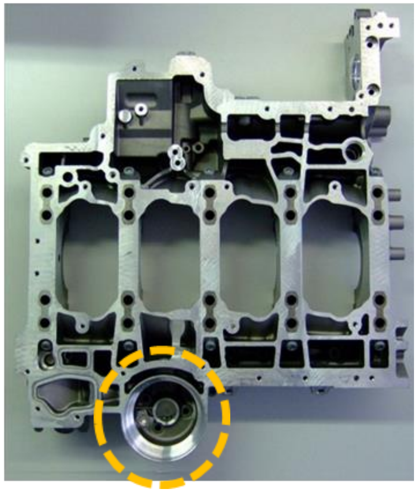
Status quo in industrial application of Additive Manufacturing
Tooling: High pressure die casting

Motivation:

- critical porosity at oil filter housing of a bed plate (V8 engine)




tooling insert with conformal coolng



Finished part

Solution:

- laser beam melted tooling insert with conformal cooling in hybrid design

Results:

- less hotspots → less porosity (- 50 %) → less scrap → less cost
- reduction of cycle time → higher productivity

DGH-GROUP | DGH HEIDENAU

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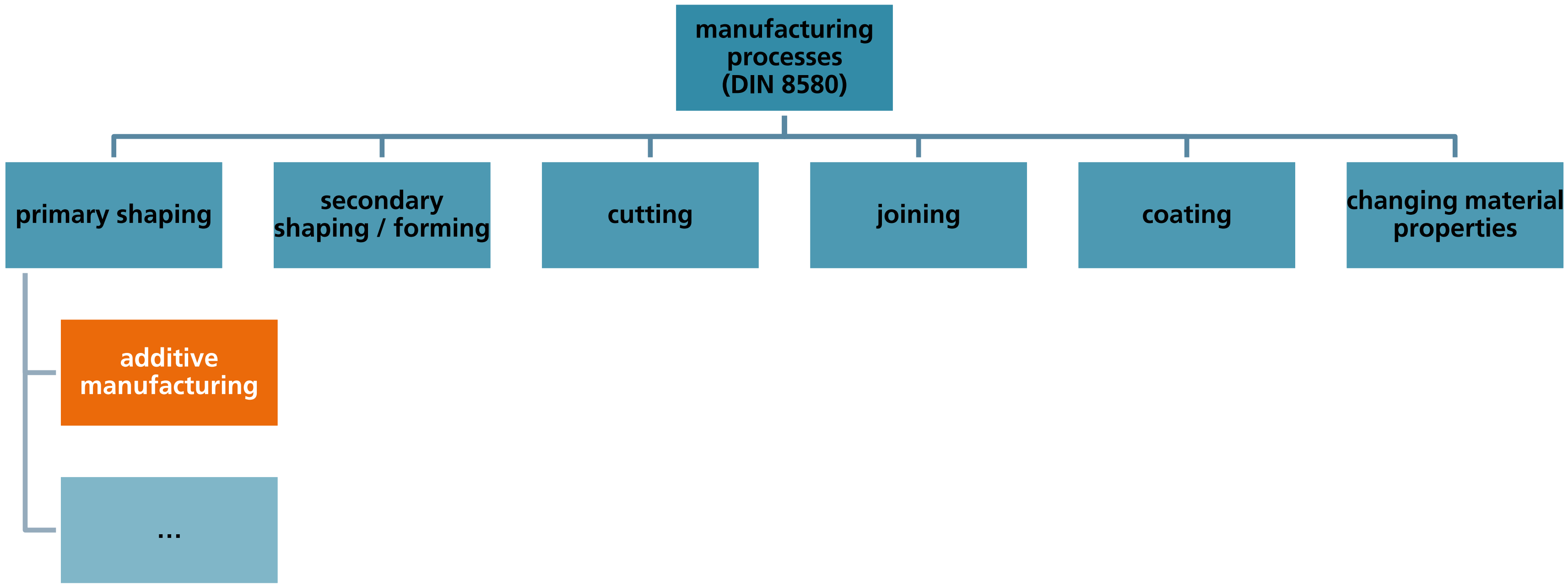
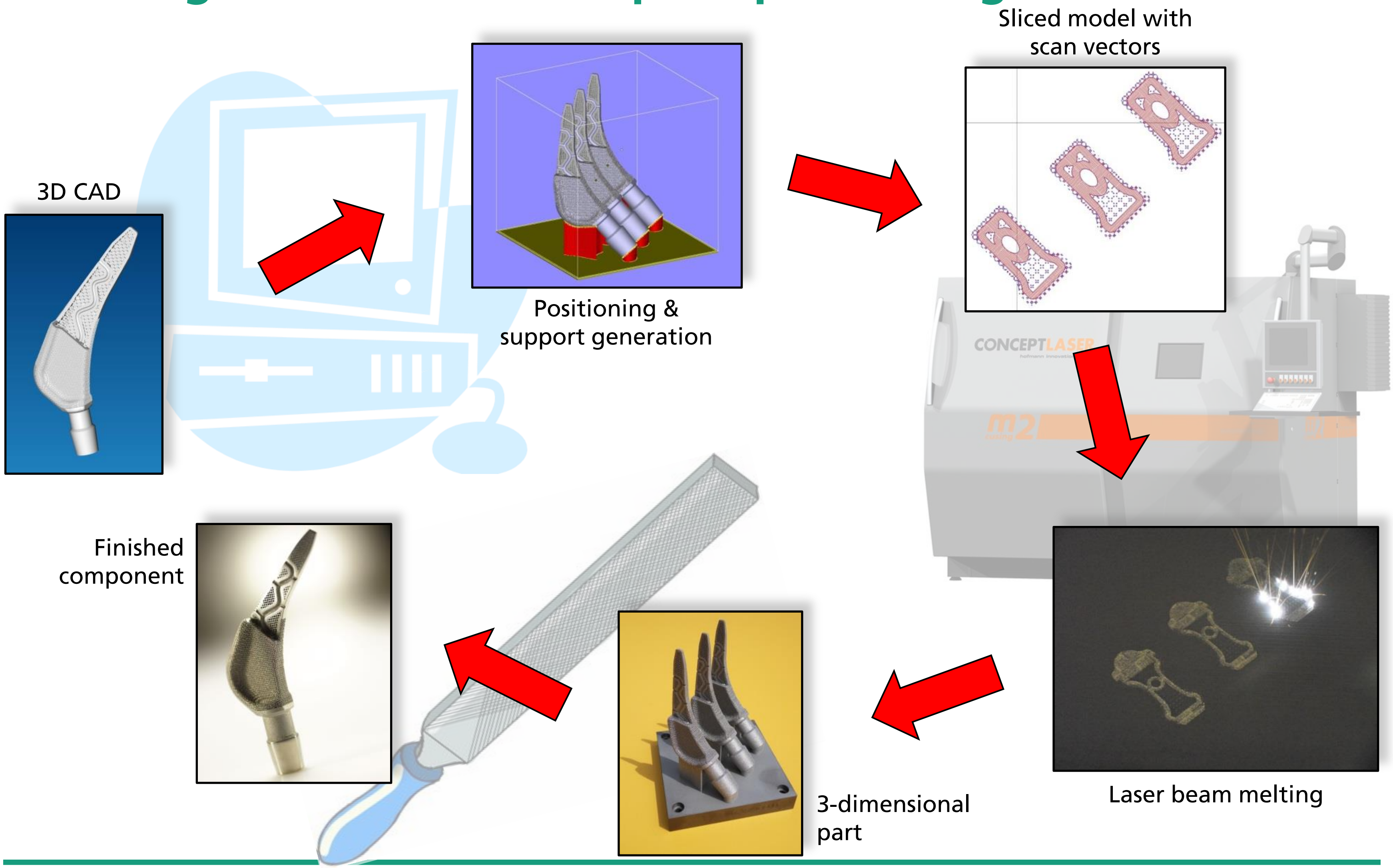
Challenges

