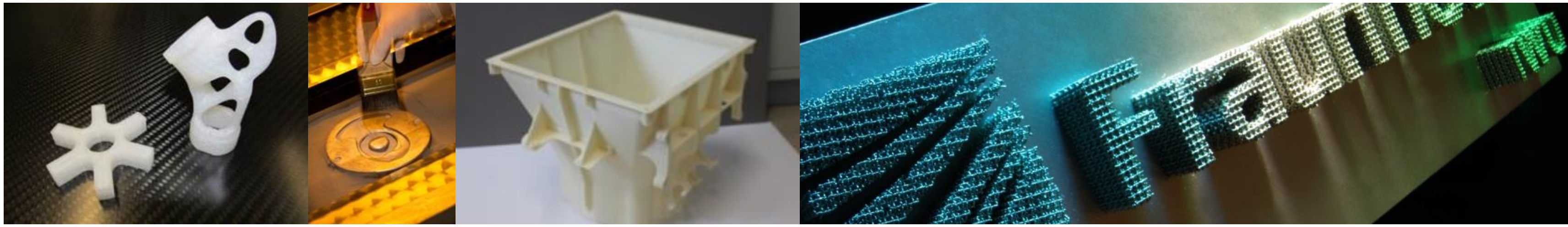
SMART PRODUCTION WITH ADDITIVE MANUFACTURING

Dr. Bernhard Mueller
Fraunhofer Institute for Machine Tools and Forming Technology IWU
Fraunhofer Additive Manufacturing Alliance

RPD2018 – Rapid Product Development Conference at MOULDSEVENT 2018, Marinha Grande (Portugal), October 1-2, 2018

Agenda



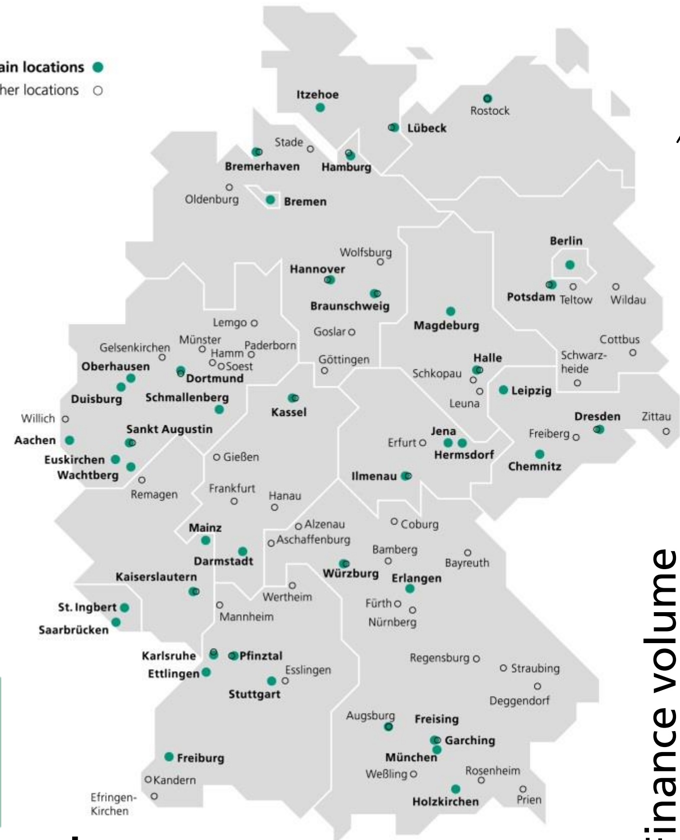
- Introduction to Fraunhofer, IWU and the AM Alliance
- Smart Production at Fraunhofer and at IWU
- Additive Manufacturing for Smart Production and vice versa
  - Digital AM factory
  - Sensor/actuator integration through AM
  - Process monitoring in AM
- Wrap-up

Fraunhofer IWU

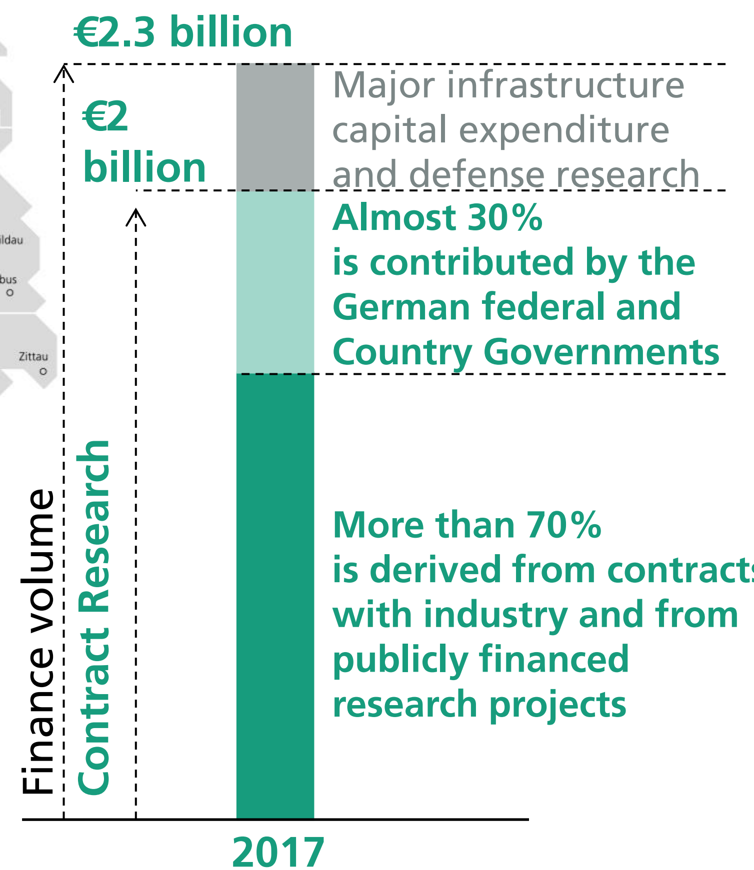
The Fraunhofer-Gesellschaft at a Glance

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

25,527 staff



72 institutes and research units



Fraunhofer IWU

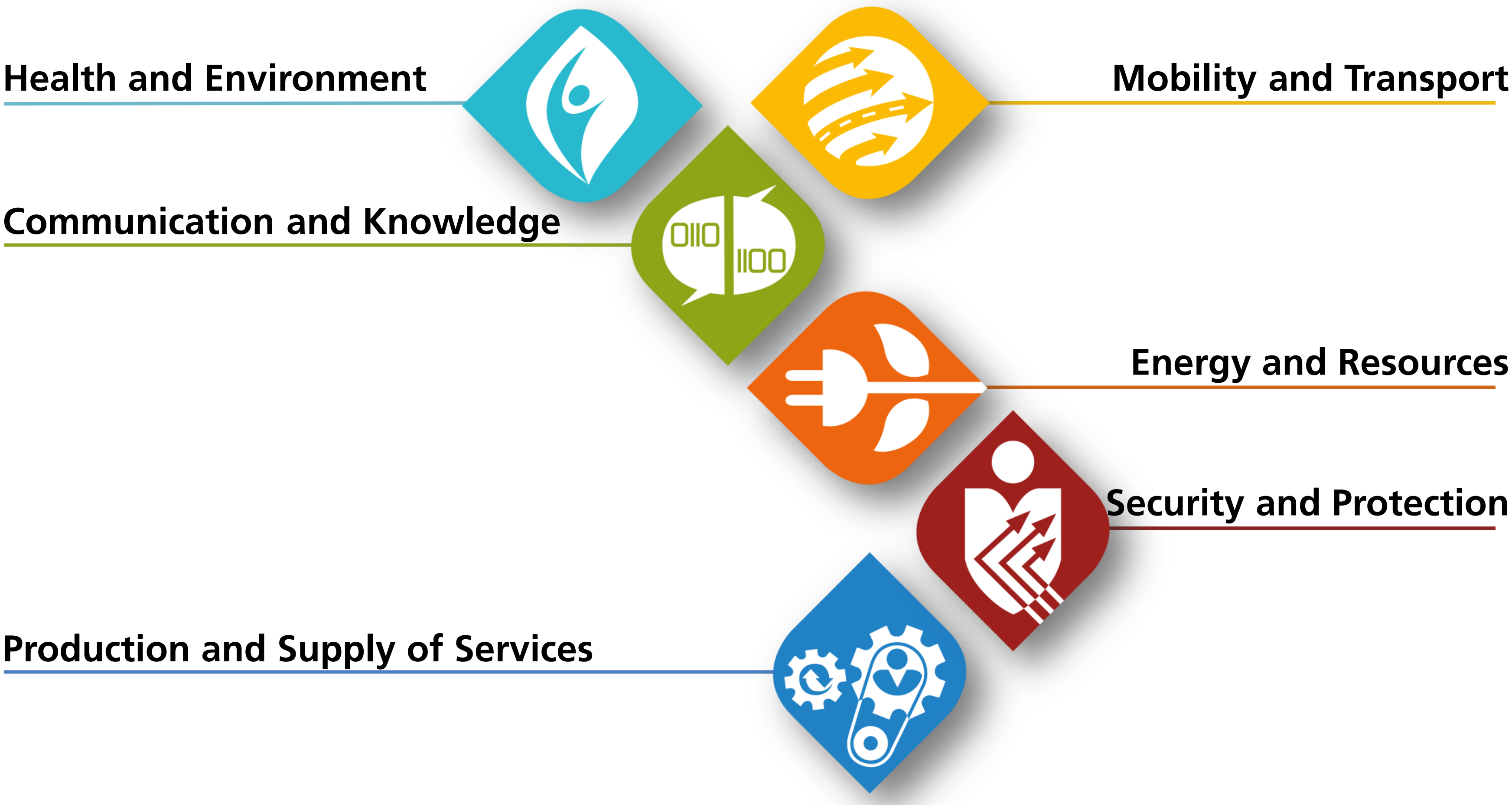
Joseph von Fraunhofer (1787 - 1826)

The Fraunhofer-Gesellschaft (since 1949)

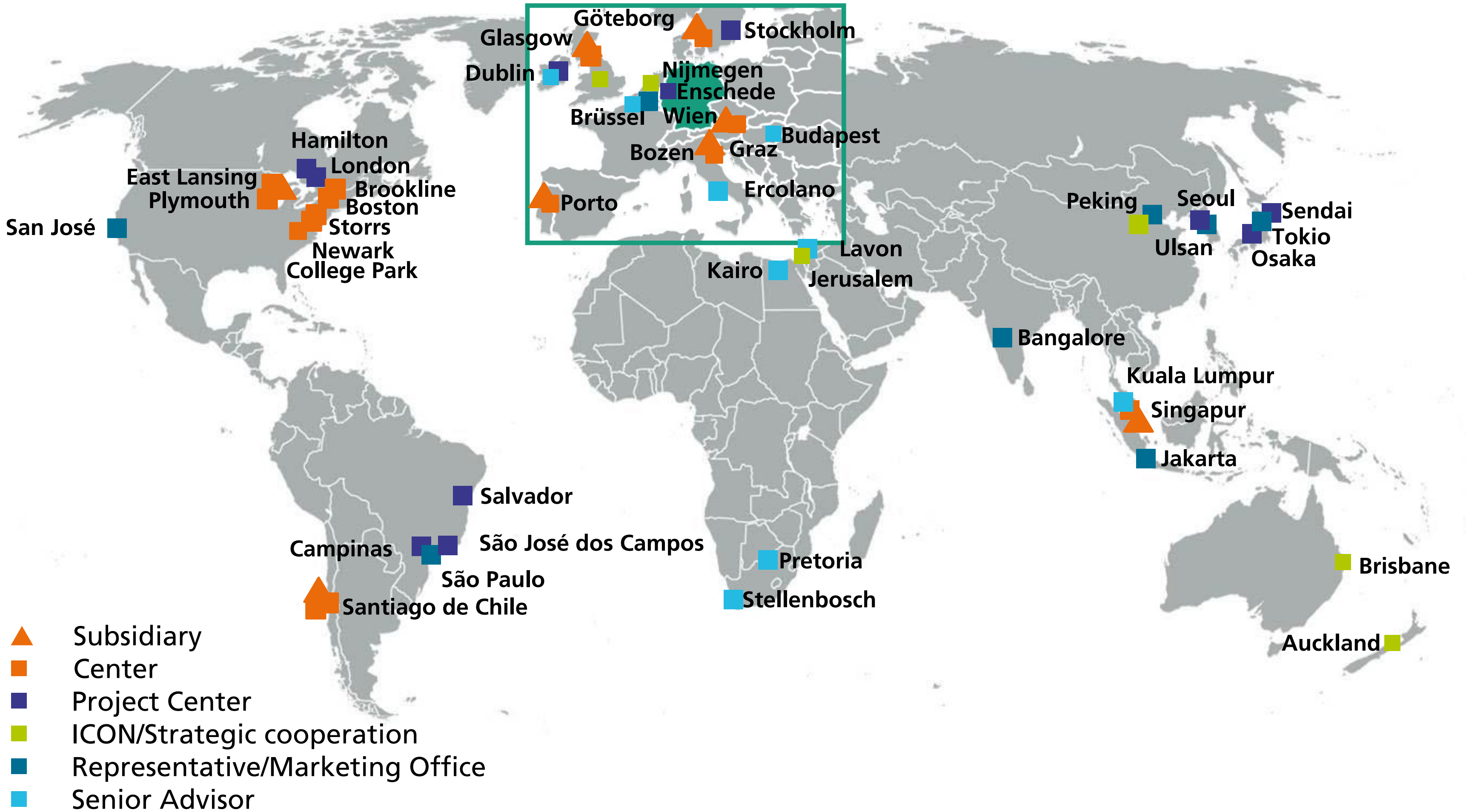
Joseph von Fraunhofer		The Fraunhofer-Gesellschaft
Discovery of the »Fraunhofer lines« in the solar spectrum	Researcher	Research and development on behalf of industry and state
New methods for processing lenses	Inventor	mp3 music format, white LED, high-resolution thermal camera
Director and partner in a glassworks	Entrepreneur	Research volume: approx. €2 billion annually

Fraunhofer IWU

Fraunhofer fields of research

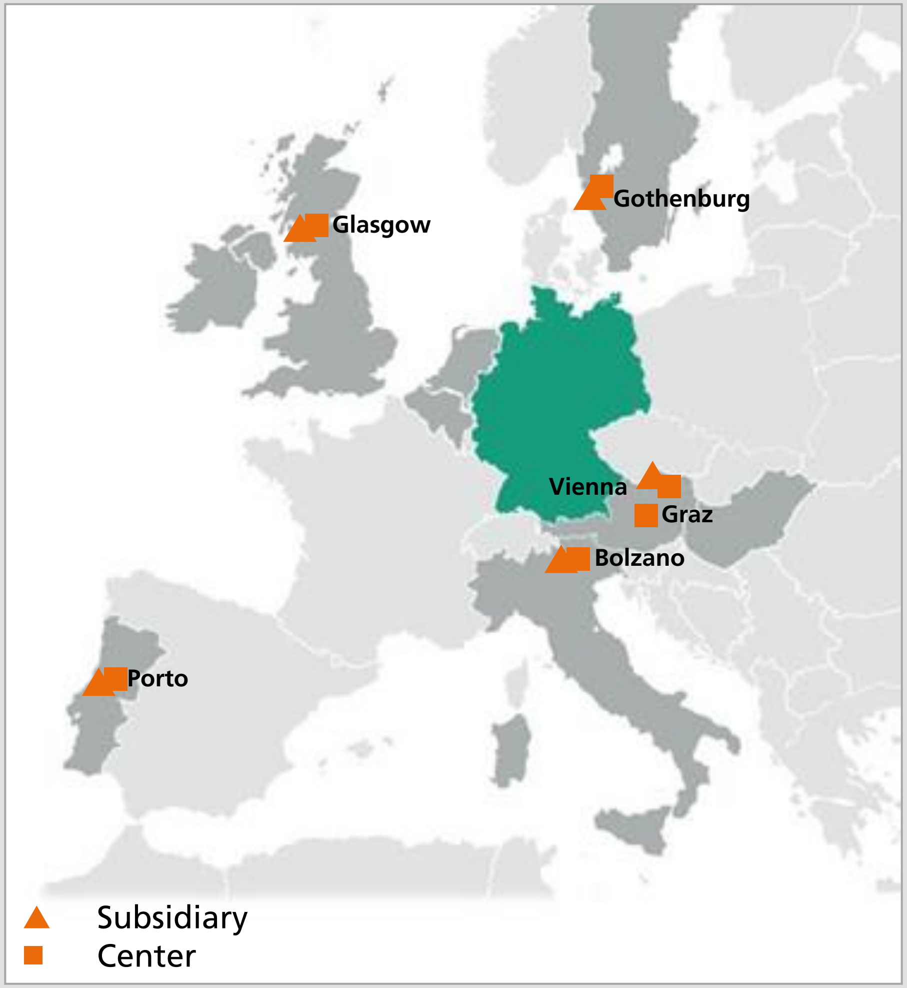


Fraunhofer-Gesellschaft
Worldwide



Fraunhofer IWU

Fraunhofer-Gesellschaft
Subsidiaries and Centers in Europe



Fraunhofer Austria Research
- Geschäftsbereich Produktions- und Logistikmanagement, Vienna
- Geschäftsbereich Visual Computing, Graz

Fraunhofer Italia Research
- Fraunhofer Innovation Engineering Center IEC, Bolzano

Fraunhofer Portugal Research
- Fraunhofer Center for Assistive Information and Communication Solutions AICOS, Porto

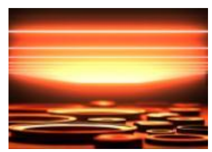
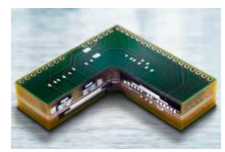
Fraunhofer Chalmers Centrum
- Fraunhofer Chalmers Research Center for Industrial Mathematics FCC, Gothenburg

Fraunhofer UK Research
- Fraunhofer Centre for Applied Photonics CAP, Glasgow

Fraunhofer IWU

Fraunhofer Groups
Pooling expertise




Institutes working in related subject areas cooperate in Fraunhofer Groups and foster a joint presence on the R&D market. They help to define the Fraunhofer-Gesellschaft's business policy and act to implement the organizational and funding principles of the Fraunhofer model.

