AACHEN CENTER
FOR ADDITIVE
MANUFACTURING


# Discover3DPrinting @formnext 2022

## Basic AM Seminar

Viktoria Krömer | November 2022

formnext

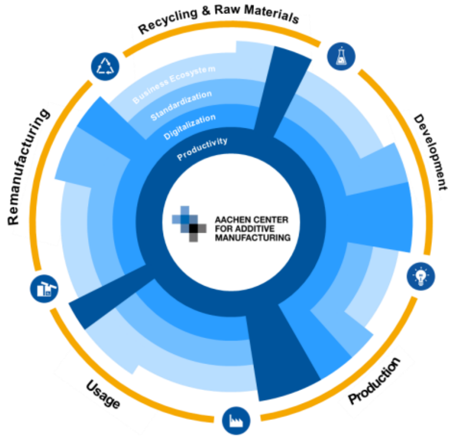
# The ACAM Offers Services in the Areas of Consulting, Engineering, Research and Education with a Focus on the Additive Manufacturing Industry

## Your presenter

*Viktoria Krömer*

- Consultant for ACAM Aachen Center for Additive Manufacturing GmbH
- Research Associate at the Laboratory for Machine Tools and Production Engineering (WZL) of RWTH Aachen University

## Perspective and focus




## Community

**BUSINESS Members**

oerlikon, TOYOTA, GMH GRUPPE, ZOLLERN, GRÄNGES, MTDG

**BASIC Members**

Materials Magic, PROTIQ, TÜV, DAIDO STEEL, SCHAEFFLER, LMT TOOLS, NISSAN, SCHÄFER, toolcraft, AMEXCI, APPLIED MATERIALS, aalberts, DENSO Crafting the Core, kurtz ersa, MESSER, voestalpine, Danfoss, GE Additive, OTTO FUCHS, Linde, THE AVIATION AM CENTRE, Hydro, AddUp, VDM Metals, GEA, AUBERT&DUVAL

**COOPERATION Members**

Efficient Elements, WINOVU, ACUNITY, stratasys, ENABLE3D, UN, formnext, 3YOURMIND, AMGTA

## Key figures

- One-stop-shop for additive manufacturing covering the entire process chain
- Pooling of resources of RWTH Aachen Campus and facilitating industry’s access to the Additive Manufacturing expertise of leading scientific and research institutions
- Over 100 researchers engaged in topics around the AM product life cycle and industry structure
- Delivery of approx. 40 industry project in consulting, engineering and research

# Basic AM Seminar – Content

Heritage

# The Cradle of Metal AM

The cradle of metal AM

1995

First Hybrid Machine Tool

1997

Basic Patent for SLM

2001

First Tool Insert

2008

First Implant

2015

Foundation of ACAM

The world‘s most vivid and multifaceted AM ecosystem

Image Source: DAP RWTH Aachen University, Fraunhofer ILT, Campus GmbH

# RWTH Aachen Campus
## A Unique Research Landscape – the Engineering Valley

*„Megatrends such as digitalization, automation, mobility, climate change, globalization or demographic change are changing the world and creating major challenges for society. The combination of different scientific disciplines and companies is necessary to solve these complex relationships and issues.“**

- **1870 founded**
- **260 institutes**
- **6.000 research assistants**
- **390 Mio. € Third party funds per year**
- **University of Excellence since 2007**


**Enrollment of the companies with the objectives:**

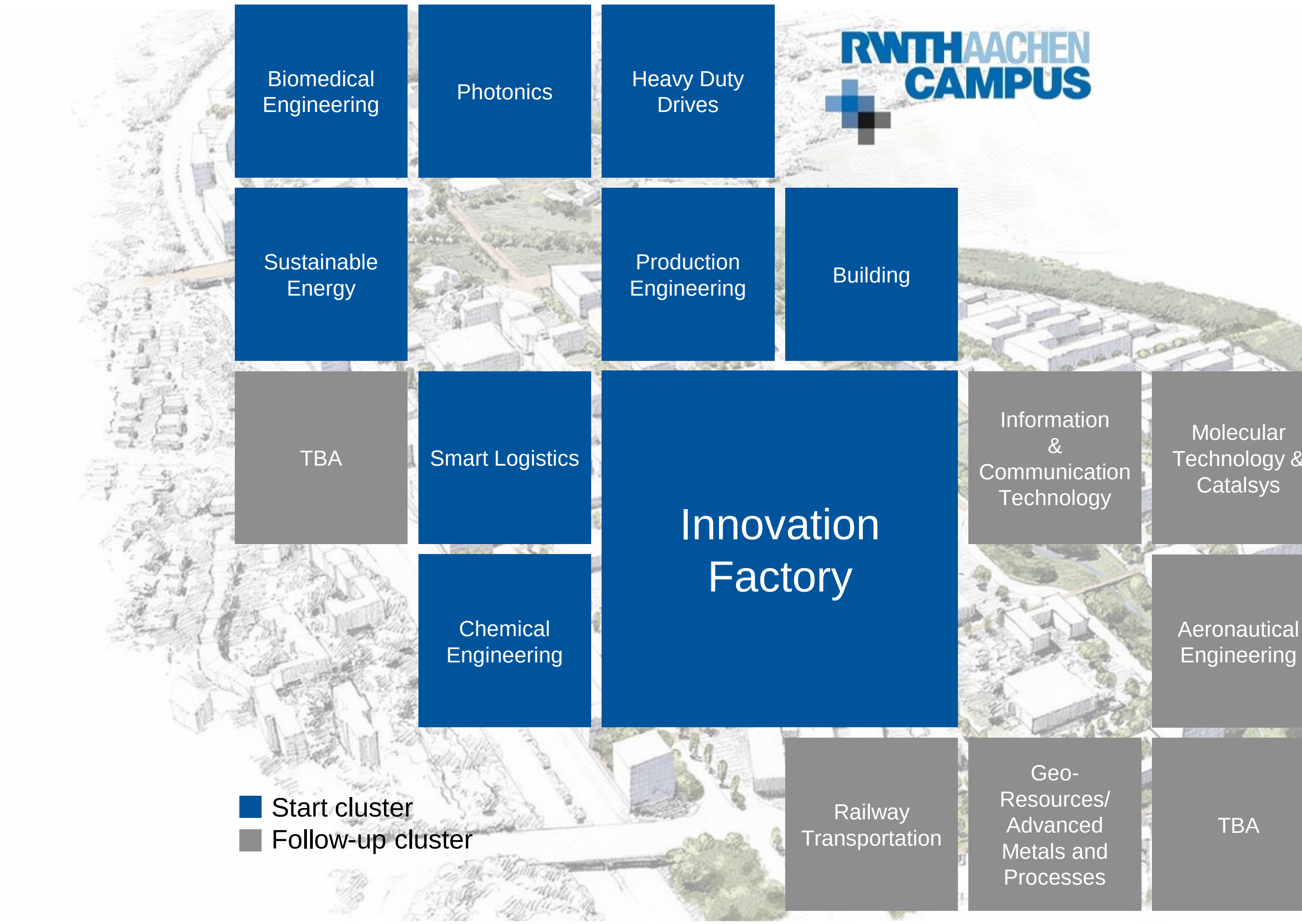
- Joint research & development
- Exchange with experts from science & business
- Use of specific further training offers
- Use of individual services

**> 400 enrolled companies**

**Exchange and development of knowledge between research and industry –**
**Companies, institutes and the university share resources, utilize synergies and jointly conduct research on sustainable innovations**