Additive mass production
Challenges: classification/establishment

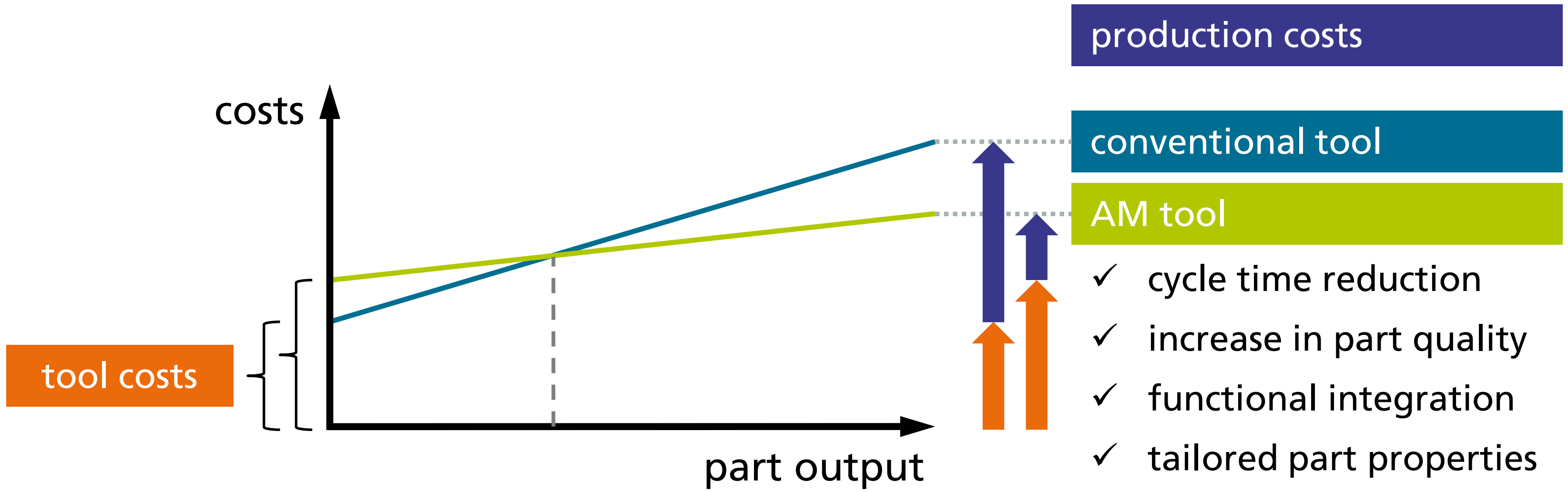


Additive mass production

Challenges: Process chain/post-processing



Additive mass production
Challenges: Cost/Economic viability



- ✓ cycle time reduction
- ✓ increase in part quality
- ✓ functional integration
- ✓ tailored part properties