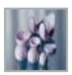
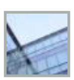
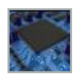
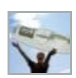
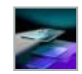
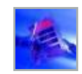
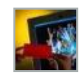
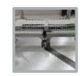
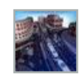
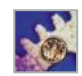
- Innovation Research
- Information and Communication Technology
- Life Sciences
- Light & Surfaces
- Microelectronics
- **Production**
- Defense and Security
- Materials and Components – MATERIALS

Fraunhofer IWU

Fraunhofer Alliances

Pooling expertise

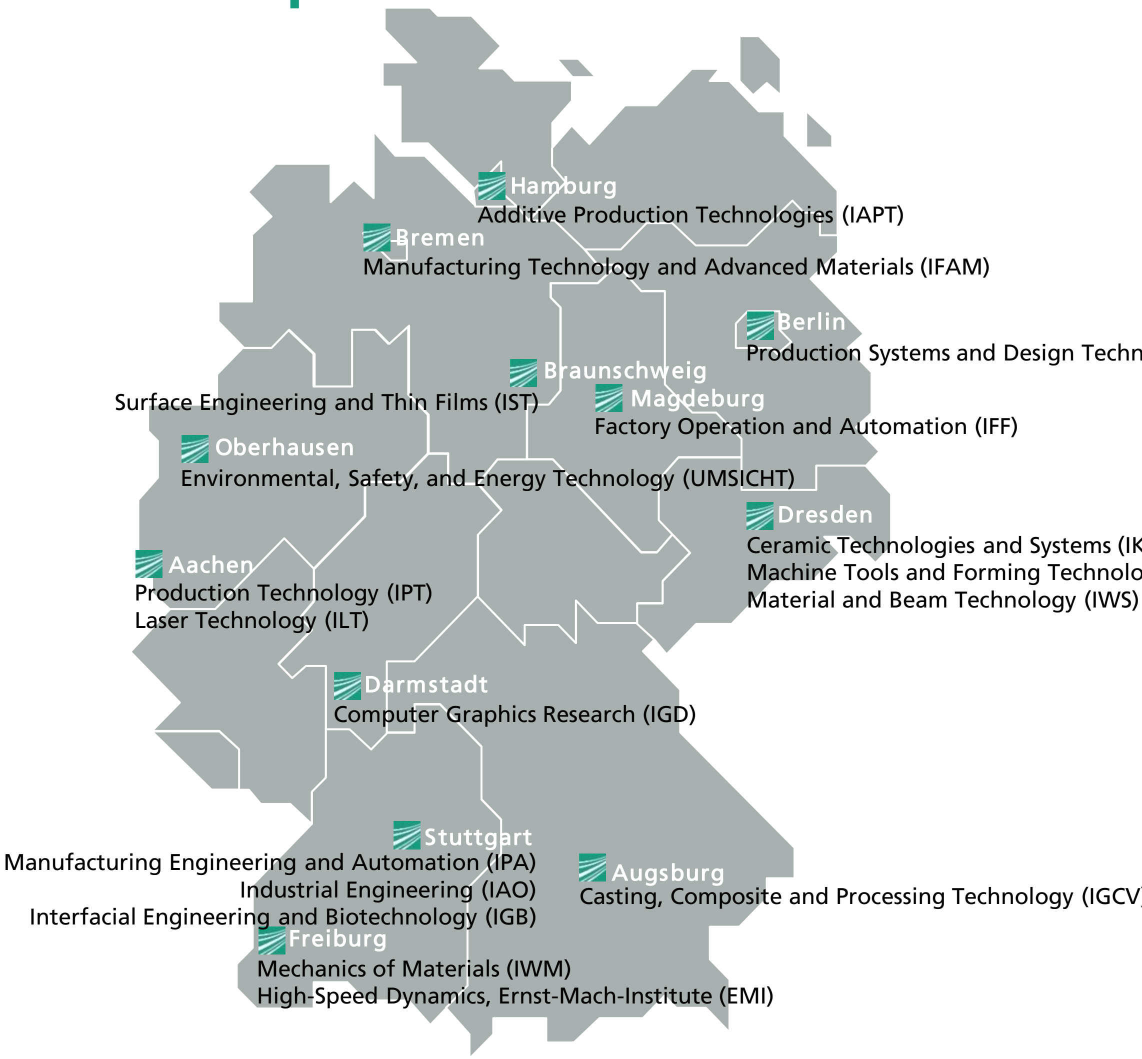
The Fraunhofer Alliances facilitate customer access to the services and research results of the Fraunhofer-Gesellschaft. Common points of contact for groups of institutes active in related fields provide expert advice on complex issues and coordinate the development of appropriate solutions.

 Adaptronics
 Additive Manufacturing
 AdvanCer
 Ambient Assisted Living
 AutoMOBILE Production
 Battery
 Big Data
 Building Innovation
 Cleaning Technology
 Cloud Computing
 Digital Media
 Embedded Systems
 Energy
 Food Chain Management
 Lightweight Structures
 Nanotechnology
 Photocatalysis
 Polymer Surfaces
 Simulation
 Space
 Technical Textiles
 Traffic and Transportation
 Vision
 Water Systems (SysWasser)

Fraunhofer IWU

Additive Manufacturing at Fraunhofer

One topic – 18 institutes – one alliance



Fraunhofer GENERATIV

Fraunhofer Additive Manufacturing Alliance

Spokesman: Dr. Bernhard Mueller

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

Fraunhofer GENERATIV

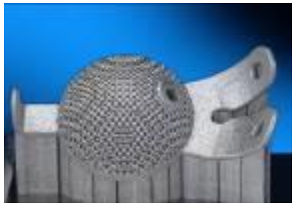
Fraunhofer Additive Manufacturing Alliance
Research areas

- **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
GENERATIV

Profile of Fraunhofer IWU

Research under the heading “Resource-Efficient Production“

- Founded Juli 1st 1991
- Currently approx. 530 employees
- Approx. € 40 million annual budget
- Locations: Chemnitz (headquarters)
  Dresden, Zittau, Wolfsburg, Leipzig
- 3 scientific fields:

Mechatronics and Lightweight Structures	Forming Technology	Machine Tools, Production Systems and Machining

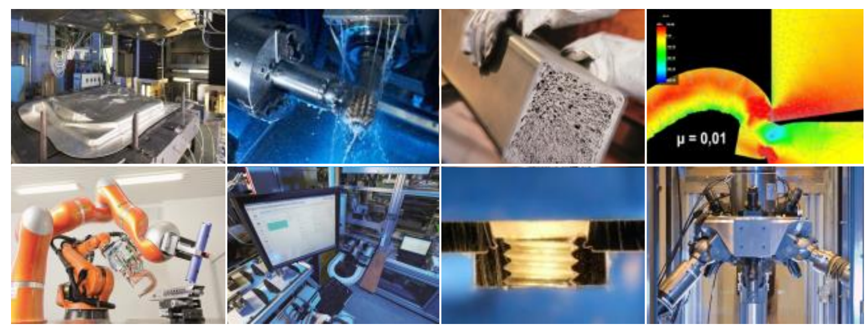
Fraunhofer IWU Dresden
Industry and research environment


- Approx. 550,000 inhabitants
- Hi-tech location with the key technologies:
  - Microelectronics / information and communication technology
  - New materials / nanotechnology / photovoltaics
  - Life sciences / biotechnology
- Germany's city with the greatest concentration of research facilities, including: “University of Excellence“ TU Dresden, 10 universities, 11 institutes and research units of the Fraunhofer-Gesellschaft, 3 Max Planck institutes, 3 Leibniz institutes, 1 Helmholtz center

Fraunhofer IWU in profile

Competencies from A to Z

Automation	Sheet metal forming	Additive manufacturing processes	Smart Production
Determining characteristic values and material characterization	Lightweight construction	Bulk metal forming	Mechatronics and adaptronics
Medical engineering	Micro and precison manufacturing		
Assembly technology and robotics	Production management		
Process chains	Simulation	Cutting/removal	Technical acoustics
Thermal and mechanical joining	Virtual and augmented reality	Machine tools	Tool and mold making



Fraunhofer IWU
Smart Production

Efficient, linked, flexible: value-added chains of the future

- Digitization as an opportunity for medium-sized enterprises
- The human role in smart factories
- Smart maintenance
- Self-regulating systems
- Intelligent process chains
- Demonstrations and cross-learning

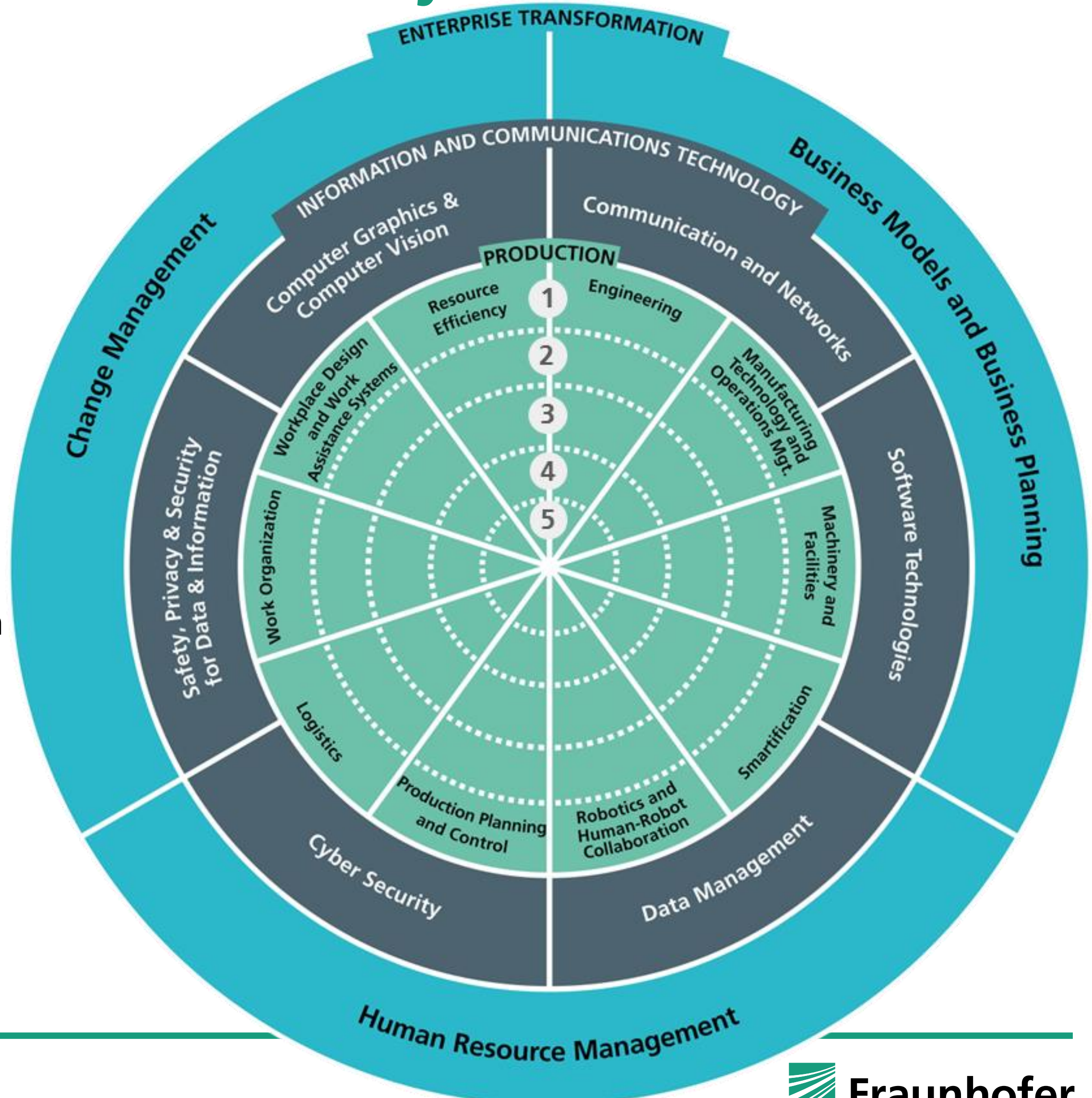
Fraunhofer IWU

Industry 4.0 – Digitalisation for Smart Production

Fraunhofer Layer Model of Industry 4.0 Value Creation

LAYERS:

- ENTERPRISE TRANSFORMATION
- INFORMATION AND COMMUNICATIONS TECHNOLOGY
- PRODUCTION



Functional Areas:

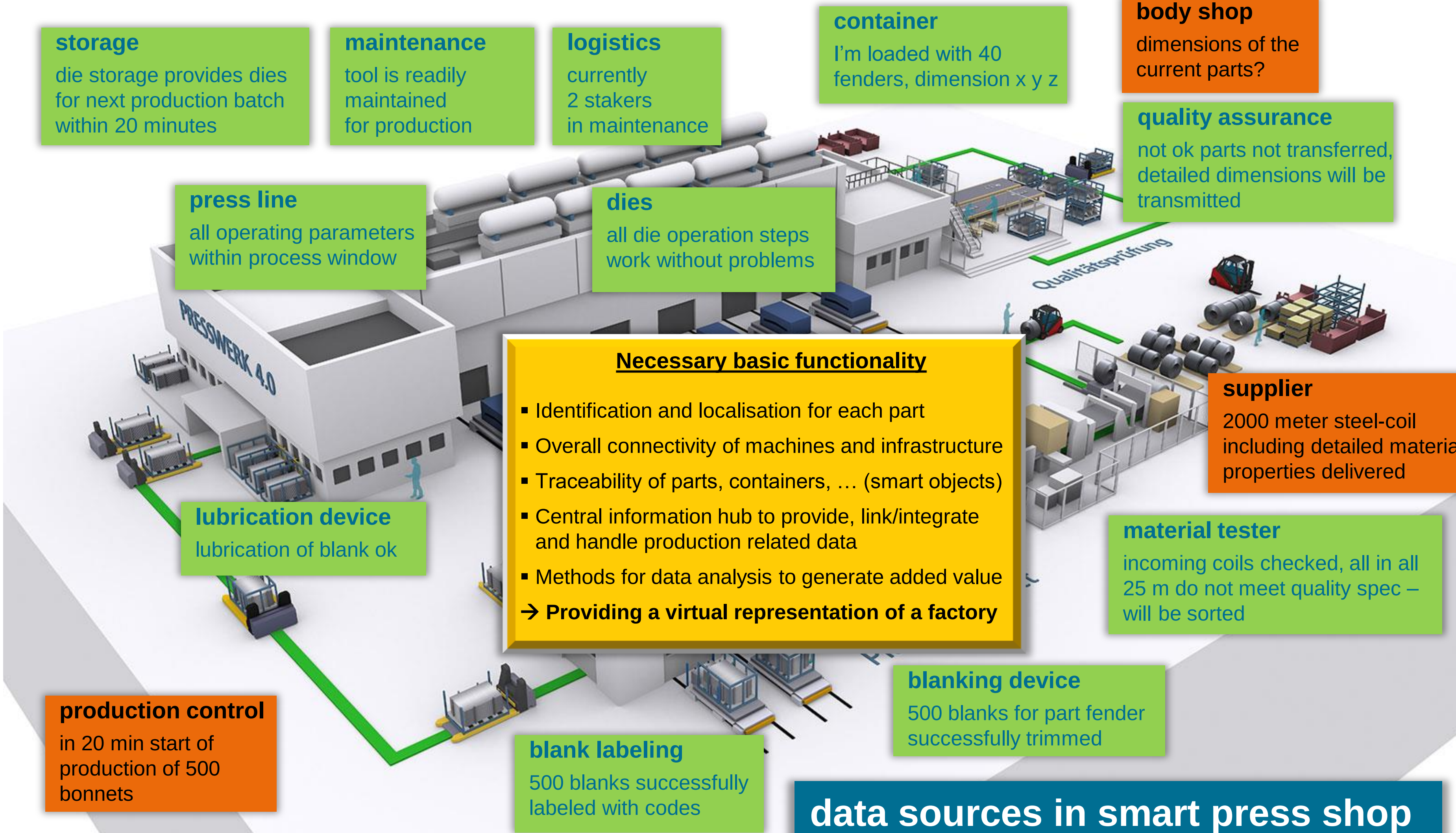
1. Data recording and processing
2. Assistance Systems
3. Interconnectedness and integration
4. Decentralization, service orientation and transformation ability
5. Self-organisation and autonomy

In reference to Neugebauer, Reimund; Hippmann, Sophie; Leis, Miriam; Landherr, Martin (2016): Industrie 4.0 - From the perspective of applied research. 49th CIRP Conference on Manufacturing Systems (CIRP-CMS 2016). Available online at www.sciencedirect.com

Fraunhofer IWU

Smart press shop

Potential data sources



storage
die storage provides dies for next production batch within 20 minutes

maintenance
tool is readily maintained for production

logistics
currently 2 stakers in maintenance

container
I'm loaded with 40 fenders, dimension x y z

body shop
dimensions of the current parts?

quality assurance
not ok parts not transferred, detailed dimensions will be transmitted

press line
all operating parameters within process window

dies
all die operation steps work without problems

Necessary basic functionality

- Identification and localisation for each part
- Overall connectivity of machines and infrastructure
- Traceability of parts, containers, … (smart objects)
- Central information hub to provide, link/integrate and handle production related data
- Methods for data analysis to generate added value

→ **Providing a virtual representation of a factory**

supplier
2000 meter steel-coil including detailed material properties delivered

lubrication device
lubrication of blank ok

material tester
incoming coils checked, all in all 25 m do not meet quality spec – will be sorted

production control
in 20 min start of production of 500 bonnets

blank labeling
500 blanks successfully labeled with codes

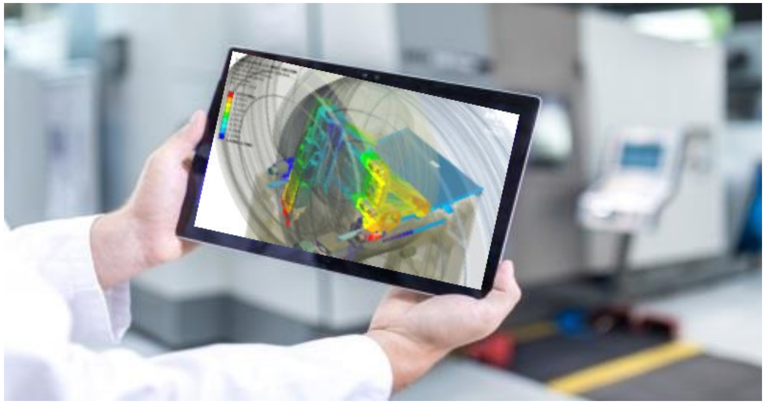
blanking device
500 blanks for part fender successfully trimmed