*Vision of the RWTH Aachen Campus

# RWTH Aachen Campus:
# **16 Research Clusters Are Developing**




**Cluster Smart Logistic**

**Cluster Heavy Duty Drives**

**Cluster Photonics**

**Cluster Sustainable Energy**

**Cluster Production Engineering**

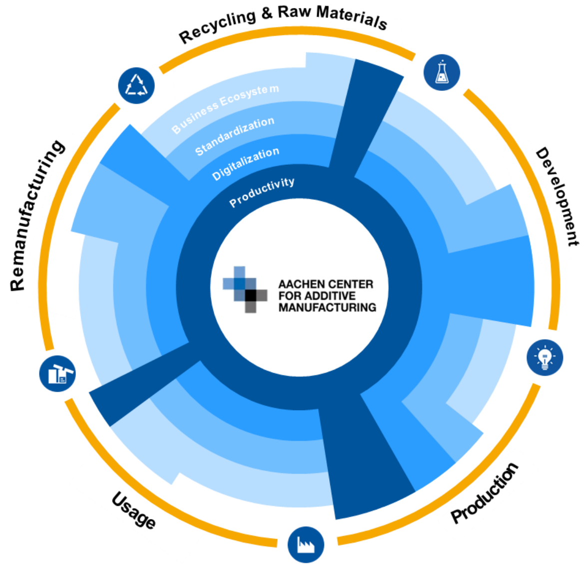
**Cluster Bio-Medical Engineering**

**Cluster Chemical Engineering**

# Community
# The Aachen Center for Additive Manufacturing

## Navigating AM complexity

Creating opportunities by leading-edge **R&D**, professional **training and education**, and agile **engineering** and **consulting** services




- Dedicating **3,000 m²** lab space to AM research
- Connecting **100+ researchers** in the field of AM

## Leading-Edge Research in Additive Manufacturing


**The ACAM is your one stop shop for Additive Manufacturing research, education, engineering and consulting.**

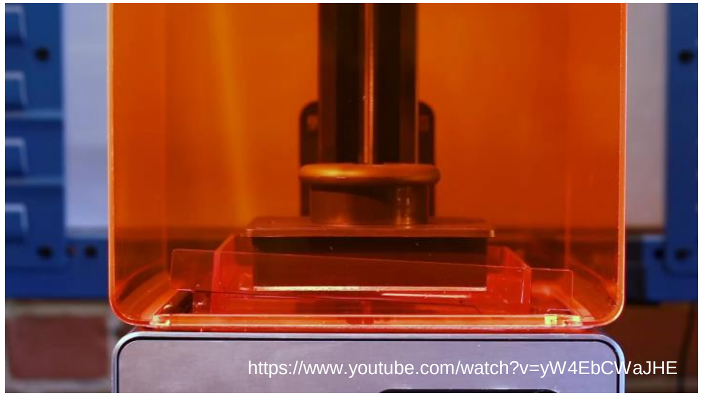
# Basic AM Seminar – Content

# Additive Manufacturing – Definition

## Definition (ASTM 52900)

*"Additive Manufacturing (AM) is defined as the process that*

- ***produces components from 3D model** data*
- *by **joining material usually layer by layer**,*
- *as opposed to subtractive and formative manufacturing methods."*

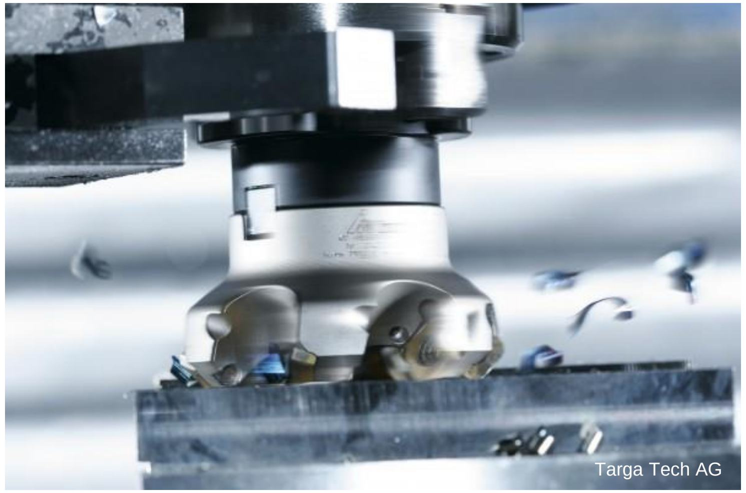




## Definition (VDI 3405)

*"Manufacturing process in which the **work piece is built up in successive layers or units**."*