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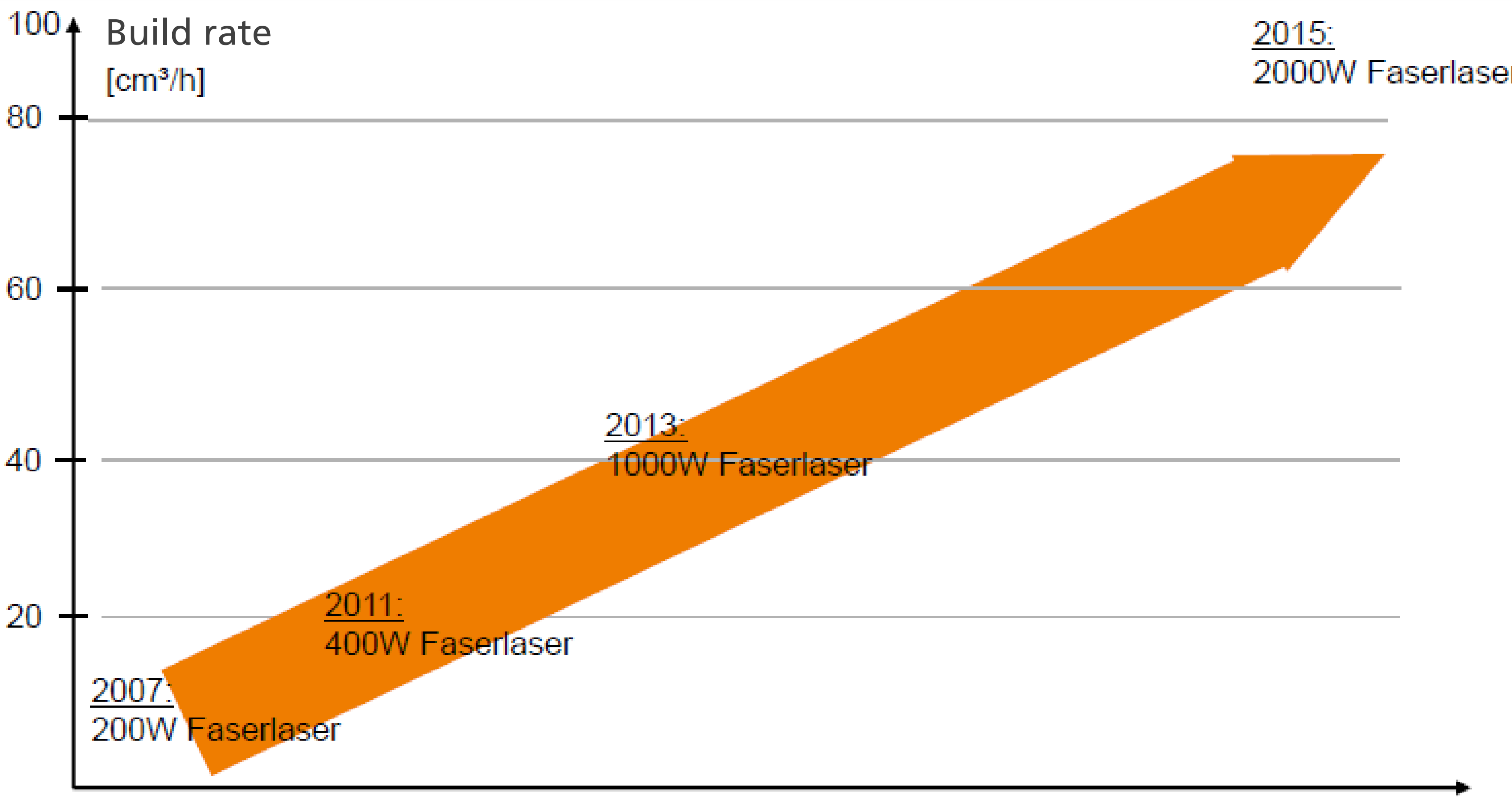
Additive mass production
Challenges: Productivity



(source: Concept Laser GmbH)

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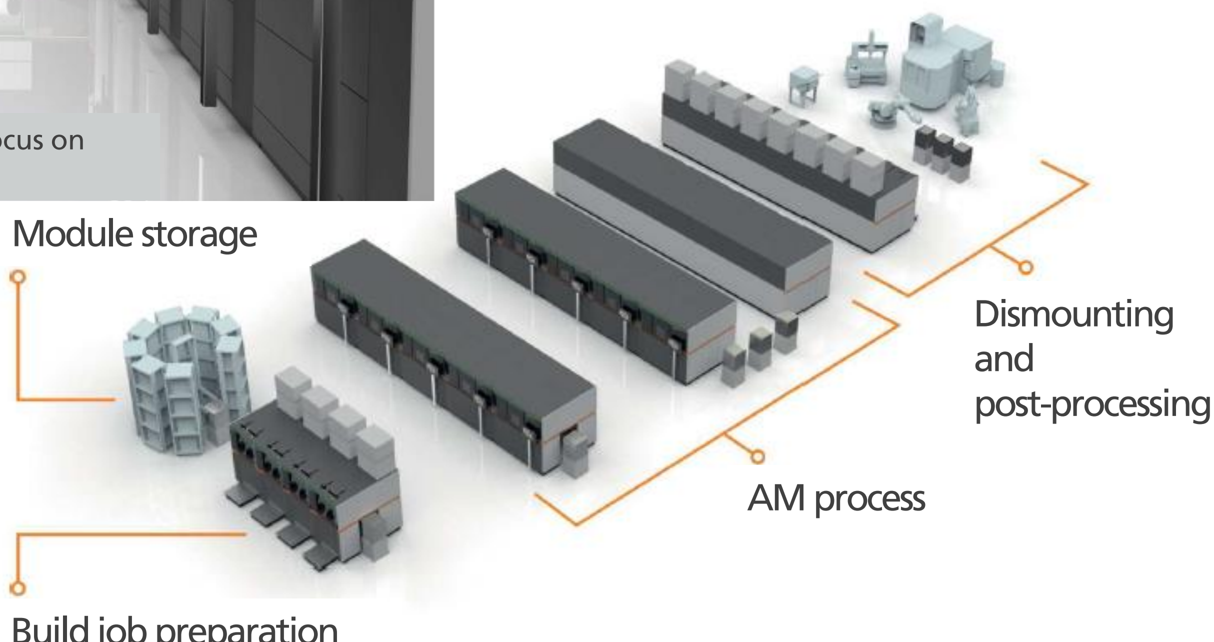
Additive mass production