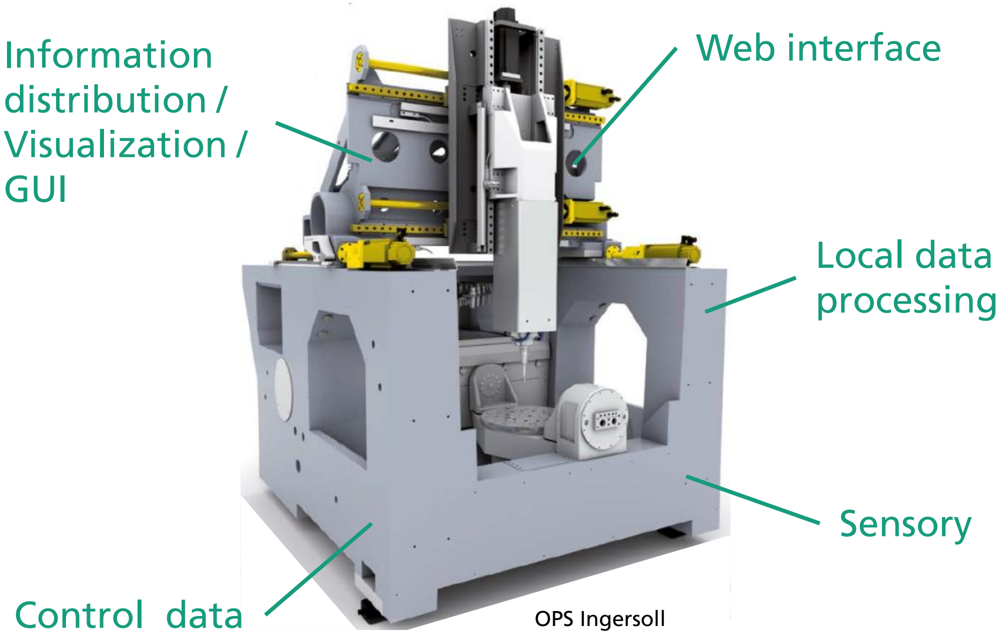
data sources in smart press shop

Smart machine tool
The technological core of an integrated digital value chain

The vision of smart machine tool includes:

- Interconnectedness and communication capabilities
- Holistic representativeness (domain-specific virtual twin)
- Local intelligence
- Local autonomy
- Adaptivity





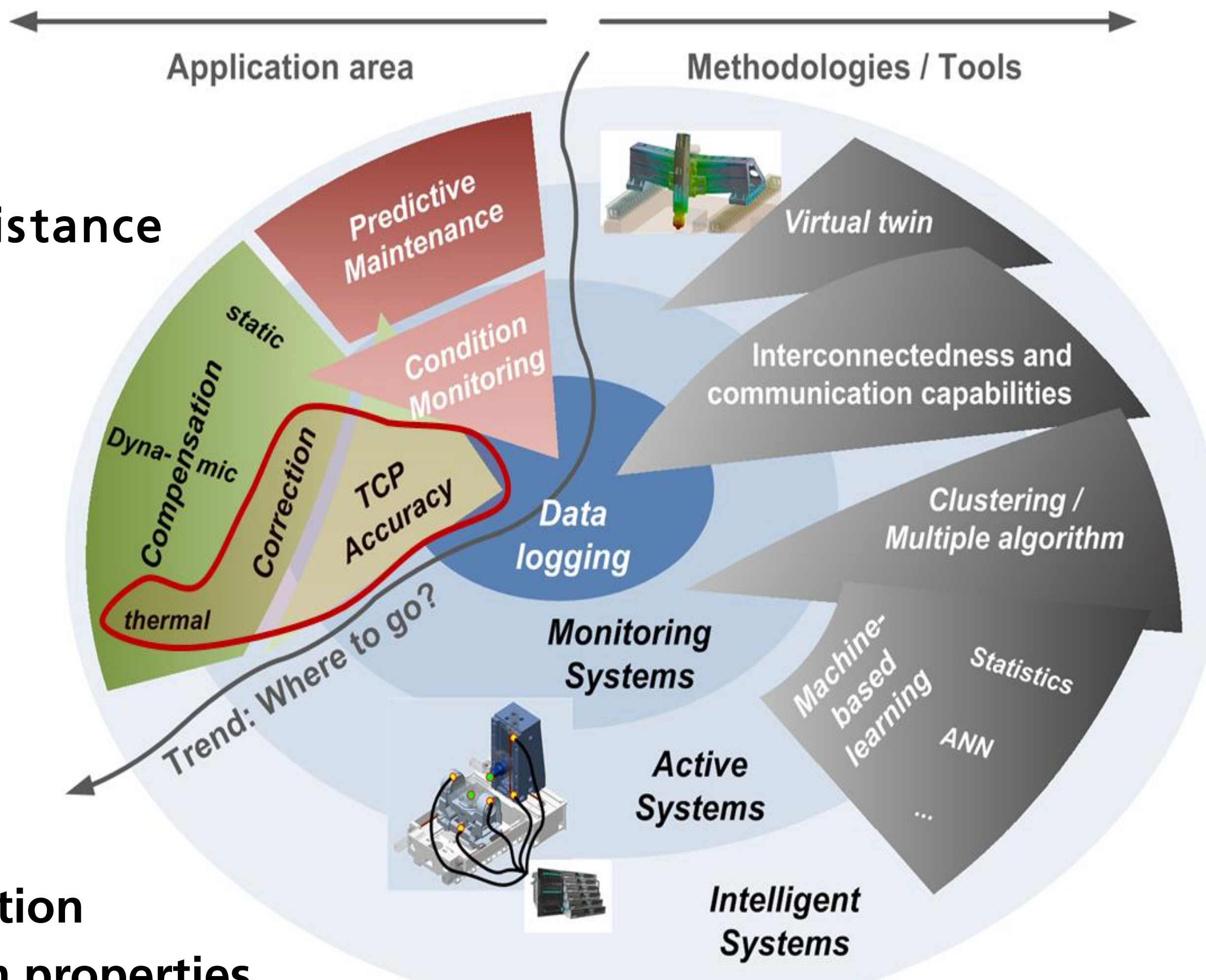
Fraunhofer IWU

Smart machine tool
Empowered by Smart Data Services

Using adaptive assistance systems for …

… **Optimization** of:
- Productivity
- TCP accuracy
  - thermal
  - dynamic
- Availability

… **without manipulation of mechanical system properties.**



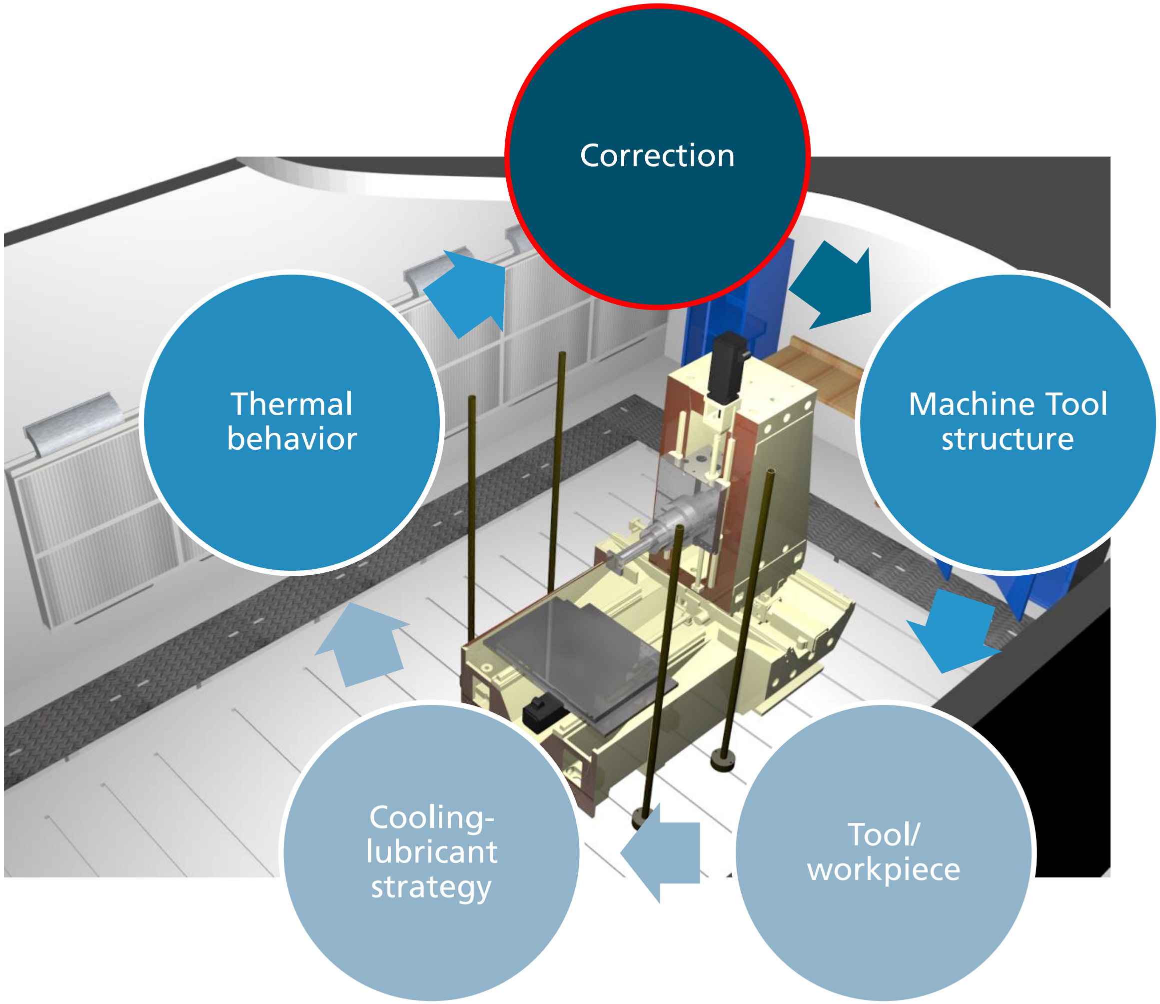
Fraunhofer IWU

Smart machine tool
Intelligent TCP correction approaches

Characteristic diagram based correction approach of thermally induced displacements

… using Machine-learning algorithm …

… based on semi-autonomous assistance systems



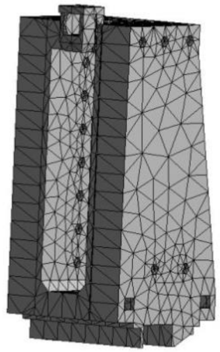
Fraunhofer IWU

Smart machine tool

Characteristic diagram based TCP correction

Machine

FE mesh

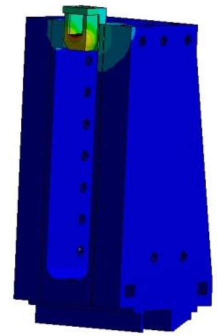


Application 1

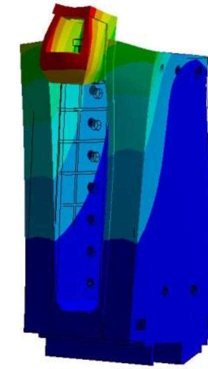
Simulation

+ Boundary conditions
+ Heat transfer coefficients
+ Heat sources

Temperature field



Deformation field



Characteristic diagram training (offline)

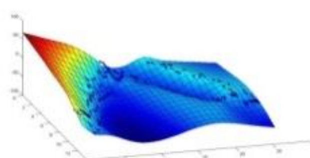
Application 2

Experiments

Measurement

Charac-teristic diagram training (offline)

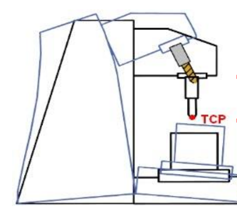
Characteristic diagram



Control and sensor data

Correction offsets

TCP shift

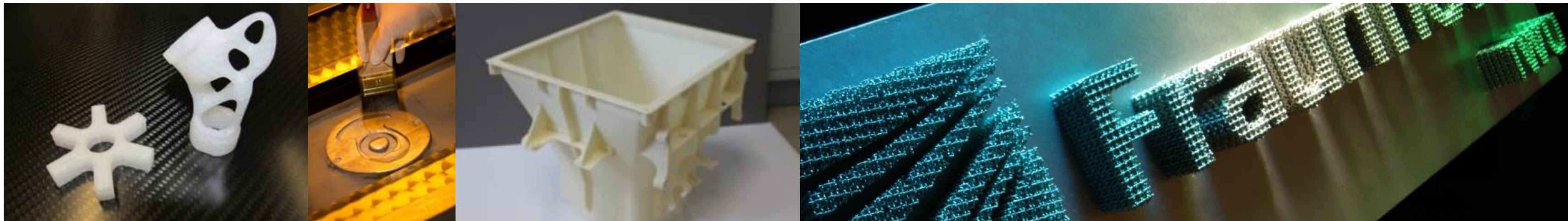


Thermally induced displacement

Control-integrated online TCP correction

Fraunhofer IWU

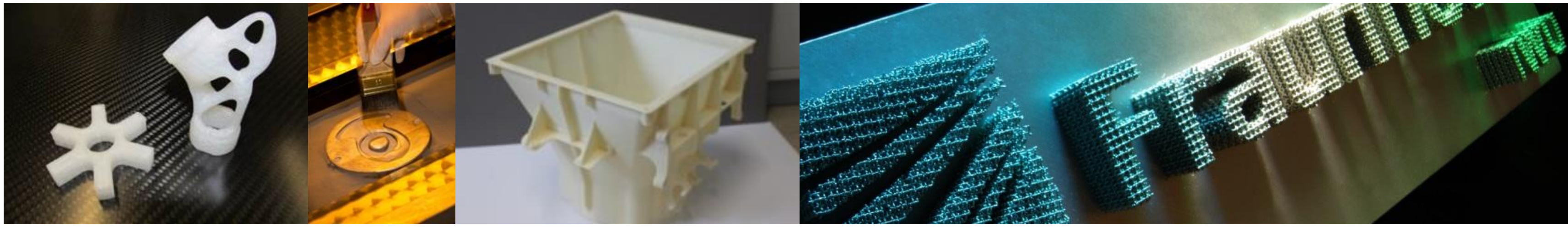
Fraunhofer IWU
Additive Manufacturing



New routes for innovative products

- Industrial 3D Printing
  → from Prototyping to Additive Manufacturing
- Additive Manufacturing of polymers
- Printing of fiber-plastic composites
- Laser Beam Melting (LBM, Powder Bed Fusion, Metal „3D Printing“)
- Numerical simulation and warpage analysis
- Research in AM processes, materials and applications

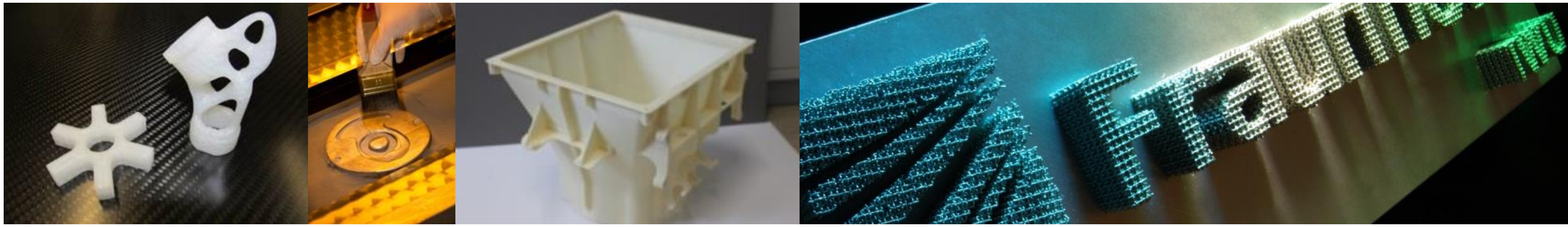
How can Additive Manufacturing enable Smart Production?



- The digital factory – AM as a truly digital manufacturing technology
- Enabling production process monitoring and adaptive control right at its heart: at the interface between production system and manufactured product – with sensor/actuator integration in tools & dies and in machine tools
- Process monitoring and adaptive control of AM processes on a unique level – monitoring every single voxel of material during its creation

Fraunhofer IWU

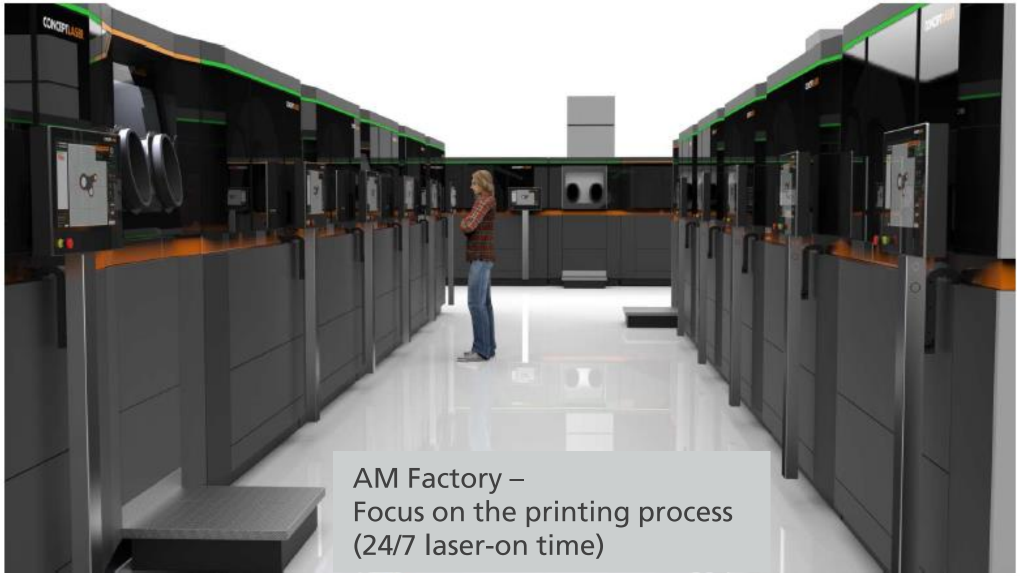
How can Additive Manufacturing enable Smart Production?