# Introduction to AM
# Subdivision of Manufacturing Technologies

## Subtractive Manufacturing




Manufacturing of geometry by removing of defined areas from workpiece

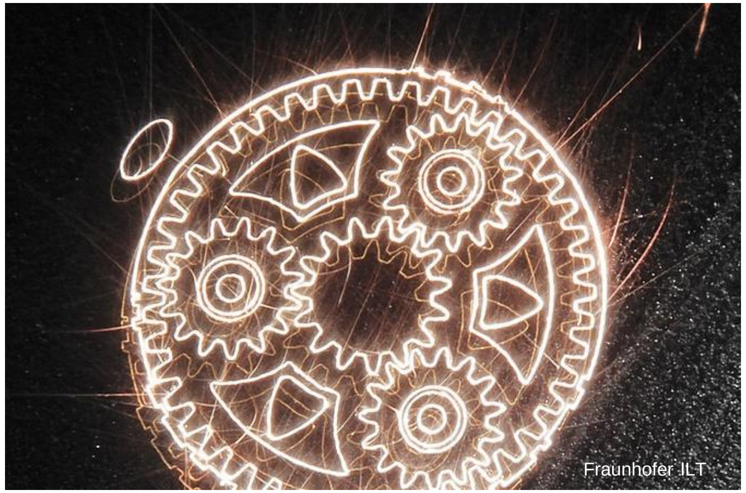
- Milling
- Turning
- …

## Formative Manufacturing


Forming a given volume into geometry under the condition of constant volume

- Deep Drawing
- Molding
- …

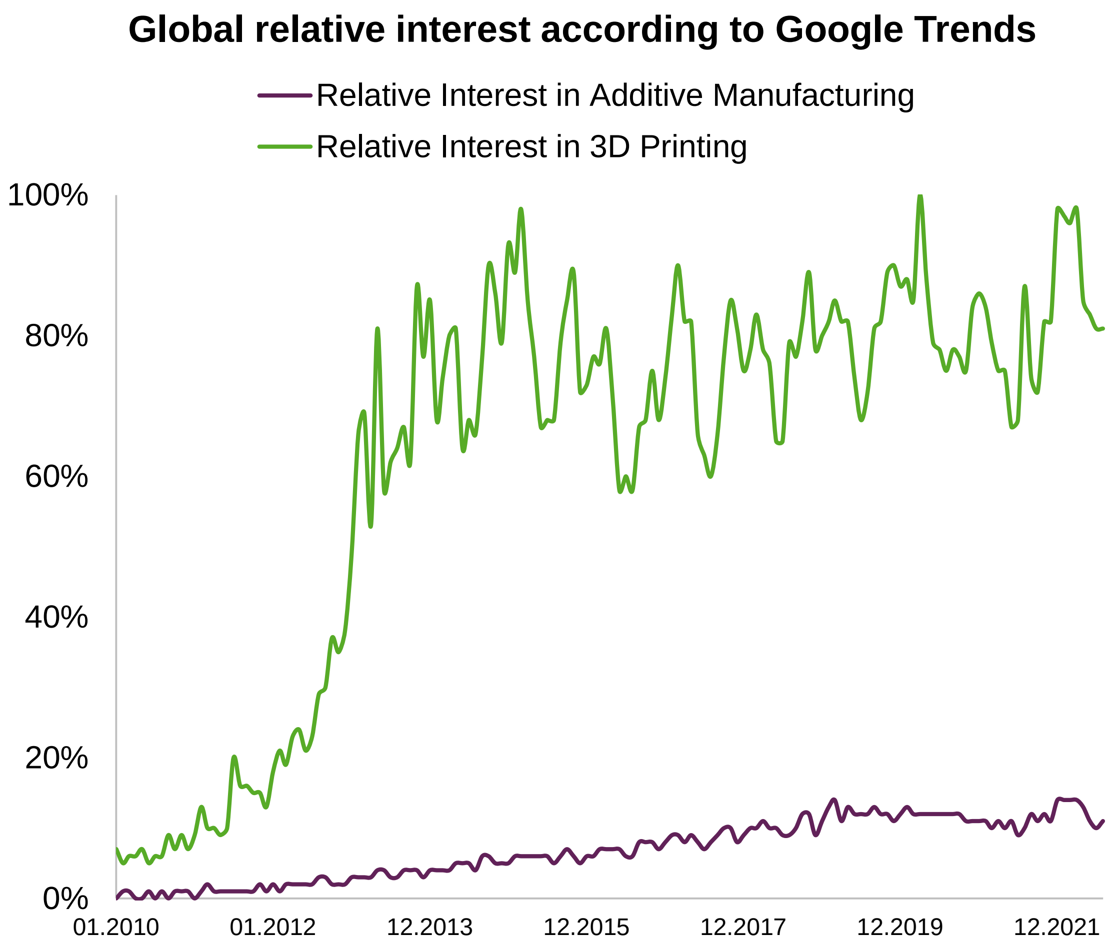
## Additive Manufacturing




Stacking of volume elements (usually in layers)

- Laser Powder Bed Fusion
- Laser Metal Deposition
- …

# Global Interest on AM According to Google Trends




- **Overall positive trend** of relative interest in AM and 3D printing in online search engines
- **Lower interest in AM compared to 3D printing** because **AM** is the **more scientific term**
- **Strong increase (hype) until 2013/2014** of the search term **3D printing**

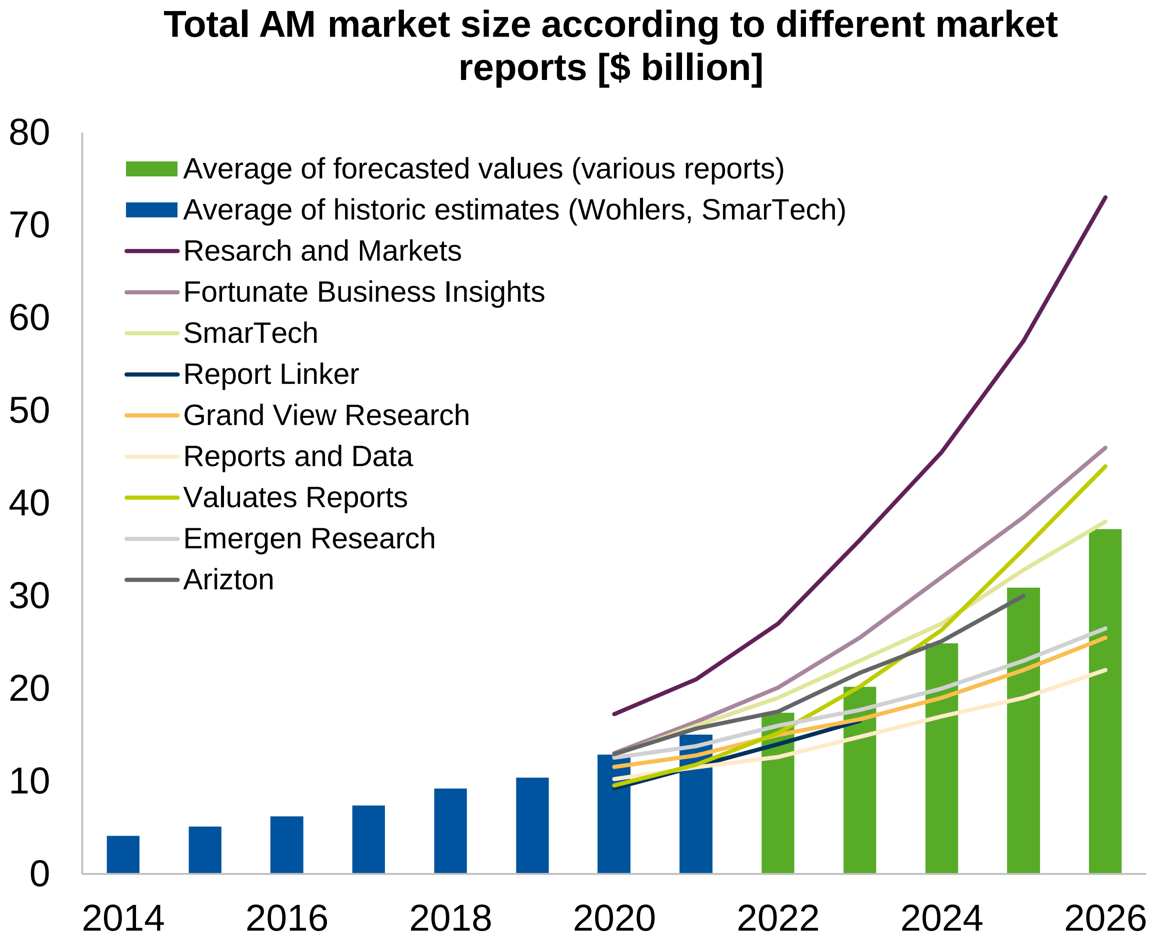
**"3D Printing has the potential to revolutionize the way we make almost everything"**