Challenges: Equipment capable for mass production



(source: Concept Laser GmbH)

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Fraunhofer Direct Digital Manufacturing Conference DDMC
Berlin, March 14-15, 2018

DDMC2018
Fraunhofer Direct Digital Manufacturing Conference

Range of topics:

- Product Development
- Technologies
- Materials
- Quality

Save the date!

Next conference: **MARCH 14-15, 2018**

Call For Papers

Abstract Submission: **JUNE 30, 2017**

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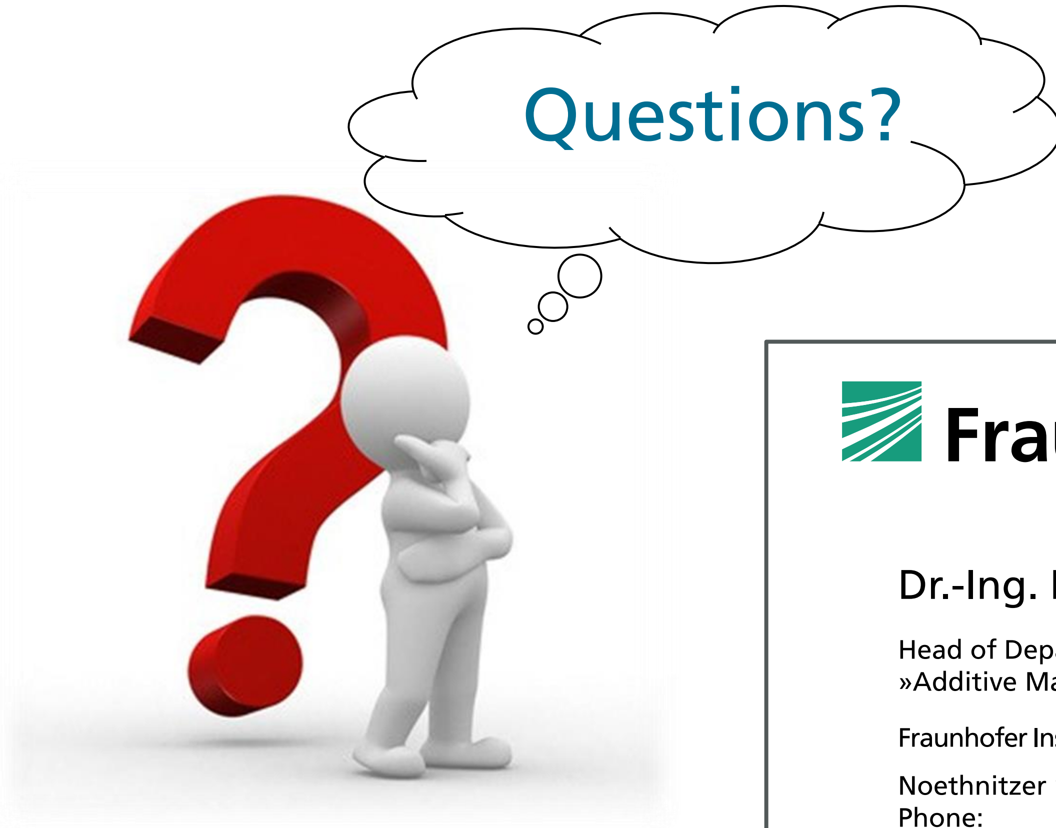

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