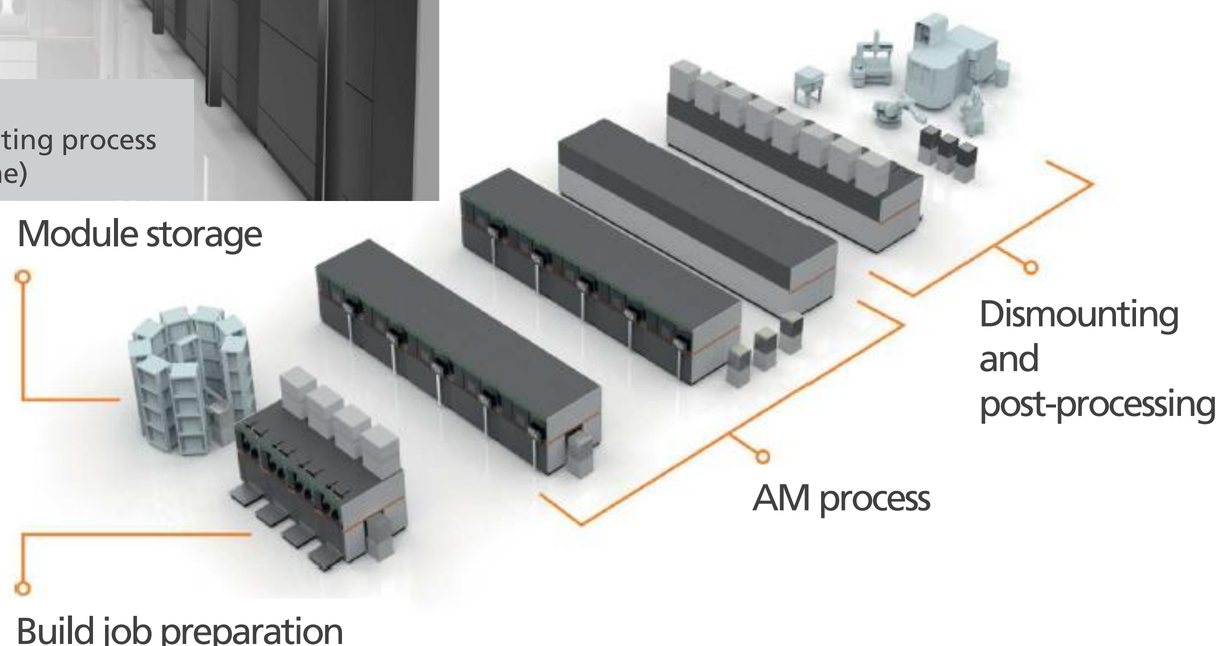


- The **digital factory** – AM as a truly digital manufacturing technology
- Enabling production process monitoring and adaptive control right at its heart: at the interface between production system and manufactured product – with **sensor/actuator integration** in tools & dies and in machine tools
- **Process monitoring** and adaptive control of AM processes on a unique level – monitoring every single voxel of material during its creation

Fraunhofer IWU

AM factory of tomorrow



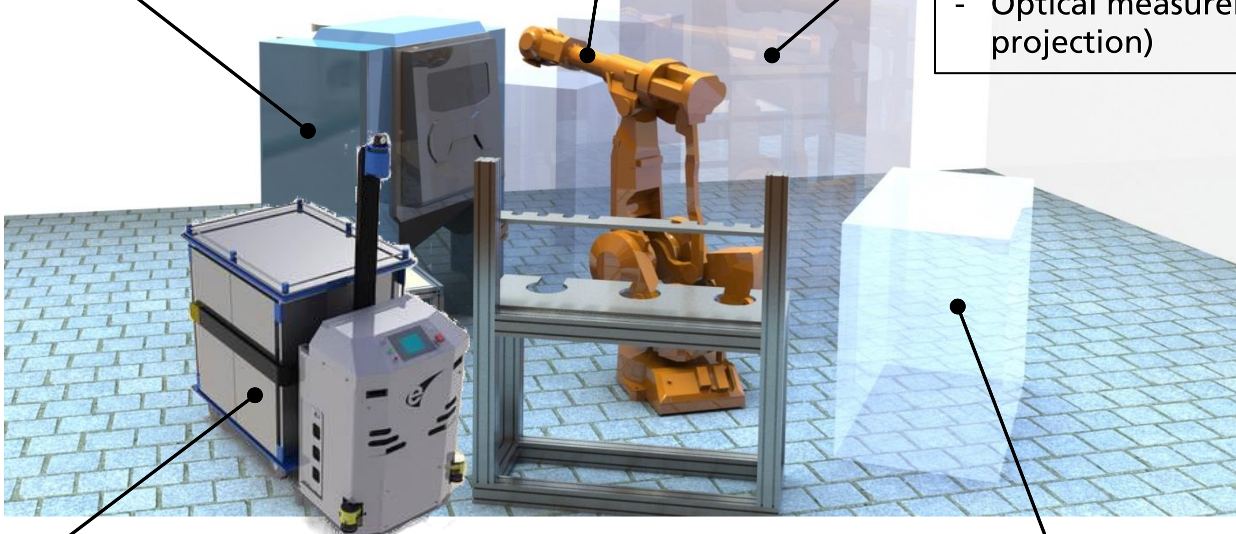


(source: Concept Laser GmbH)

Fraunhofer focus project futureAM

Concept of fully automated AM (post-)process chain

- Circular arrangement of different modules around industrial robot



futureAM
Fraunhofer IWU

Novel Concept for Large Part Additive Manufacturing

Polymer Additive Manufacturing with Industrial Robots

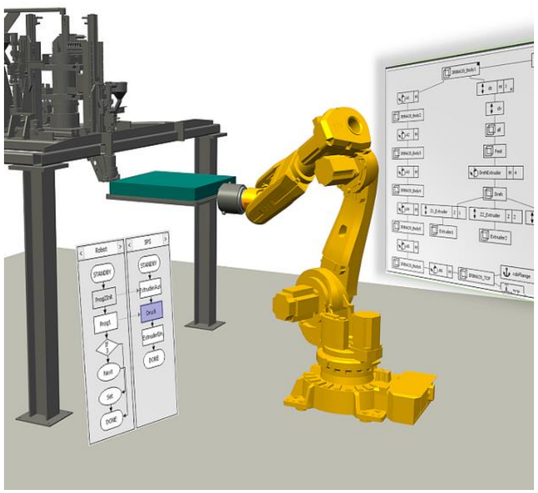
Automated manufacturing of large parts with 6-axis industrial robots

- Layer-by-layer material deposition by combining a special pellet extruder (needle nozzle) with an articulated robot
- Using standard pellets of any type (ABS, PMMA, PP, PC, PC/ABS, PLA)
- Thick layers and high build rates of up to 5 kg/h
- Heated work platform and continuous online temperature readings
- Genuine 3D parts without anisotropy through build platform's six-axis movement

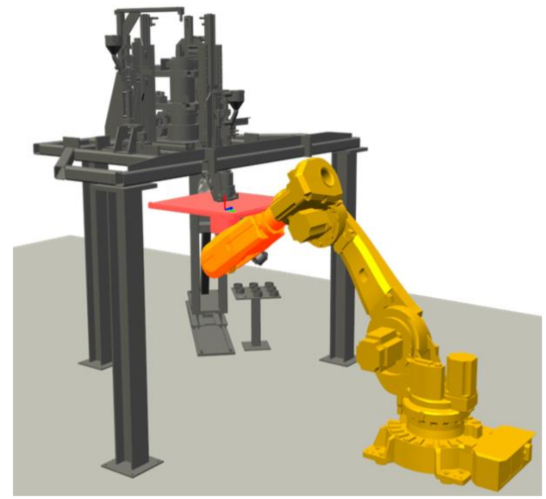
Fraunhofer IFF

Novel Concept for Large Part Additive Manufacturing

Digital Product Development for Additive Manufacturing



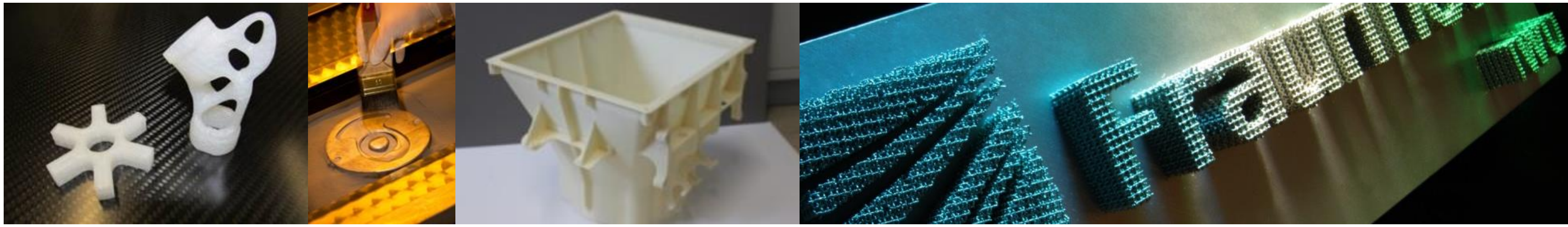
Motion planning and robot simulation with Digital Engineering



- Representation of the complete robot motion path with direction
  - Layering, approaches, evasive movements
- Visualization of the machine (graphical generation of the kinematic structure)
  - Representation of the position of every axis
- Shortened development and commissioning times
  - Testing of geometry and function before (!) manufacturing starts
- Detection of collisions by range of motion analysis
  - Internal machine collisions, workpiece collisions, safety zone

Fraunhofer IFF

How can Additive Manufacturing enable Smart Production?



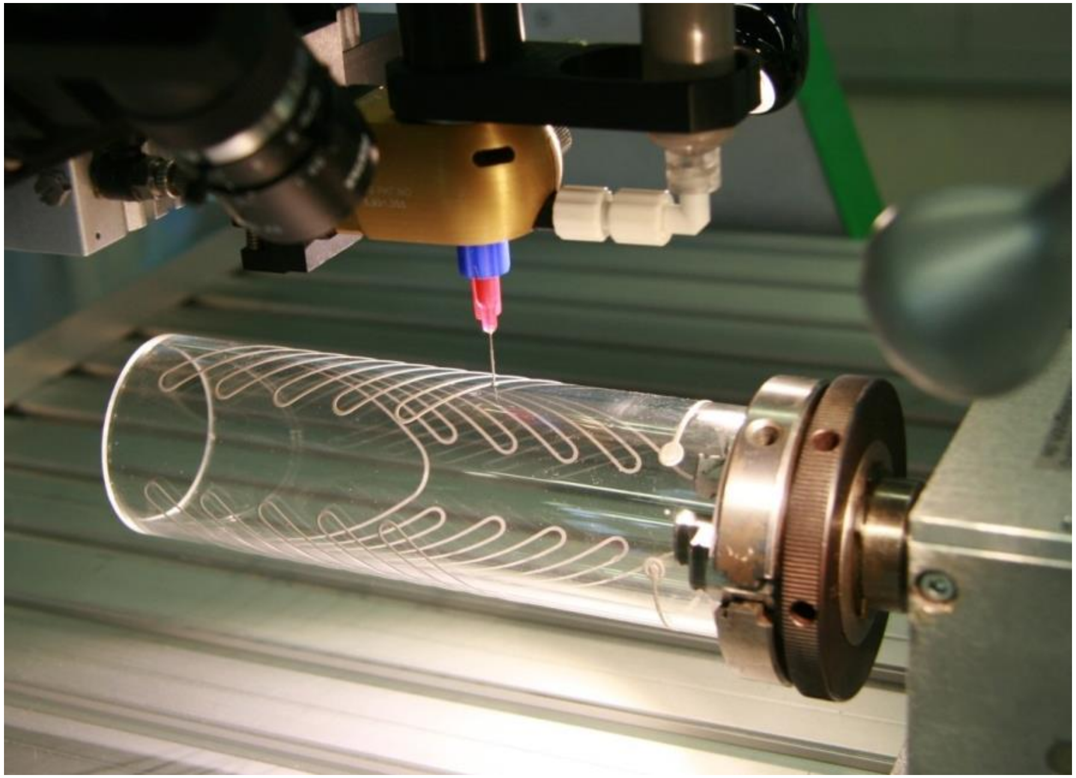
- The digital factory – AM as a truly digital manufacturing technology
- Enabling production process monitoring and adaptive control right at its heart: at the interface between production system and manufactured product – with **sensor/actuator integration** in tools & dies and in machine tools
- Process monitoring and adaptive control of AM processes on a unique level – monitoring every single voxel of material during its creation

Fraunhofer IWU

3D Printed Electronics
Sensor integration on 3D (printed) parts

Printing on 3D parts:

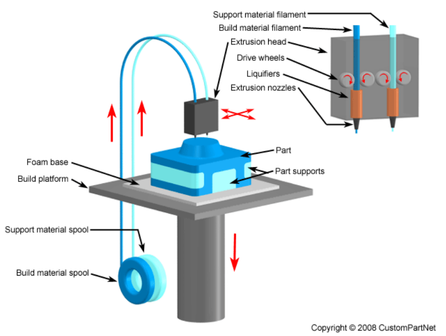
- Printing sensors, actuators and heating structures on complex parts
- High flexibility of the process concerning geometry of printed structures and substrates
- New application potential for IIoT and Industry 4.0 (Smart Production)

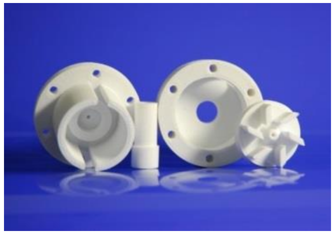


Printed heating structure on glass cylinder

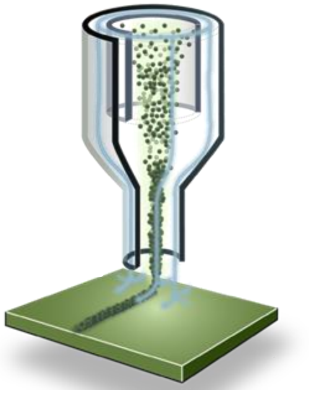
3D Printed Electronics

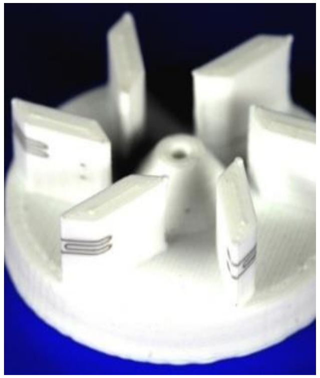
Sensor integration on 3D printed parts





FFF printed components of an oil pump (ABS)

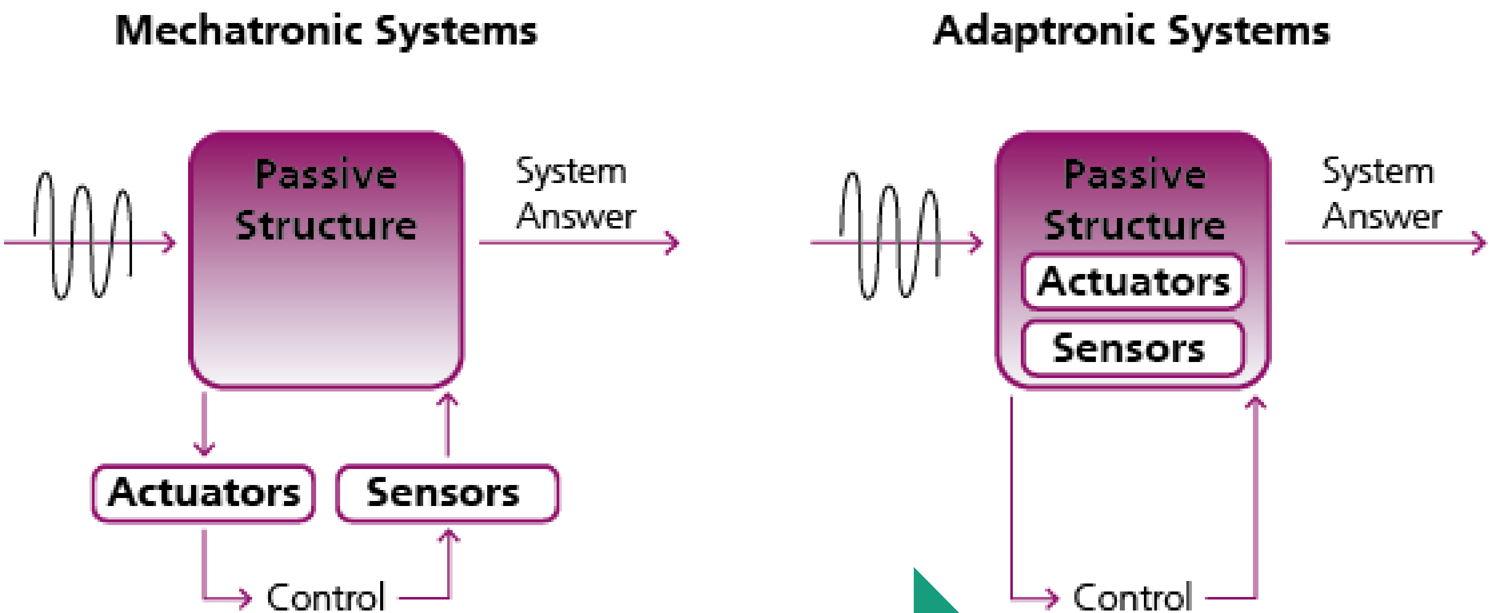




Aerosol Jet® printed CuNiMn sensor structures, sintered by use of photonic sintering; resulting resistance: 250 Ω