Barack Obama, State of the Union, Feb 2013


Source: Google Trends

Introduction to AM

# Positive Historic and Future Development of the AM Market

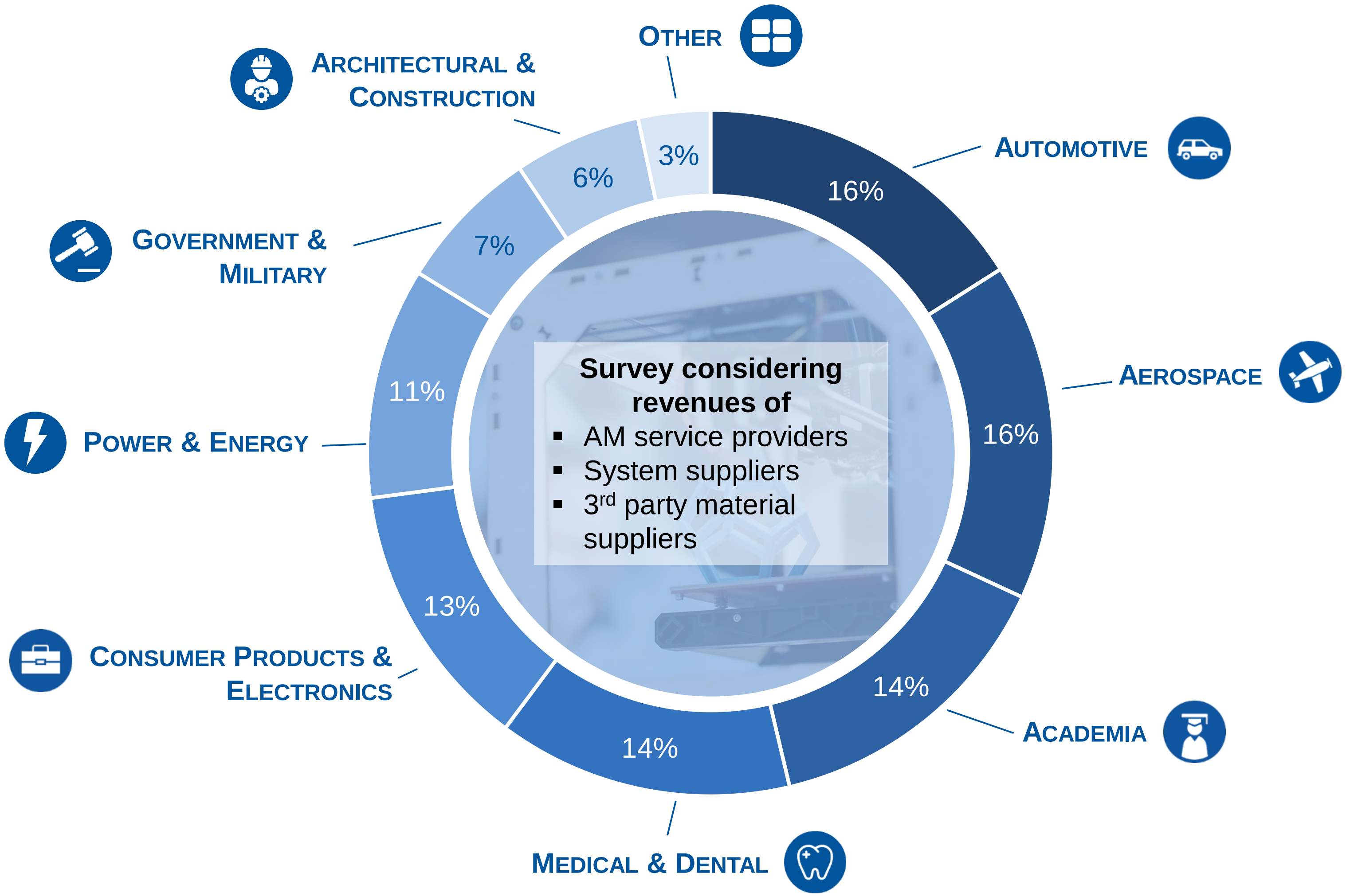



- **Overall positive** forecasted and historic growth rates in all reports
- **Diverging positive forecasts** indicate a **developing** volatile and uncertain market

- **Included revenue (primary market):**
  - AM systems
  - Software
  - Materials
  - Services

Source: Hubs Additive manufacturing trend report 2021 and cited sources

# Introduction to AM
# **Market Overview**




Source: Wohlers Report 2021

# General AM Process Chain

| | Pre-Processing | In-Processing | Post-Processing | Final Component |
|---|---|---|---|---|
| **Physical Dimension** | ▪ Material preparation<br>▪ Production resource preparation<br>▪ Machine preparation | ▪ Physical generation of geometry | ▪ Build job removal and cleaning<br>▪ Part finishing<br>– e.g., support removal, heat treatment, surface treatment, quality assurance | ▪ Assembly<br>▪ Labelling, packaging, shipping |
| **Digital Dimension** | ▪ Data preparation (CAD & CAM)<br>▪ Build job preparation<br>▪ Production planning | ▪ Execution of machine code<br>▪ Printing process monitoring | ▪ Acquisition and evaluation of quality assurance data | ▪ Evaluation of data for long-term improvement |

# Introduction to AM
## Key Characteristics of Additive Manufacturing

### Additive


*Geometry is generated by adding material instead of removing or forming*

### Toolless

*Component geometry is independent from tool*

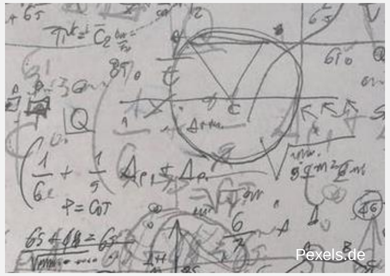


### Digital


*Direct manufacturing based on 3D models*

### Complex

*Different technologies require specific expert knowledge*



# AM Benefits and Barriers

## AM Benefits

- **Design freedom**: Complex features, lightweight, monolithic
- **Flexible design** iterations and engineering changes
- **Integration of functions**
- Economic **small quantities** and **individualization**
- **Short time** and efficiency **idea to product**
- **Short supply chain**
- **Insourcing:** Appealing due to high degree of automation
- **Sustainability** by material reduction or efficiency in performance

## AM Barriers

- **Long printing times**
- Almost **no economies of scale**
- **Low surface quality** as-built
- **Large geometrical tolerances** as-built
- **Requires** "Additive Mindset" and **skills**
- **Complex quality assurance** and **certification**
- **Health and security** measures required

AM **benefits and barriers** are **not generic –** consideration of use case, AM technology and process chain mandatory

Image Sources: Unsplash, Pexels

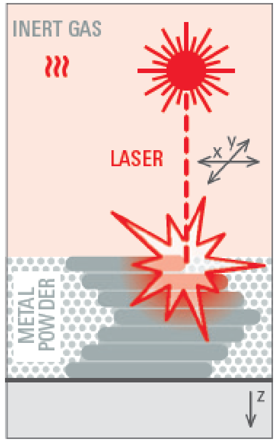
# Basic AM Seminar – Content

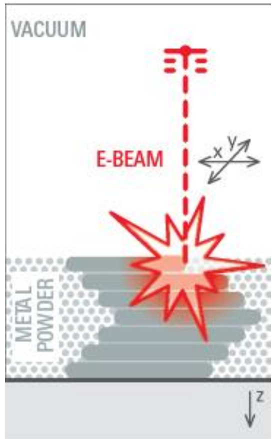
# AM Technology Overview
## Segmentation of Established Metal AM Technologies

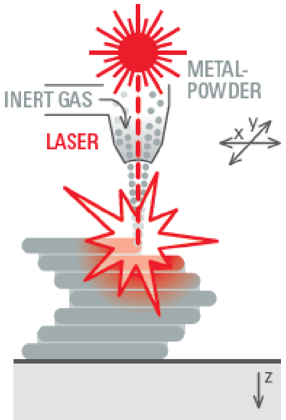
**Additive Manufacturing**

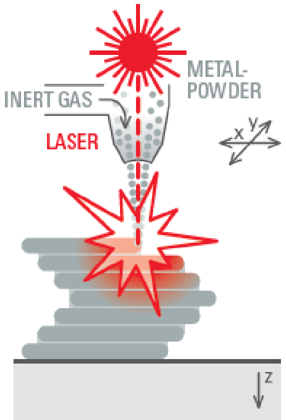
**Metal**

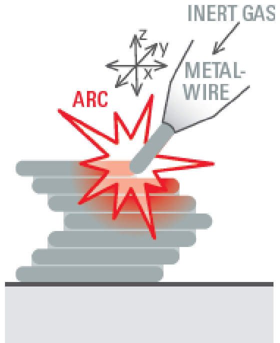
| *Powder Bed Fusion* | | *Direct Energy Deposition* | | | *Material Extrusion* | *Binder Jetting* | *Material Jetting* |
|---|---|---|---|---|---|---|---|
| Fused with laser | Fused with electron beam | Laser energy absorbed by substrate | Laser energy absorbed by powder feedstock | Fused with electric arc | With filament, green part to be sintered | Joined with bonding agent, to be sintered | Cured with heat, to be sintered |
| **L-PBF** Laser Powder Bed Fusion | **EBM** Electron Beam Melting | **LMD** Laser Metal Deposition | **EHLA** Extreme High Speed LMD | **WAAM** Wire Arc Additive Manufacturing | **Metal FDM** Metal Fused Deposition Modeling | **BJ** Binder Jetting | **NPF** Nano Particle Jetting |