Additive Manufacturing for Smart Production

Structural integration of sensor and actuator systems



Functional consolidation w/ Additive Manufacturing

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

= Intelligence in mechanical structures

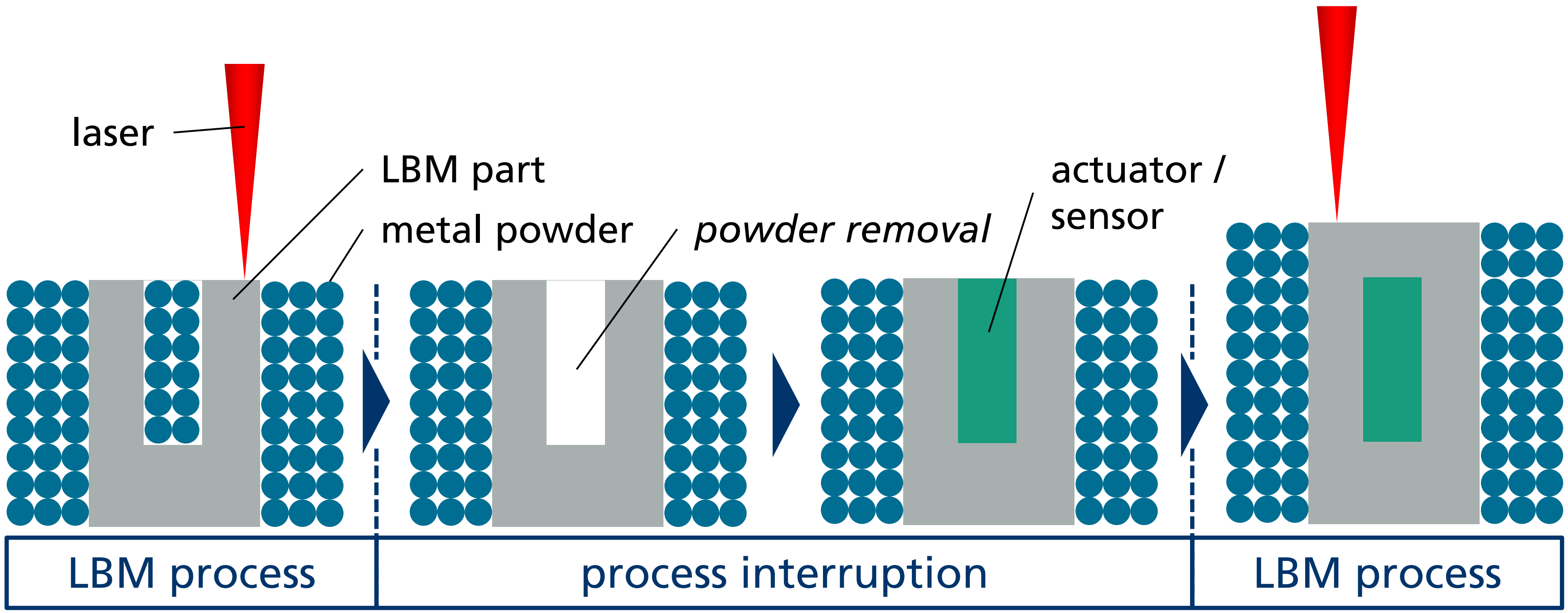
Fraunhofer IWU

Structural sensor/actuator integration with AM
Approach for thermal management during embedding

- Multi-material / multi-layer design of the actuator/sensor component
  - Isolating layers out of ceramic for thermal protection
  - Metallic layers for sufficient heat distribution and force-fit and materially bonded integration inside the metallic structure
  - Protection of the transducer packaging
- Additive manufacturing (LBM) part design and process control
  - Utilization of unmelted powder material as isolation
  - Laser processing sequence

Fraunhofer IKTS Fraunhofer IWU

Structural sensor/actuator integration with AM
Experimental procedure

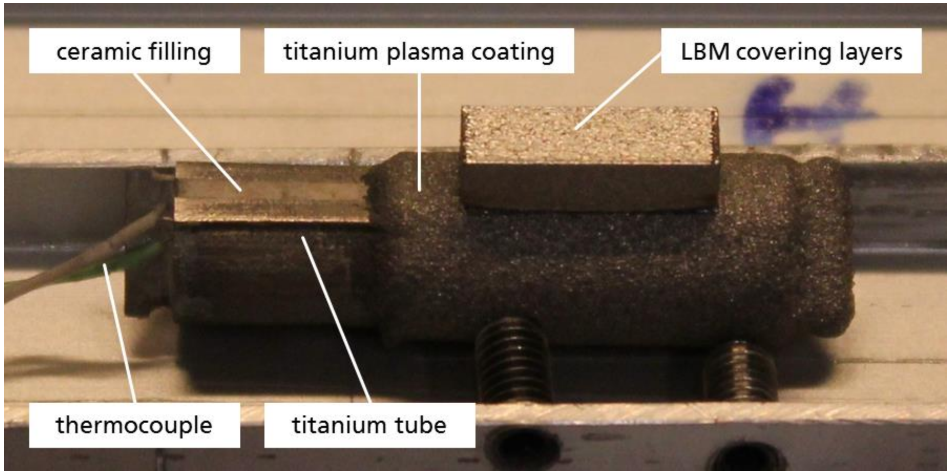


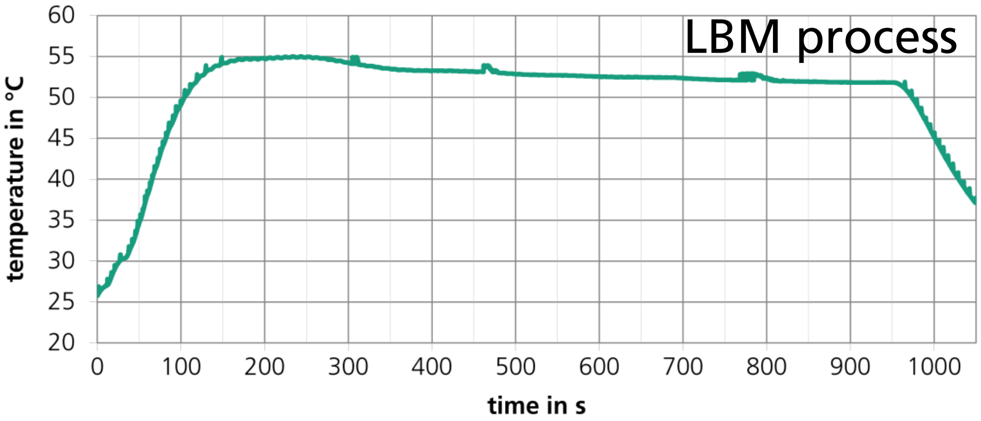
Structural sensor/actuator integration with AM

Heat exposure to sensor with plasma spraying and AM

- Temperatures inside actuator/sensor:
  - During plasma spraying: 90 - 115 °C
  - During LBM process: max. 55 °C

→ in the range of working temperature for a lot of temperature-sensitive sensors and actuators

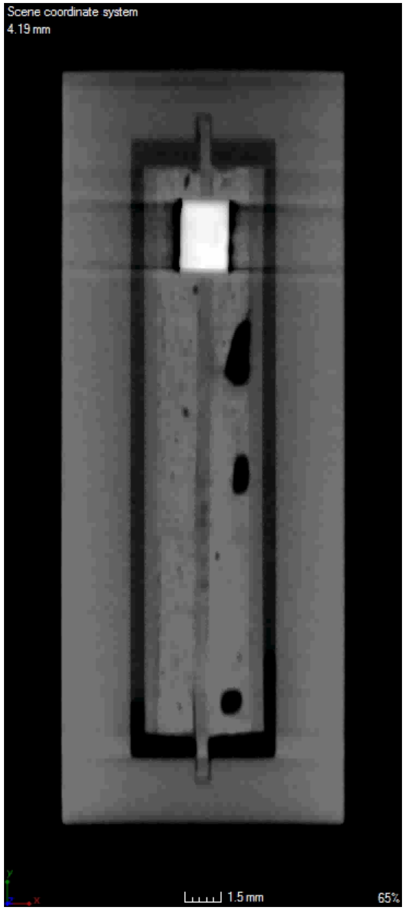


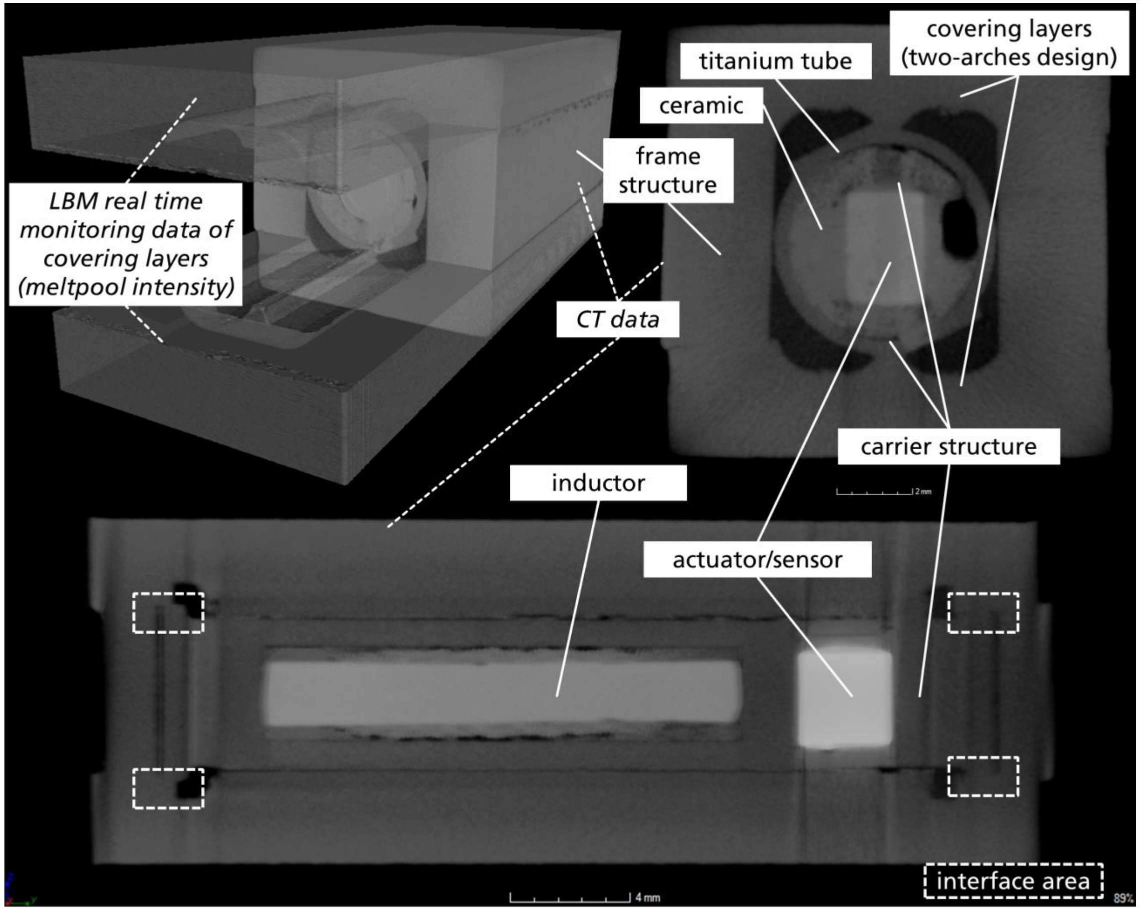


Fraunhofer IKTS

Fraunhofer IWU

Structural sensor/actuator integration with AM
CT images of AM-embedded sensor/actuator system