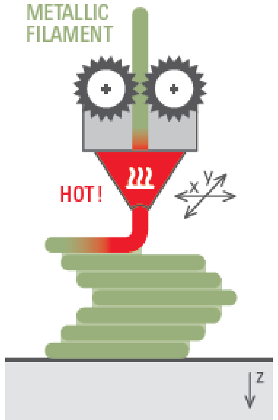


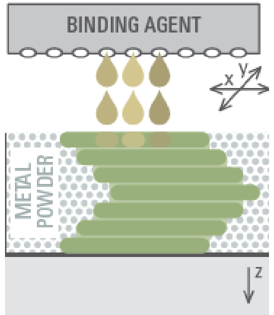



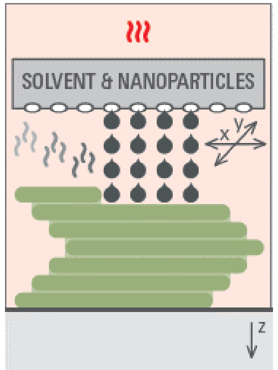



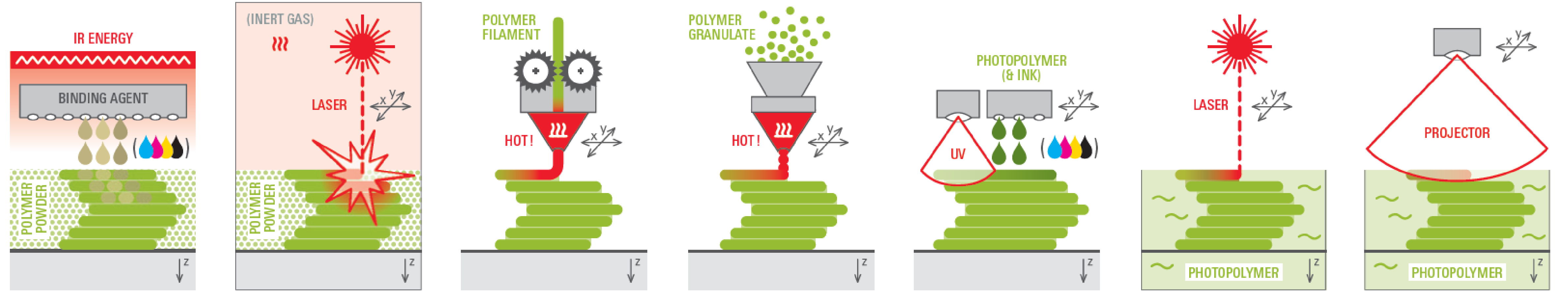

Source: Derived from Fomrnnext AM Field Guide Compact and DIN EN ISO/ASTM Terminology

# AM Technology Overview
## Segmentation of Established Polymer AM Technologies

**Additive Manufacturing**

**Polymer**

- ***Powder Bed Fusion***
  - Fused with agent + energy → **MJF** Multi Jet Fusion
  - Fused with laser → **SLS** Selective Laser Sintering
- ***Material Extrusion***
  - With filament → **FDM** Fused Deposition Modeling
  - With granulate → **Granulate FDM**
- ***Material Jetting***
  - Cured with UV light → **MJ** Material Jetting
- ***Photopolymerization of Resins***
  - Cured with laser → **SLA** Stereo Lithography
  - Cured with projector → **DLP** Digital Light Processing



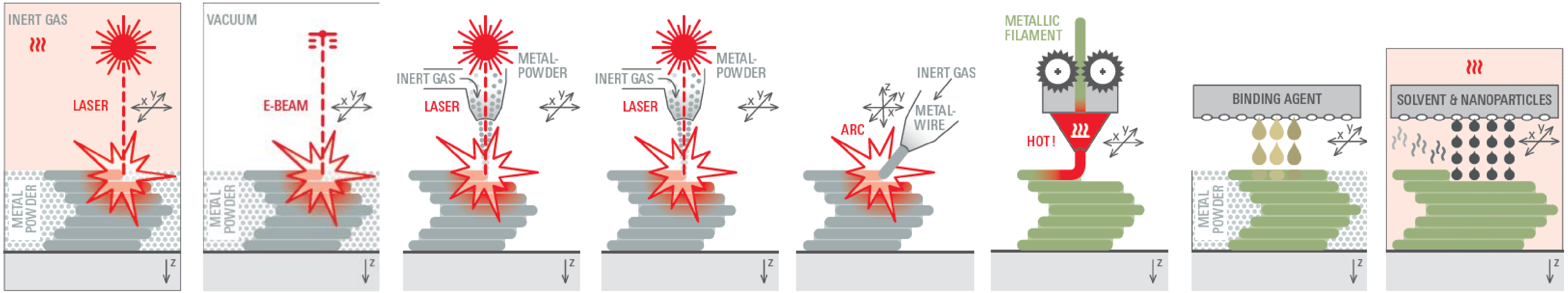

Source: Derived from Fomrnnext AM Field Guide Compact and DIN EN ISO/ASTM Terminology

# AM Technology Overview
## Segmentation of Established Metal AM Technologies

**Additive Manufacturing**

**Metal**

| *Powder Bed Fusion* | | *Direct Energy Deposition* | | | *Material Extrusion* | *Binder Jetting* | *Material Jetting* |
|---|---|---|---|---|---|---|---|
| Fused with laser | Fused with electron beam | Laser energy absorbed by substrate | Laser energy absorbed by powder feedstock | Fused with electric arc | With filament, green part to be sintered | Joined with bonding agent, to be sintered | Cured with heat, to be sintered |
| **L-PBF** Laser Powder Bed Fusion | **EBM** Electron Beam Melting | **LMD** Laser Metal Deposition | **EHLA** Extreme High Speed LMD | **WAAM** Wire Arc Additive Manufacturing | **Metal FDM** Metal Fused Deposition Modeling | **BJ** Binder Jetting | **NPF** Nano Particle Jetting |

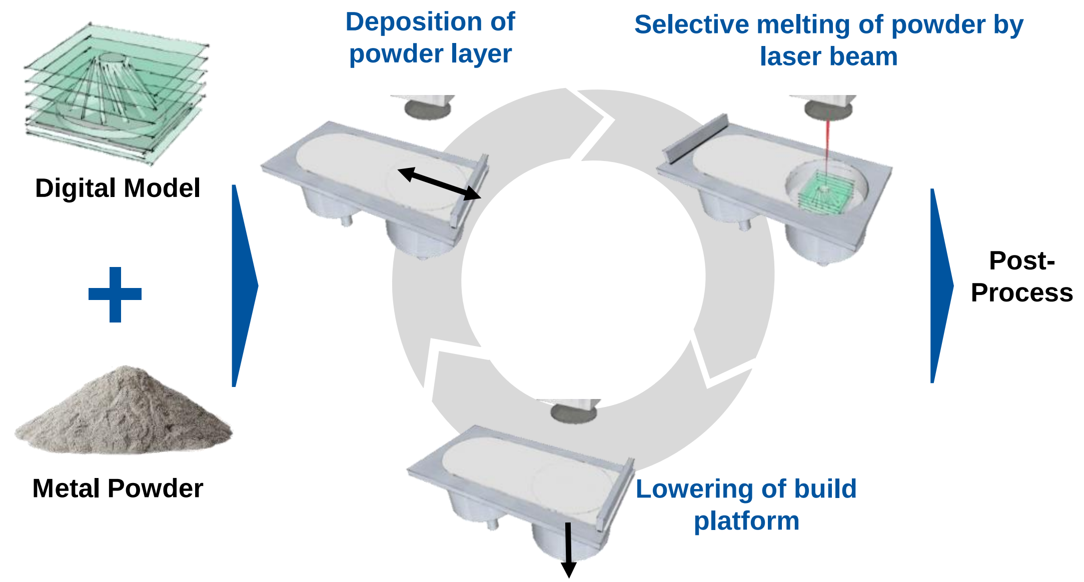



Source: Derived from Fomrnnext AM Field Guide Compact and DIN EN ISO/ASTM Terminology