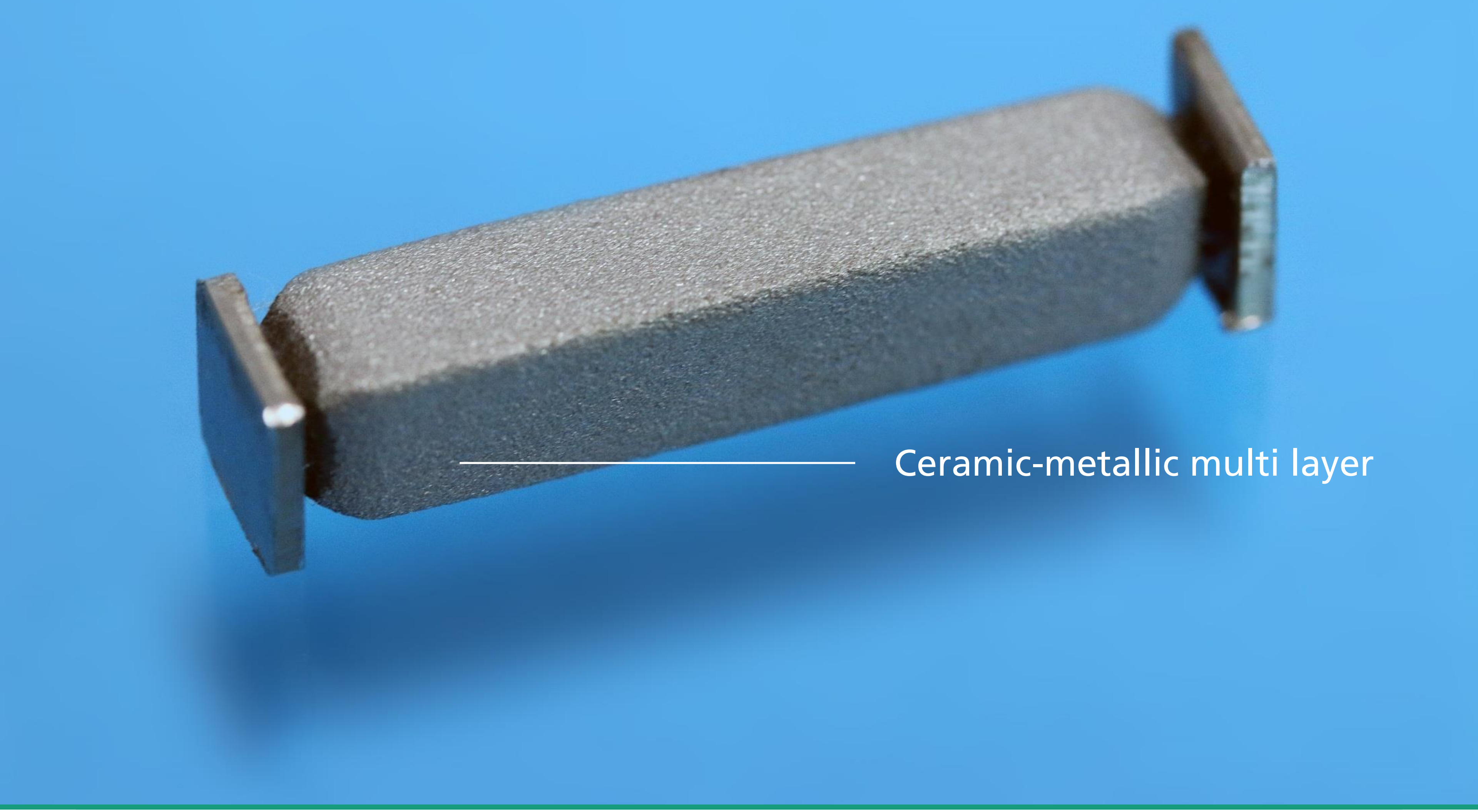




Fraunhofer IKTS
Fraunhofer IWU

Structural sensor/actuator integration with AM

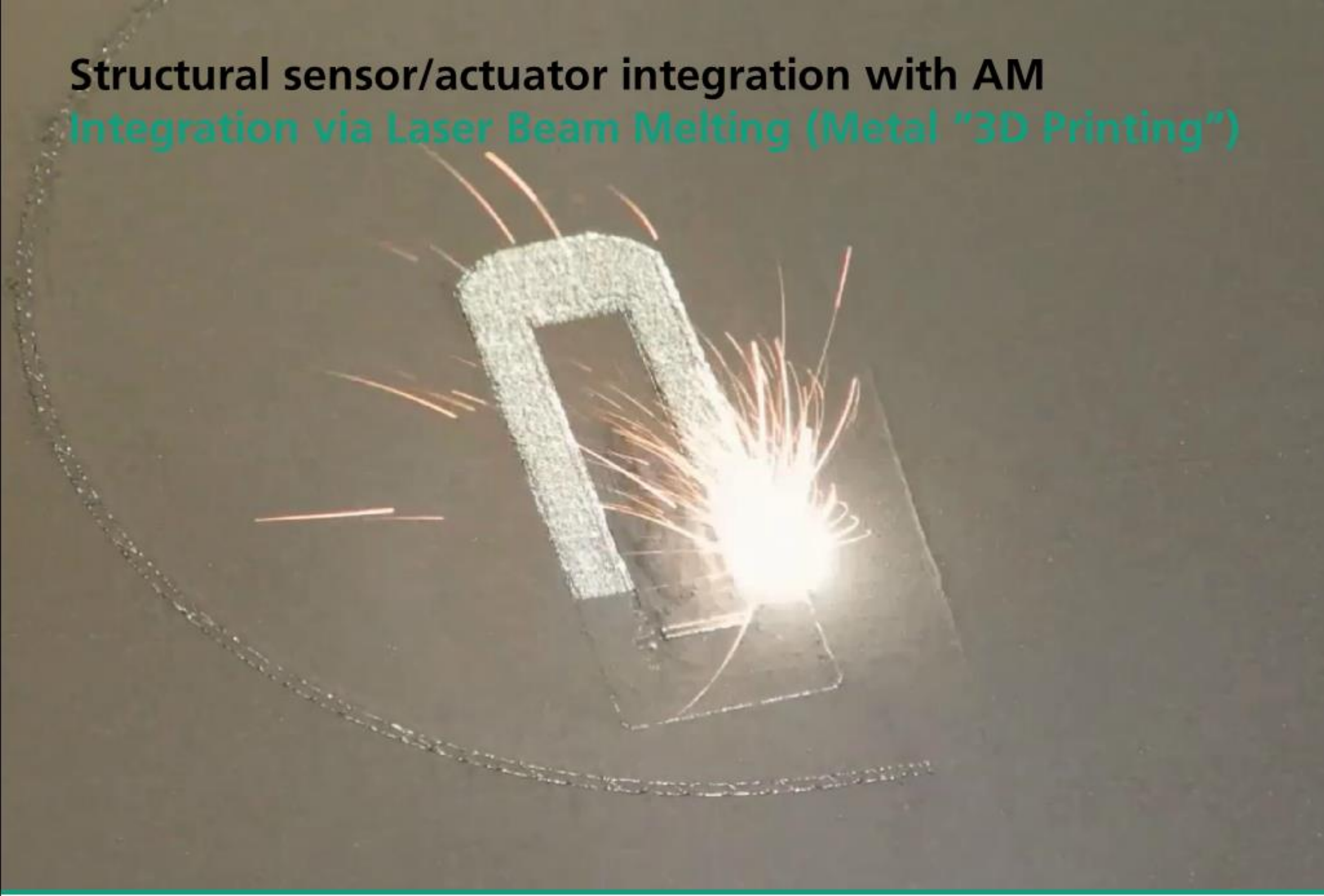
Sensor/actuator System



Fraunhofer IKTS Fraunhofer IWU

Structural sensor/actuator integration with AM

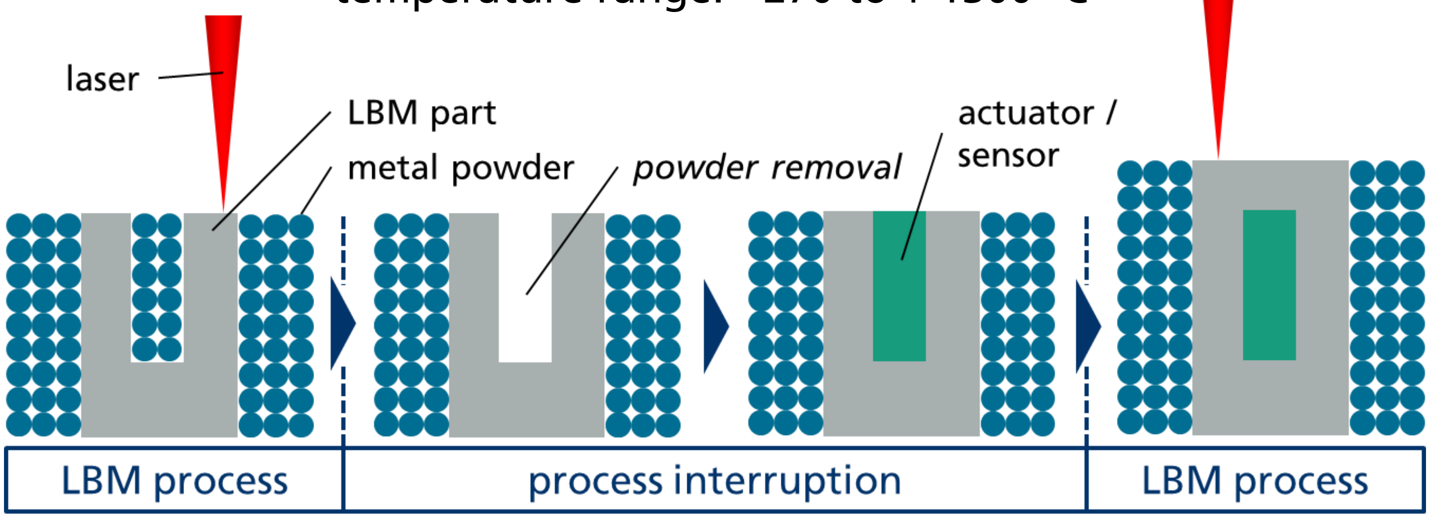
Integration via Laser Beam Melting (Metal "3D Printing")



Structural sensor integration with AM
Application study in hot sheet metal forming tooling

Selection criteria:

- very high local temperature exposure during embedding through Additive Manufacturing ➔ **Heat resistance of sensor**
- high local temperature exposure during heat treatment ➔ **Heat resistance of isolation**
- low **cost** + small **installation space** + good **availability** + high **precision**
  - **Thermo couple Type K** - double isolated, high temperature glass plaiting ≤ 700°C
    - temperature range: - 270 to + 1300 °C



Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Kommission für Technologie und Innovation KTI

HIPER FORM TOOL

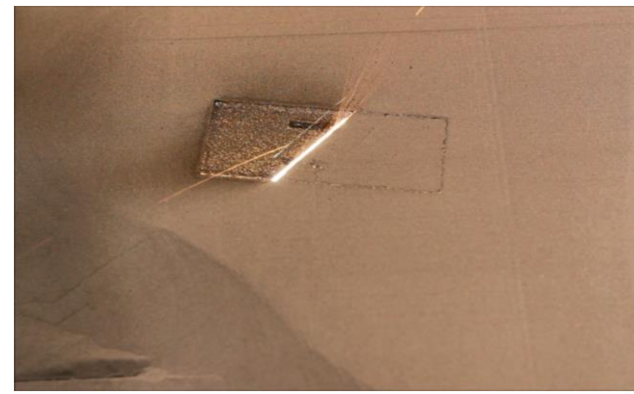
SPONSORED BY THE
Federal Ministry of Education and Research

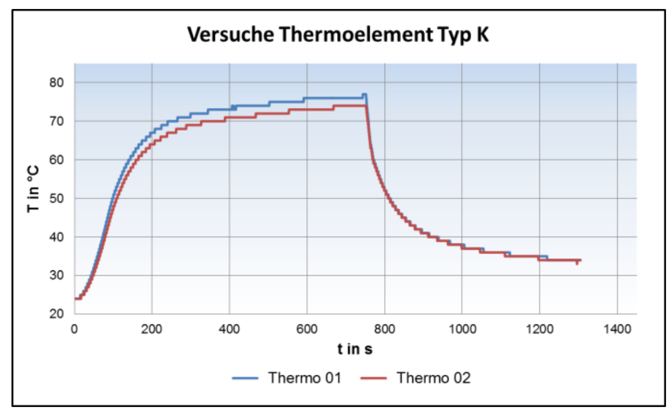
Fraunhofer IWU

Structural sensor integration with AM
Application study in hot sheet metal forming tooling

Preliminary tests

- successful integration (embedding via melting) of thermocouples in additively manufactured test part with subsequent proof of function





Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Kommission für Technologie und Innovation KTI

HIPER FORM TOOL

SPONSORED BY THE
Federal Ministry of Education and Research

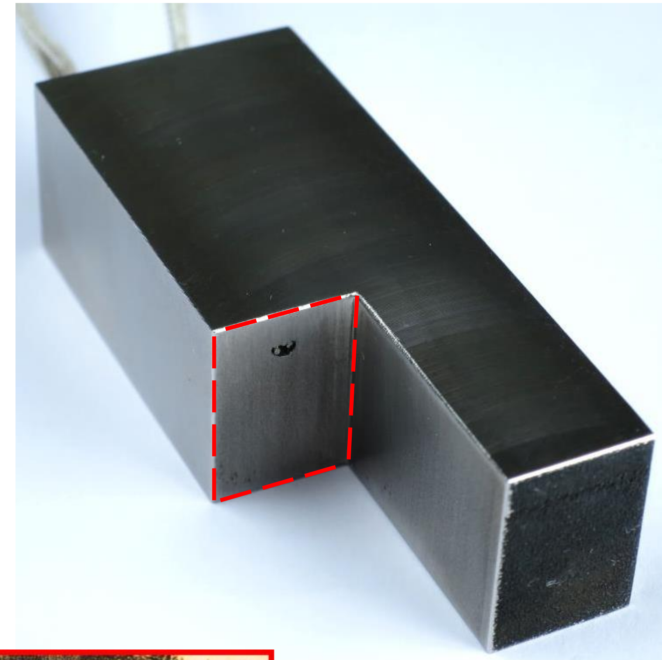
Fraunhofer IWU

Structural sensor integration with AM

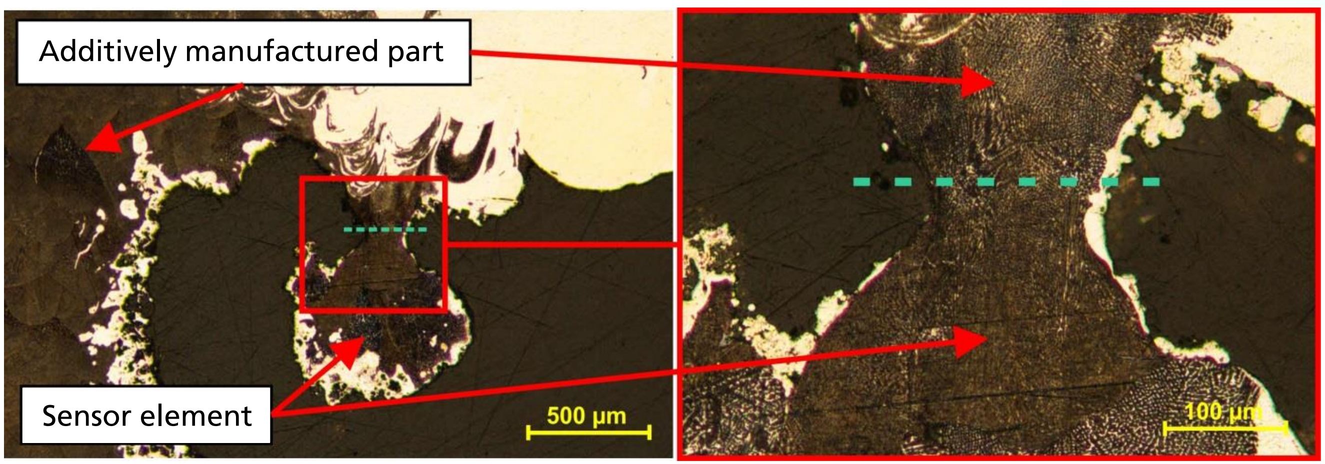
Application study in tooling

Preliminary tests

- Investigation and validation of firm bonding between test specimen and thermocouple
  - microsection analysis with etched test specimen



Test specimen with thermocouple (section)



microsection image of test specimen (etched)

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Kommission für Technologie und Innovation KTI

HIPER FORM TOOL

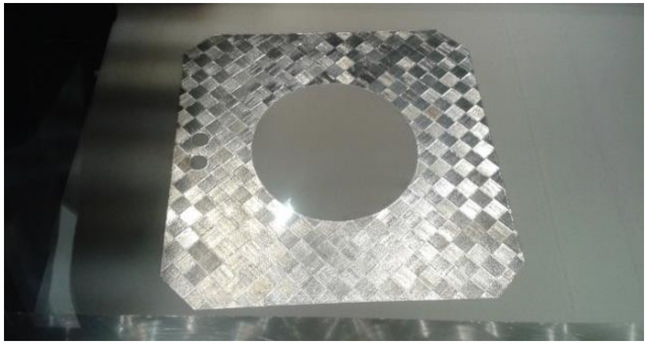
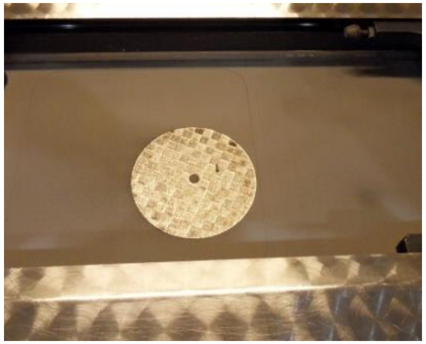
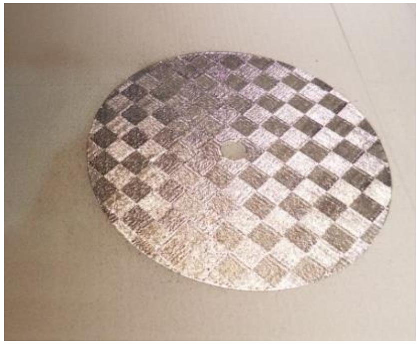
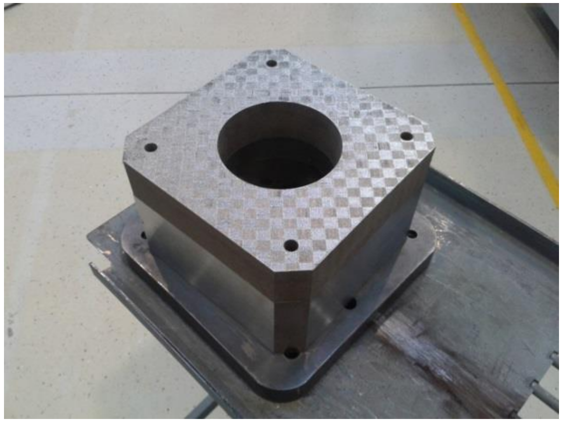
SPONSORED BY THE
Federal Ministry of Education and Research

Fraunhofer IWU

Structural sensor integration with AM
Additive Manufacturing of tooling

Laser Beam Melting (Metal „3D Printing“)

- Concept Laser M2 cusing (400 Watt laser power)
- Build time: die = 90 h, blank holder = 12 h, punch = 36 h

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Kommission für Technologie und Innovation KTI

HIPER FORM TOOL

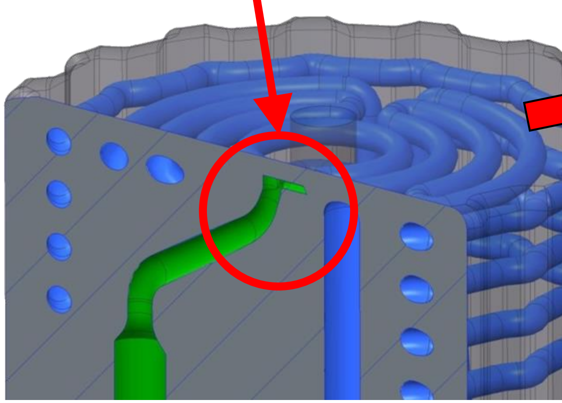
SPONSORED BY THE
Federal Ministry of Education and Research

Fraunhofer IWU

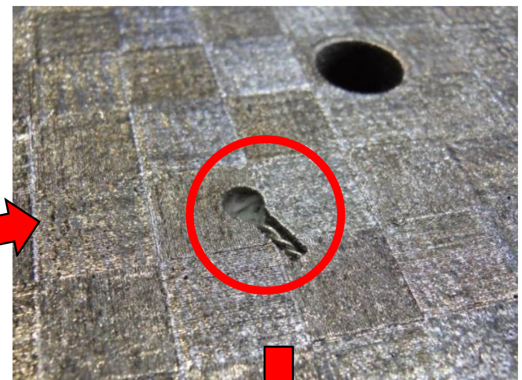
Structural sensor integration with AM
Additive Manufacturing of tooling

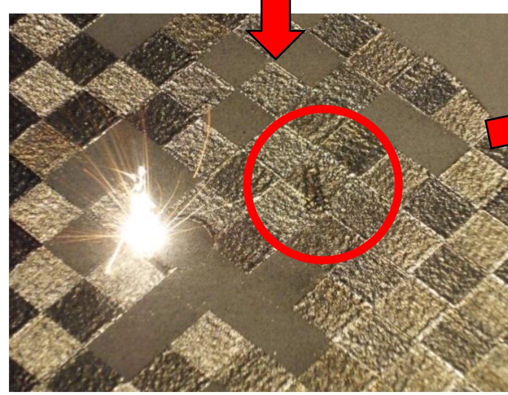
Sensor integration in tool punch

- integration as close as possible to cavity without sacrificing stability
  - ➢ only 3 mm distance to cavity surface



Position of thermocouple in the punch (CAD model)





Tooling punch with integrated thermocouple

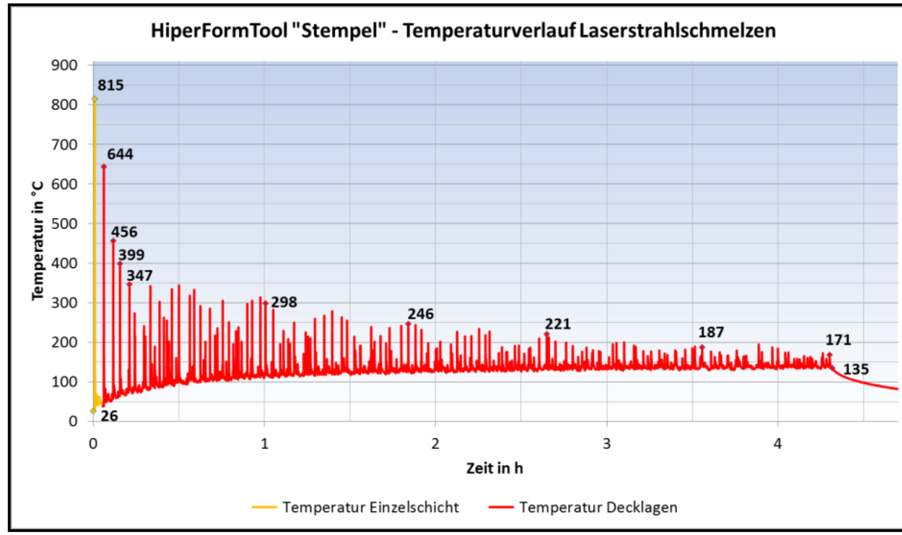
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Kommission für Technologie und Innovation KTI