AM Technologies

# Laser Powder Bed Fusion of Metal (LPBF)

## Process Principle

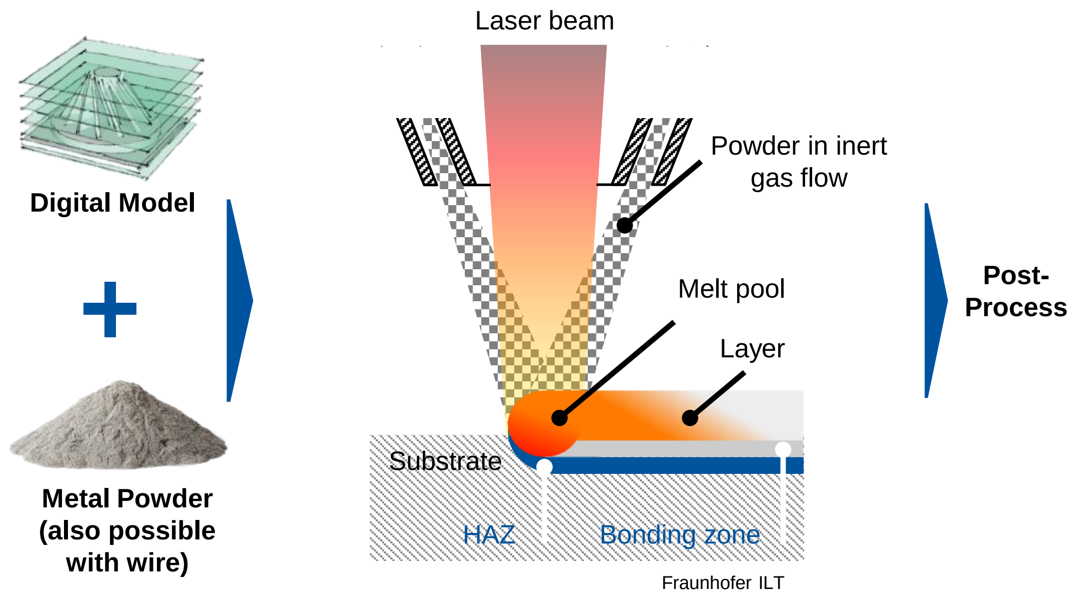



## Process in Action

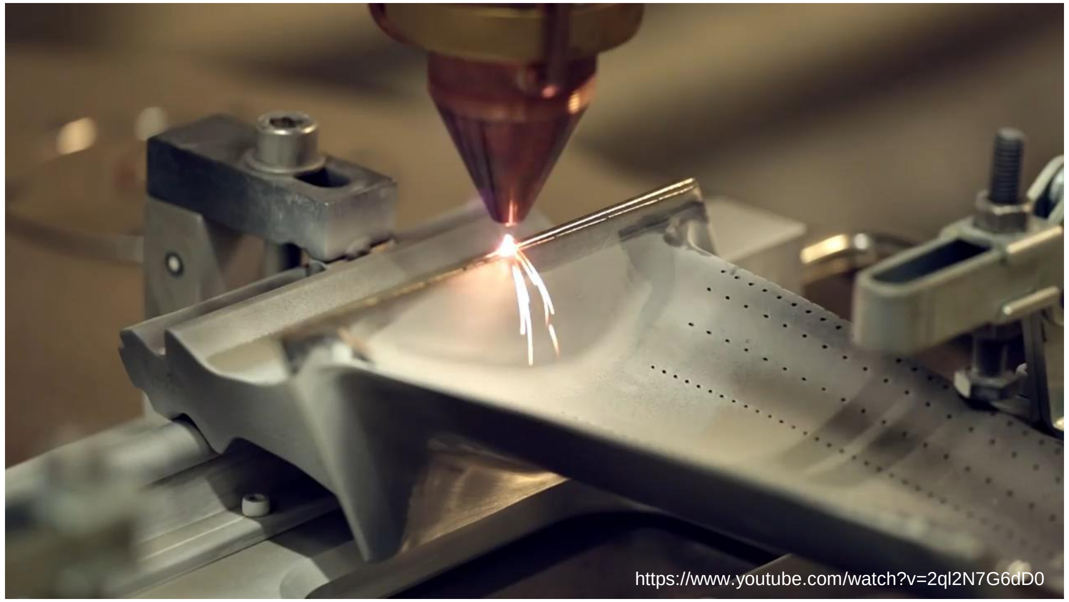

- Selective melting of metal powder layer-by-layer with one or more lasers
- Requires support structures for overhangs
- General suitability for weldable materials, comparably many alloys are qualified (e.g., steels, Ni based alloys, CoCr, copper and alloys, Ti and alloys, Al alloys, refractory metals, Mg alloys, HEA)

# AM Technologies
# **Laser Metal Deposition (LMD)**

## Process Principle



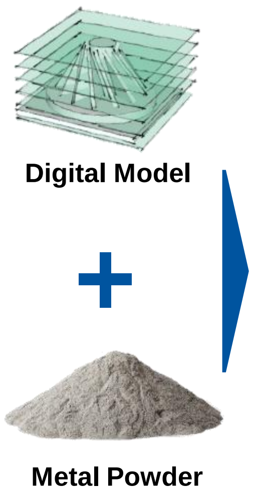

## Process in Action

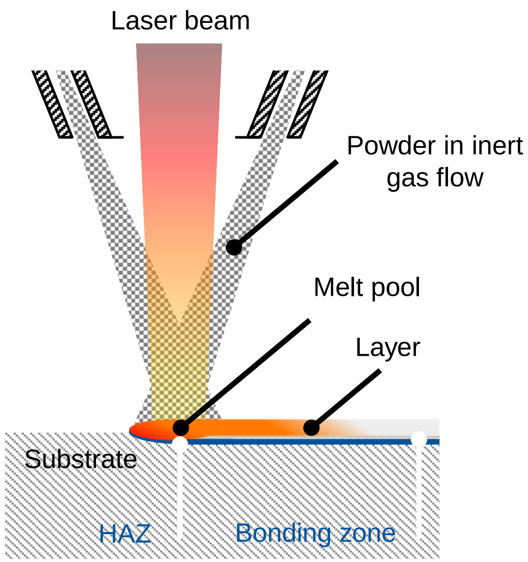



- Used for additive manufacturing, additive coating and repair (deposition on existing geometry)
- Powder is transported by an inert gas flow
- Energy for melting the metal powder is mainly deposited in the substrate, not directly in the powder
- General suitability for weldable materials, different materials qualified (e.g., steels, Ni-base alloys, Al alloys)

# AM Technologies
# Extreme High Speed Laser Metal Deposition (EHLA)

## Process Principle

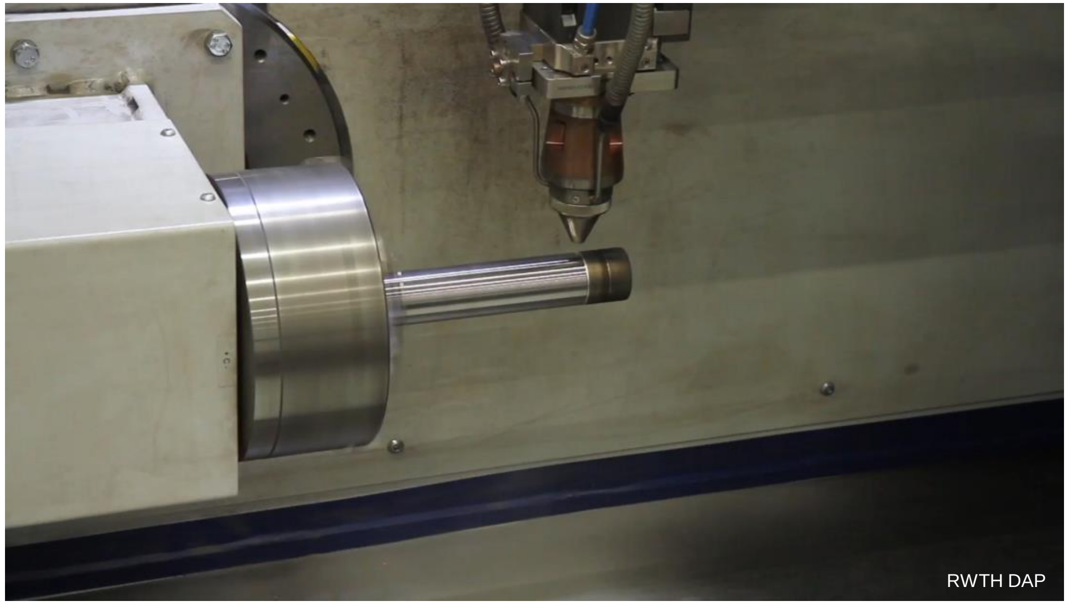



Fraunhofer ILT

**Post-Process**

## Process in Action

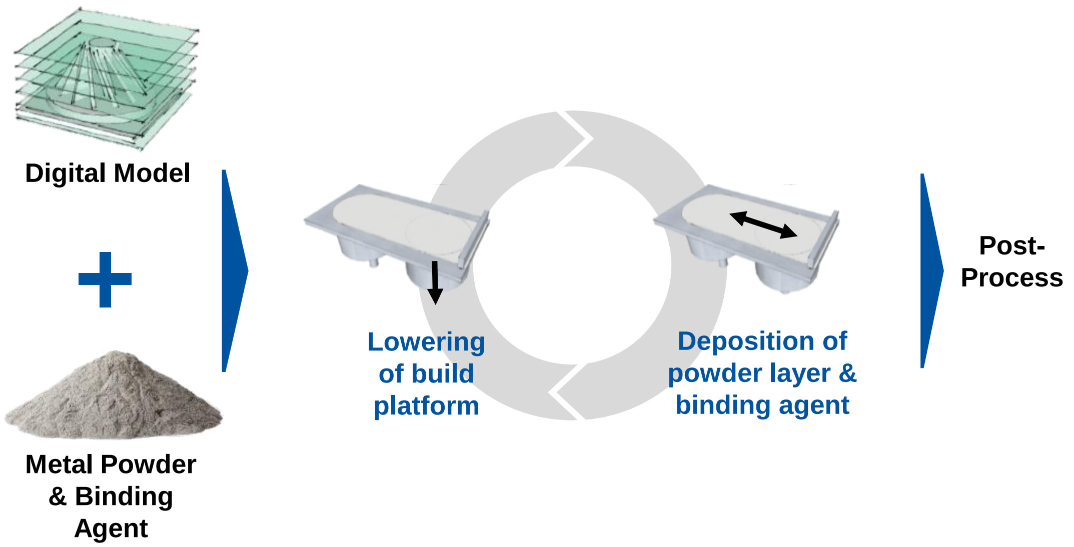


RWTH DAP

- Application of homogenous coatings on rotationally symmetrical parts with higher process speed than LMD
- Powder is transported by inert gas flow
- Energy is mainly deposited in the metal powder and not the substrate
- EHLA for AM of 3D parts is an emerging technology

# AM Technologies
# **Binder Jetting (BJ)**

## Process Principle




## Process in Action


- Production of complex geometries by selective deposition of binder agent on metal powder layer by layer
- As-built part is in green state and requires further processing steps for functionality (e.g., curing, depowdering, sintering)
- Compared to LPBF lower technological maturity and less materials qualified, but potential of higher productivity

# AM Technology Overview
## Available Metal Materials

### Precious Materials
- Mainly gold and silver material for jewelry applications

### Copper Alloys
- High heat conductivity
- Low absorption of laser radiation

### Stainless Steel
- High ductility
- Corrosion-resistant
- Easy to post-process

### Tool Steel
- High ductility
- Corrosion-resistant
- Easy to post-process

### Nickel-Based
- Corrosion-resistant
- High mechanical strength
- Hardening possible

### Cobalt-Based
- High strength & hardness
- Temperature-resistant
- Corrosion-resistant

### Titanium Alloys
- Lightweight, high strength per density
- Corrosion-resistant

### Aluminum Alloys
- Lightweight
- Low material density
- Suitable for casting

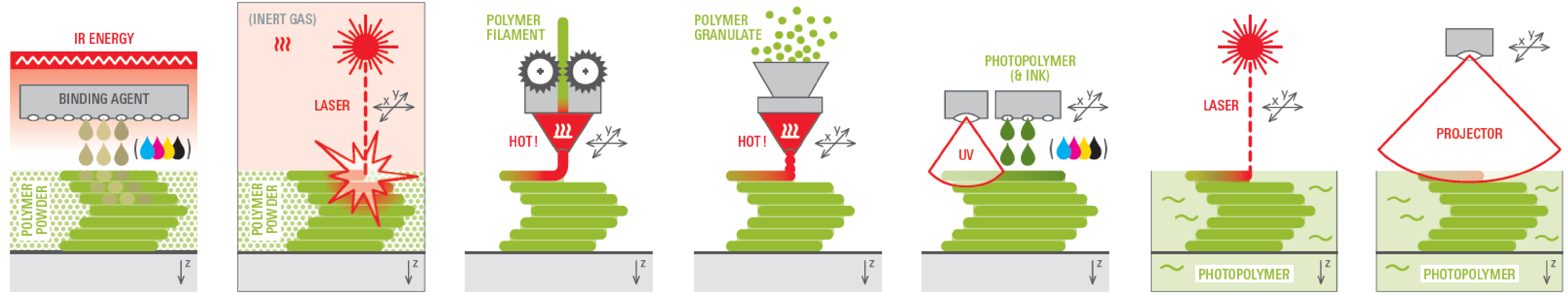
Source: BCG (2019)

# AM Technology Overview
## Segmentation of Established Polymer AM Technologies

**Additive Manufacturing**

**Polymer**

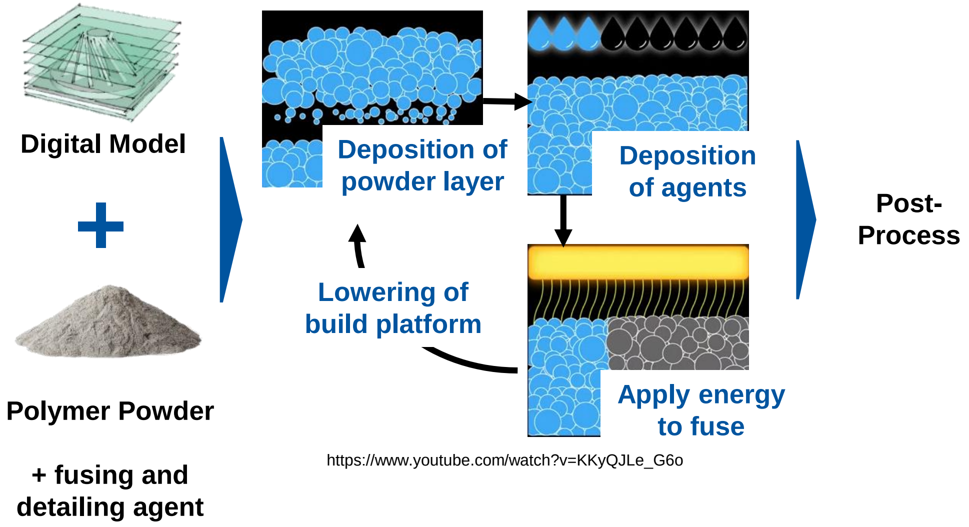
| *Powder Bed Fusion* | | *Material Extrusion* | | *Material Jetting* | *Photopolymerization of Resins* | |
|---|---|---|---|---|---|---|
| Fused with agent + energy | Fused with laser | With filament | With granulate | Cured with UV light | Cured with laser | Cured with projector |
| **MJF** Multi Jet Fusion | **SLS** Selective Laser Sintering | **FDM** Fused Deposition Modeling | **Granulate FDM** | **MJ** Material Jetting | **SLA** Stereo Lithography | **DLP** Digital Light Processing |