HIPER FORM TOOL

SPONSORED BY THE
Federal Ministry of Education and Research

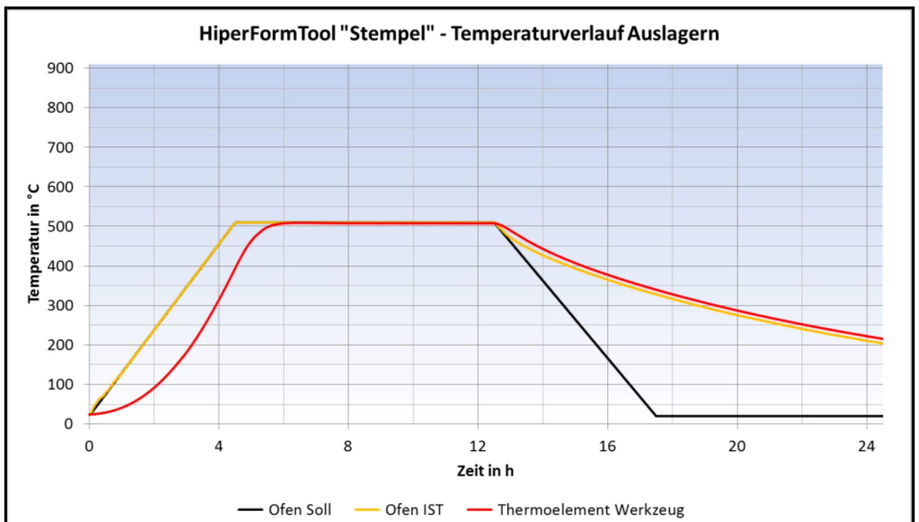
Fraunhofer IWU

Integrated Thermocouple
Proof of function



Functional test of temperature sensor

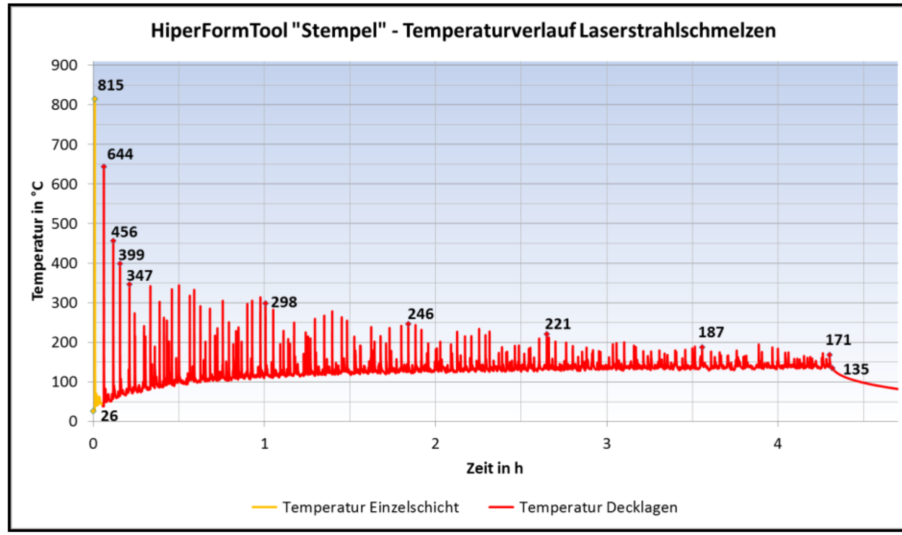
- Temperature measurement during Additive Manufacturing
  - Sampling rate 500 / s for first layer → 2 / s for remaining layers
  - Part heats up to more than 135 °C



- Temperature measurement during heat treatment
  - Sampling rate 1 / s
  - significant offset between furnace and tooling temperature

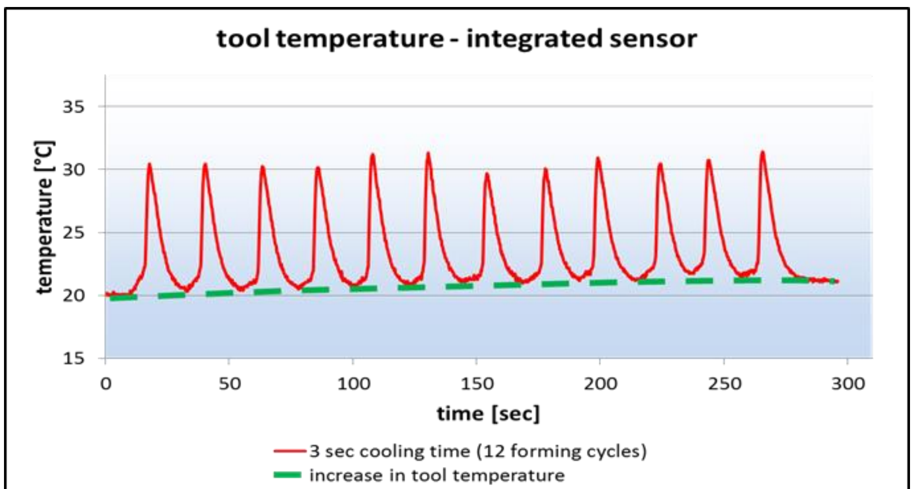
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Kommission für Technologie und Innovation KTI
HIPER FORM TOOL
SPONSORED BY THE
Federal Ministry of Education and Research
Fraunhofer IWU

Integrated Thermocouple
Proof of function



Functional test of temperature sensor

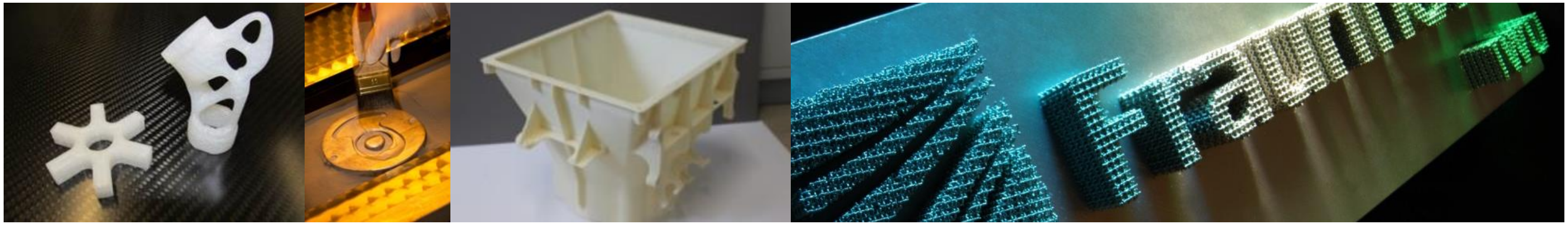
- Temperature measurement during Additive Manufacturing
  - Sampling rate 500 / s for first layer → 2 / s for remaining layers
  - Part heats up to more than 135 °C



- Temperature measurement during tooling use in hot metal forming process
  - measured with thermocouple AM embedded in the punch
  - for 12 forming cycles per holding time in multiple test series

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Kommission für Technologie und Innovation KTI
HIPER FORM TOOL
SPONSORED BY THE
Federal Ministry of Education and Research
Fraunhofer IWU

How can Additive Manufacturing enable Smart Production?



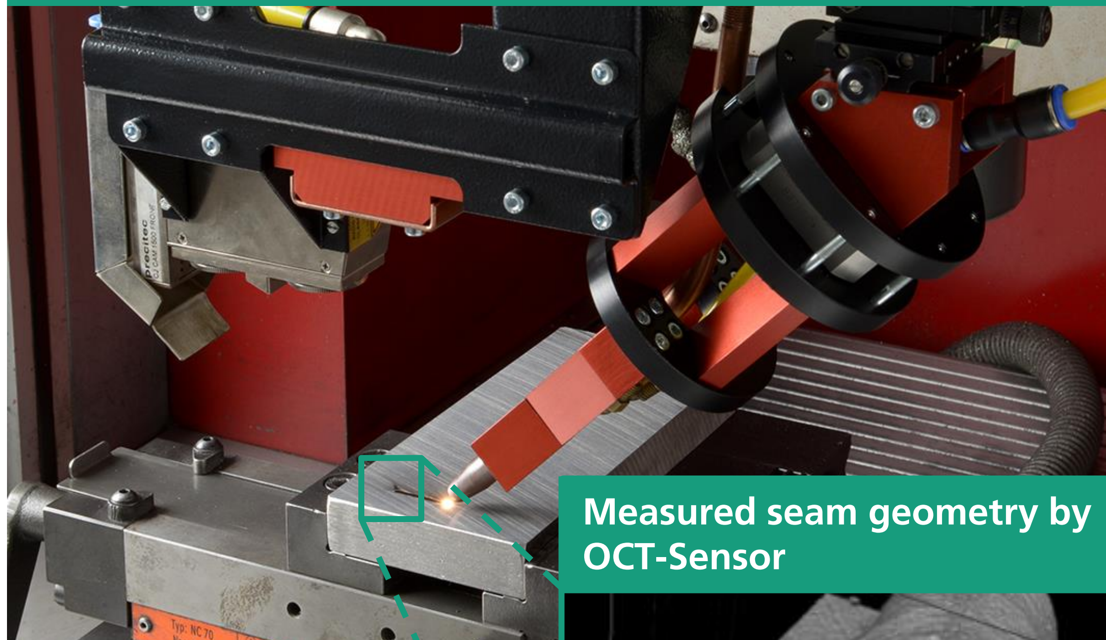
- The digital factory – AM as a truly digital manufacturing technology
- Enabling production process monitoring and adaptive control right at its heart: at the interface between production system and manufactured product – with sensor/actuator integration in tools & dies and in machine tools
- **Process monitoring** and adaptive control of AM processes on a unique level – monitoring every single voxel of material during its creation

Fraunhofer IWU

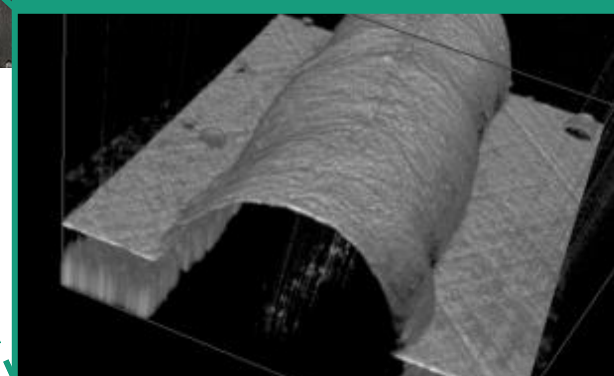
Sensor Integration for Process Control in Hybrid LMD-W machines

- Detection of seam geometry by OCT sensors to adapt position of next layer
- Detection of pores and other defects of welded seam by OCT sensors
- Detection of process instability due to increasing process forces
- Protection of the hybrid machine tool, because collision can be detected by force measurement
- Constant material flow and immediate stop due to measurement of wire feed rate

Wire arm with integrated force measurement for wire-based laser metal deposition (LMD-W)



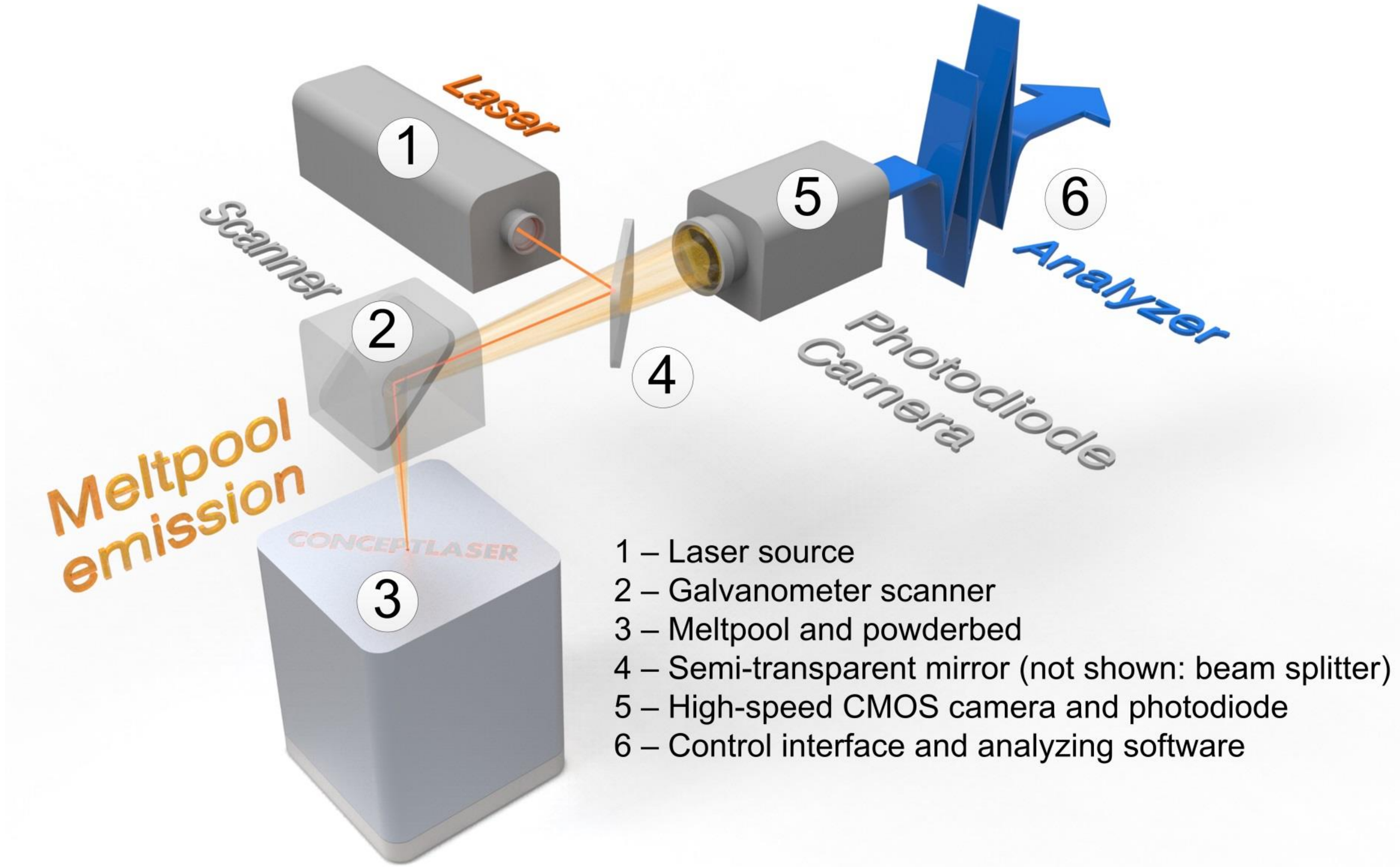
Measured seam geometry by OCT-Sensor



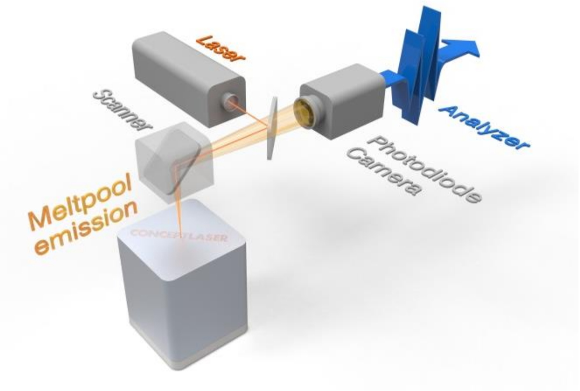
LMD-W: Wire based Laser Metal Deposition

Fraunhofer IPT

QM Meltpool 3D real-time monitoring system



QM Meltpool 3D real-time monitoring system

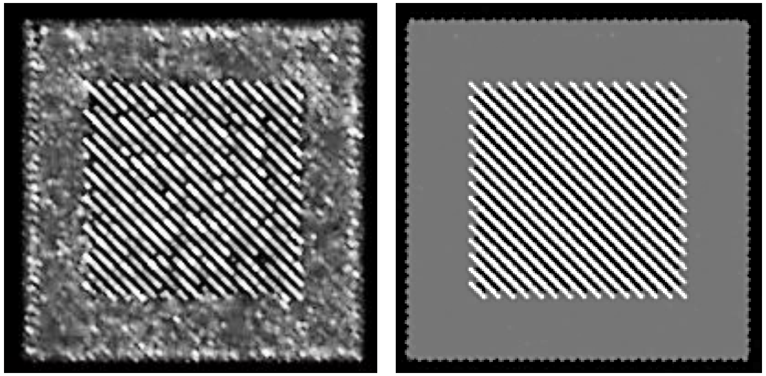


Hardware:

- Photodiode and infrared camera are coaxially positioned in the optical path (on axis)
- Detection of thermal radiation of the meltpool
- Camera (CAM): melt pool area/size (x/y), 15 kHz, observing area 1 mm²
(min. resolution depending on scan speed, e. g. 100 µm at 1,500 mm/s)
- Photodiode (PHD): melt pool intensity, 50 kHz, observing area 400 mm²

Software:

- Correlation of the detected signals to the corresponding scanner positions (processed in real-time on an IPC)
- Visualization of sensor signals as grey scale images for each layer and part
- Analyzation during or after the process



CONCEPTLASER a GE Additive company
Fraunhofer IWU

QM Meltpool 3D real-time monitoring system

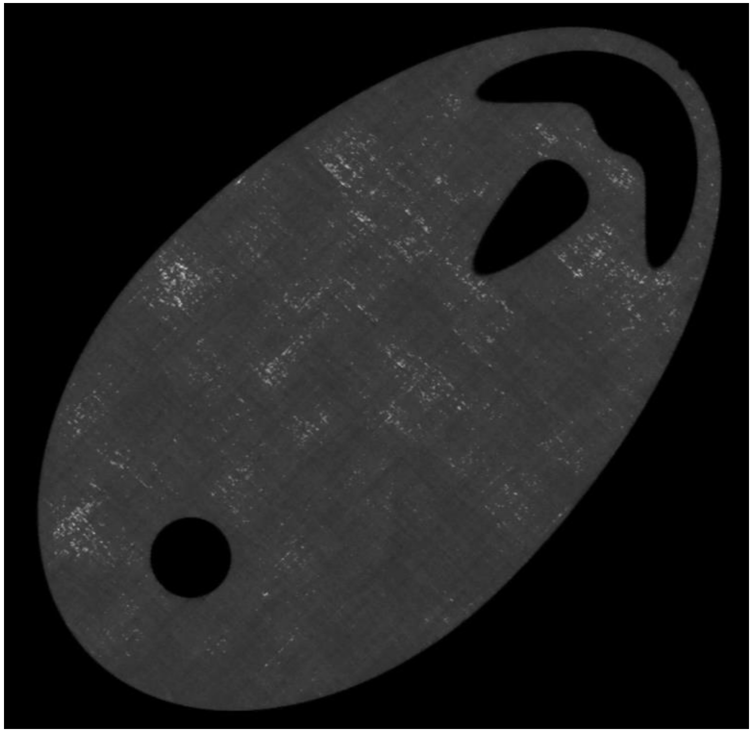
Live view of meltpool area (camera data):

CONCEPTLASER a GE Additive company
Fraunhofer IWU

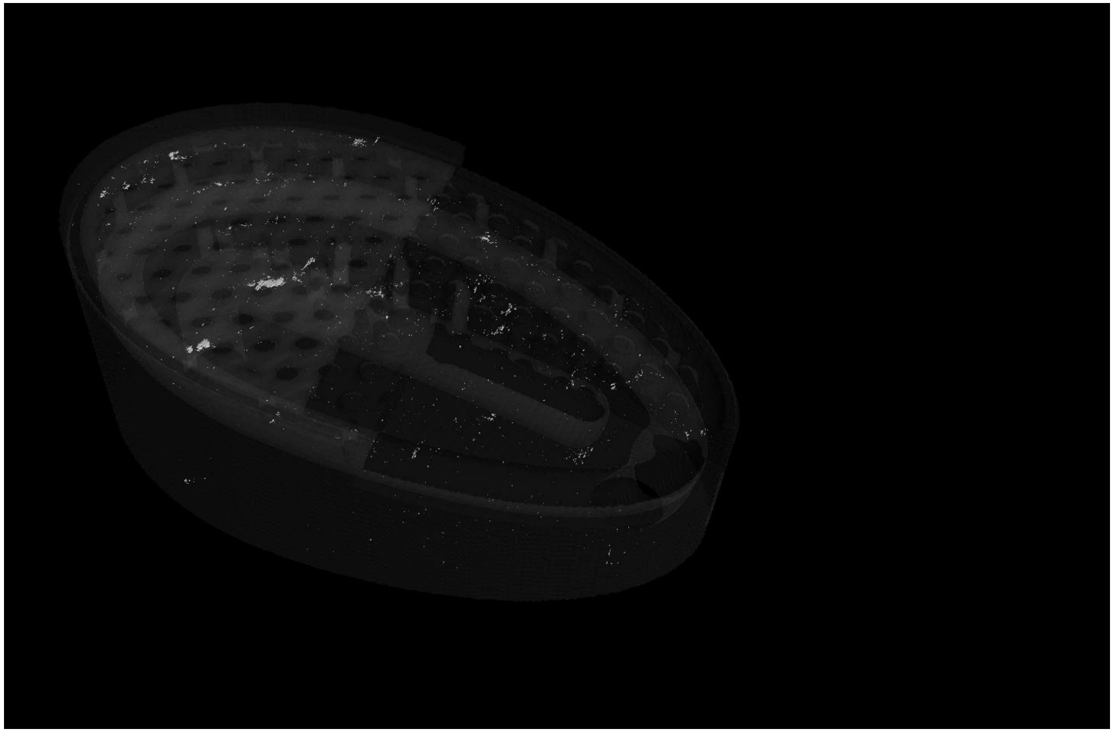
QM Meltpool 3D real-time monitoring system

2D and 3D visualization of camera data on the example of a mold insert with conformal cooling system:

2D visualization – fly through image stack in z-direction



3D visualization – highlighted areas with meltpool sizes out of spec

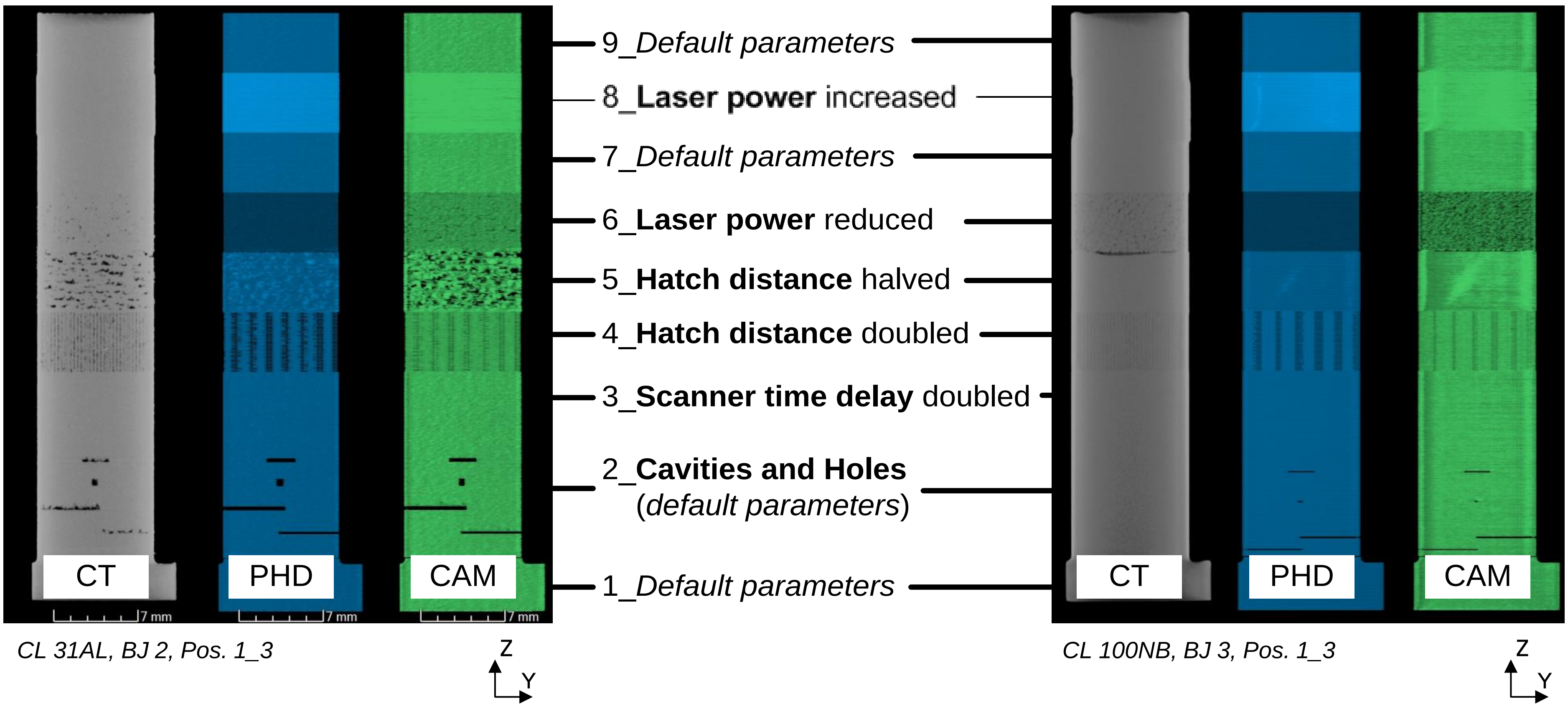


CONCEPTLASER
a GE Additive company

Fraunhofer
IWU

QM Meltpool 3D real-time monitoring system

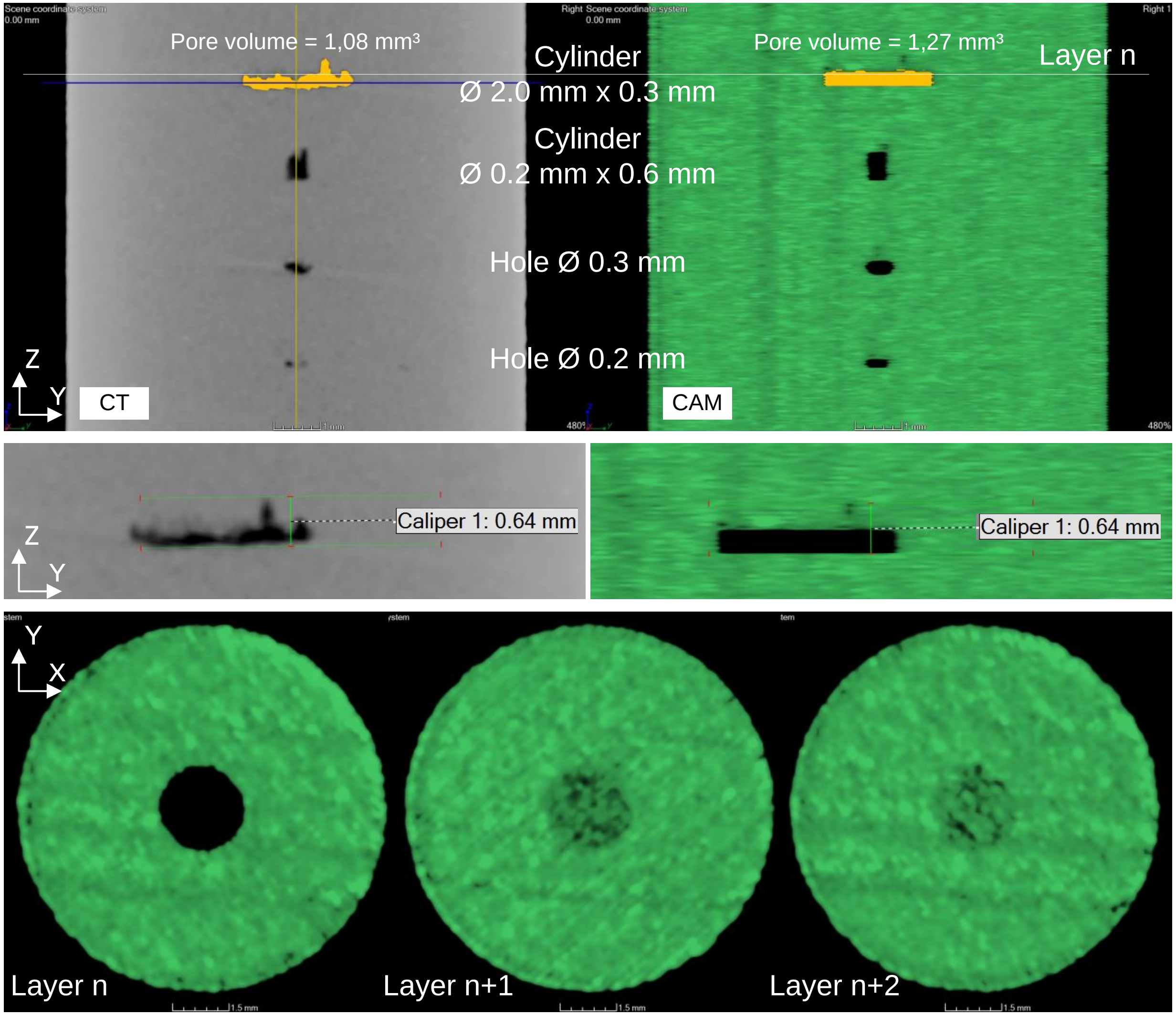
Overview Specimen 1 – CT vs. CAM vs. PHD:



QM Meltpool 3D real-time monitoring system

<u>Cavities and holes:</u>

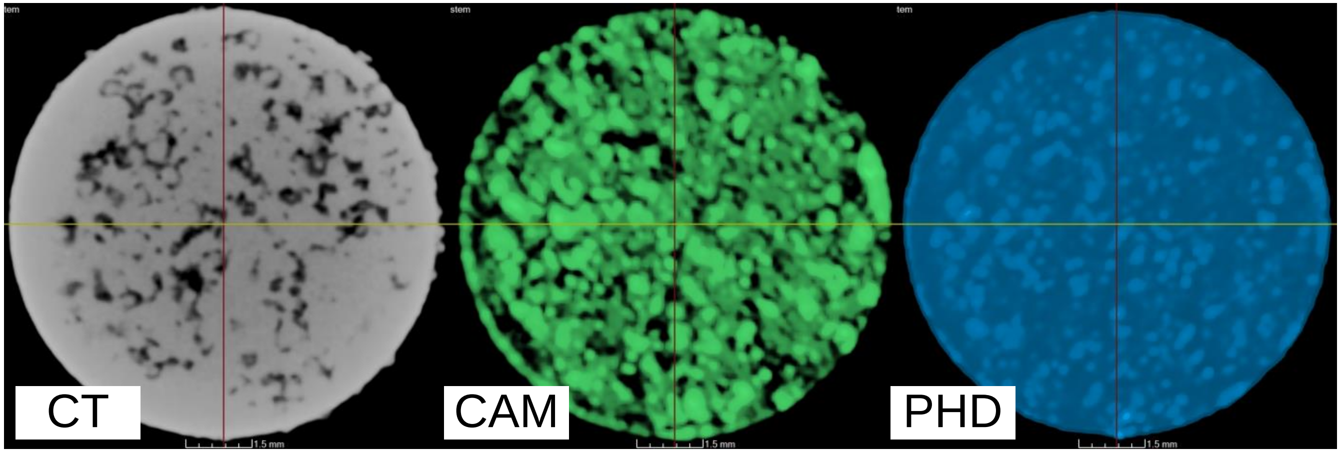
- Specimen 1
- Cross-sections
- sample CL 31 AL, BJ 2, Pos. 1_3



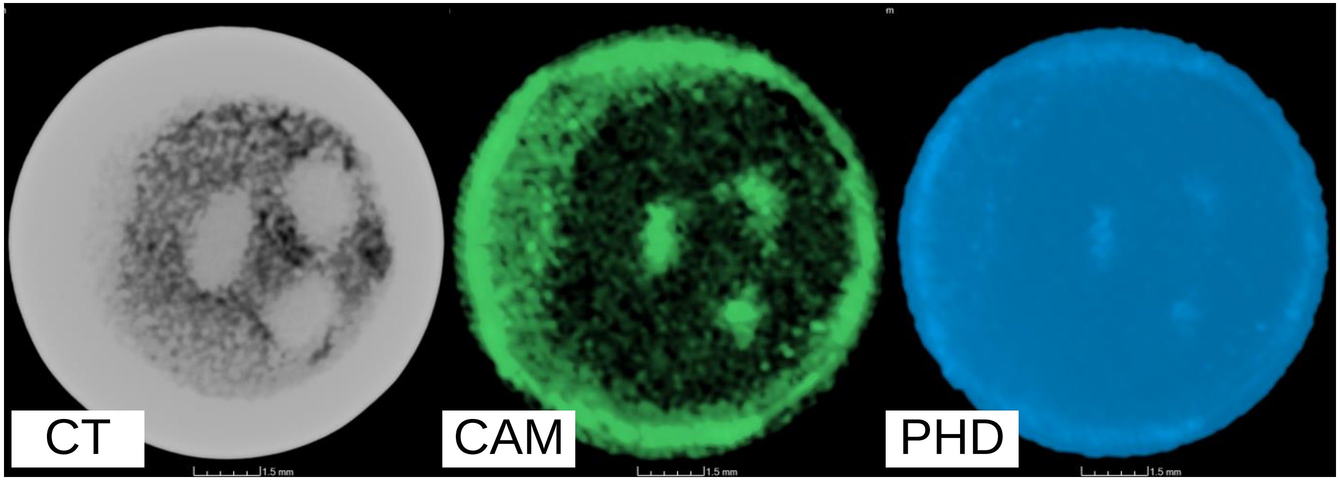
QM Meltpool 3D real-time monitoring system

Porosity (section 5 – hatch distance halved):

CL 31AL,
BJ 2, Pos. 1_3



CL 100NB,
BJ 2, Pos. 1_3



Fraunhofer Direct Digital Manufacturing Conference DDMC in Berlin/Germany

Range of AM-related topics:

- Product Development
- Technologies
- Materials
- Quality

DDMC 2018 proceedings out now:
https://www.bookshop.fraunhofer.de/buch/Fraunhofer-Direct-Digital-Manufacturing-Conference-DDMC-2018/249002

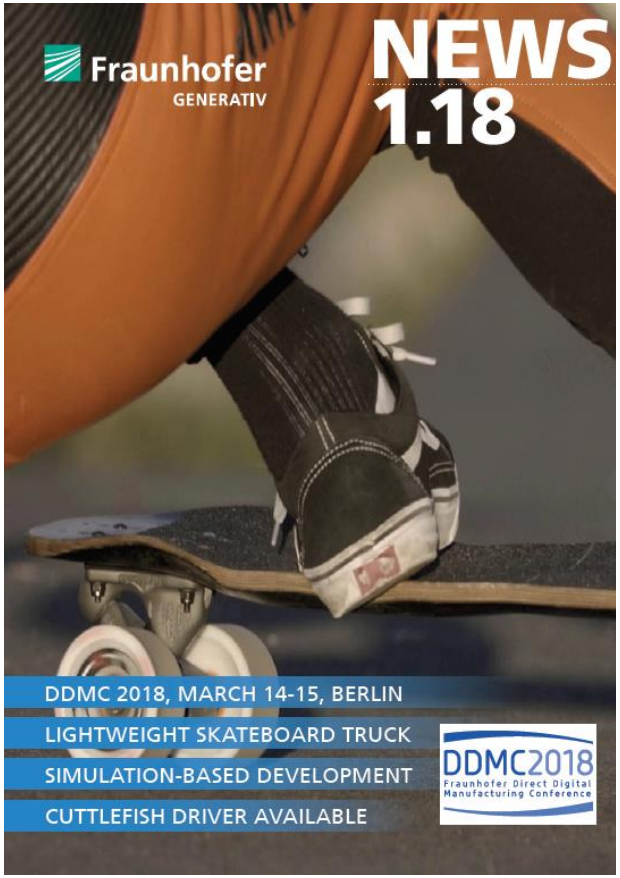
Save the date: **MARCH 18-19, 2020**

Call for papers: due by **JUNE 30, 2019**

DDMC2018
Fraunhofer Direct Digital Manufacturing Conference

Fraunhofer GENERATIV

Fraunhofer AM Alliance
NEWS 1.18



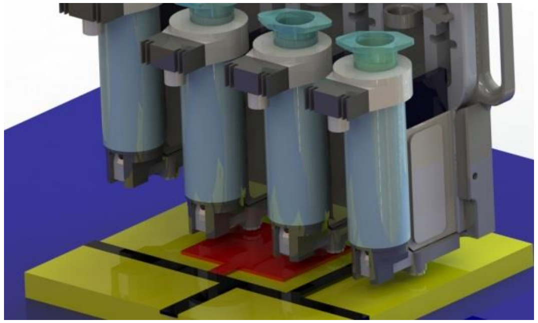
Highlights:

- Review of Fraunhofer DDMC 2018
- Lightweight Skateboard Truck
- Simulation-based Development
- Cuttlefish Driver available

Online at:

https://www.generativ.fraunhofer.de/en/profile.html

Leave your business card with me to receive a **paper copy via mail!**



Thank you for your attention!

Meet the Fraunhofer

Additive Manufacturing Alliance

at formnext

Frankfurt (Germany)

November 13-16, 2018

Hall 3.0, Booth E70

to celebrate with us

our 20th anniversary!

Fraunhofer Additive Manufacturing Alliance
Thank you for your attention!

Acknowledgements

Dr. Bernhard Mueller
Group Manager, Additive Manufacturing Dept. @ Fraunhofer IWU
Spokesman Fraunhofer Additive Manufacturing Alliance
Bernhard.Mueller@iwu.fraunhofer.de
Tel. +49 351 4772-2136

with contributions from:

Uwe Friess, Dr. Tino Langer (✞), Thomas Toeppel, Mathias Gebauer (all Fraunhofer IWU)

Dr. Uwe Klaeger (Fraunhofer IFF)

Moritz Wollbrink (Fraunhofer IPT)

Dr. Volker Zoellmer (Fraunhofer IFAM)

Dr. Holger Lausch (Fraunhofer IKTS)