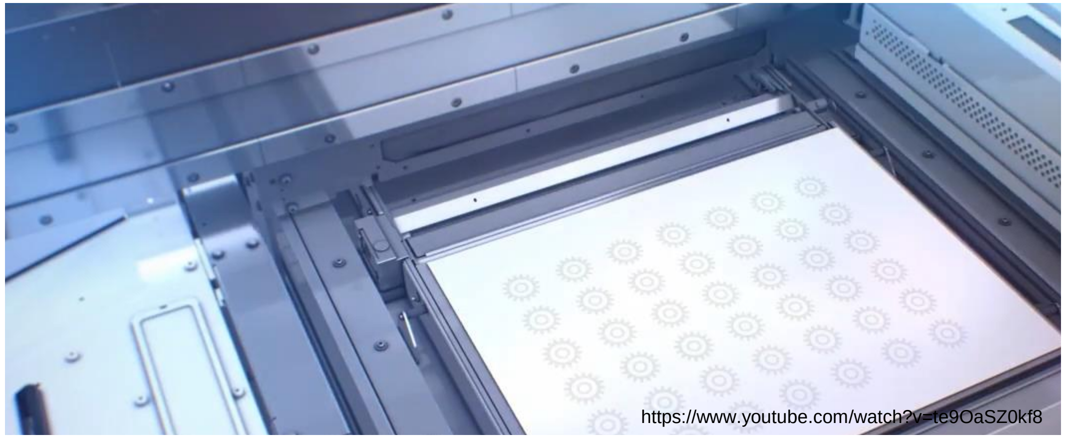

Source: Derived from Fomrnnext AM Field Guide Compact and DIN EN ISO/ASTM Terminology

# AM Technologies
# **Multi Jet Fusion (MJF)**

## Process Principle



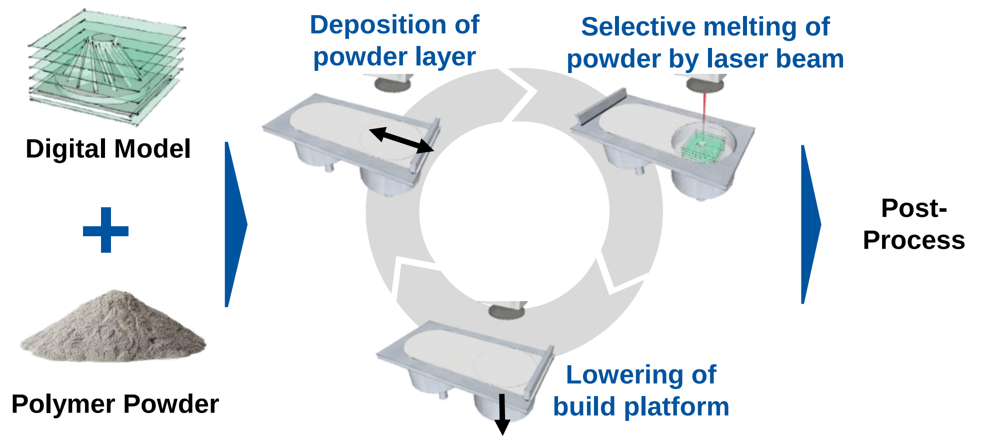

## Process in Action



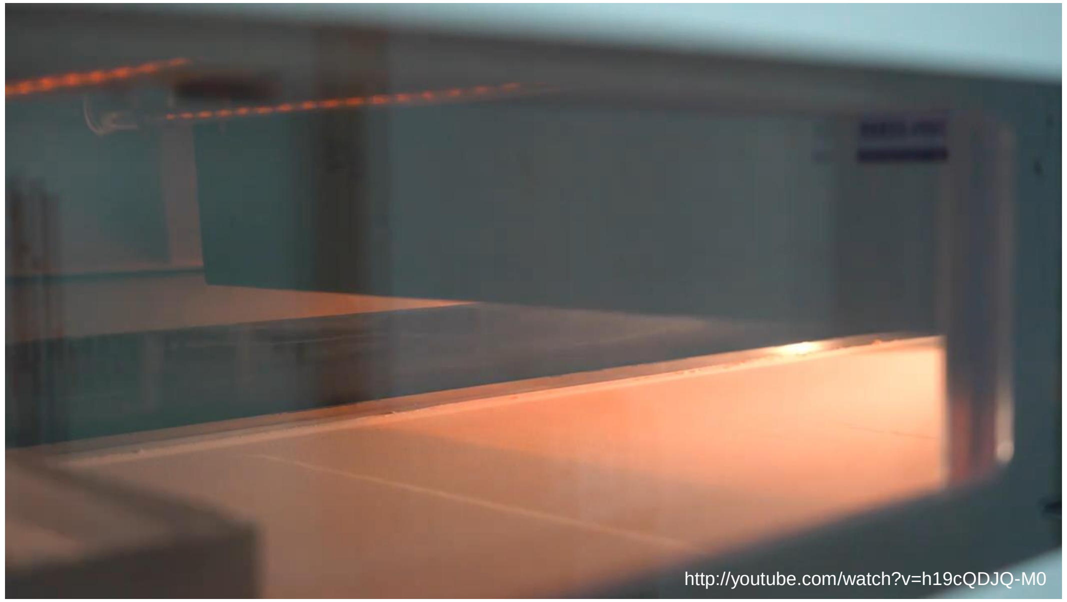

- Layer-by-layer application of material applied to powder in build chamber
- Introduction of liquid binder by inkjet print heads to bond powder particles together
- Energy input (curing) through UV lamps

# AM Technologies
## Selective Laser Sintering (SLS)

### Process Principle



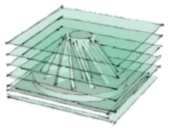

### Process in Action




- Production of complex geometries by selective melting of polymer powder with one or more lasers
- As-built parts are usually white (polymer color)
- Many different materials available (e.g., PA11, PA12, TPU, PEEK, TPE, PP)

# AM Technologies
# Fused Deposition Modeling (FDM)

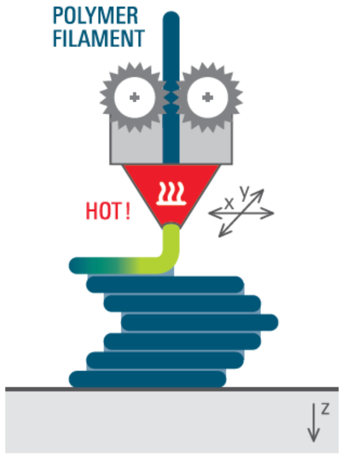
## Process Principle



Digital Model

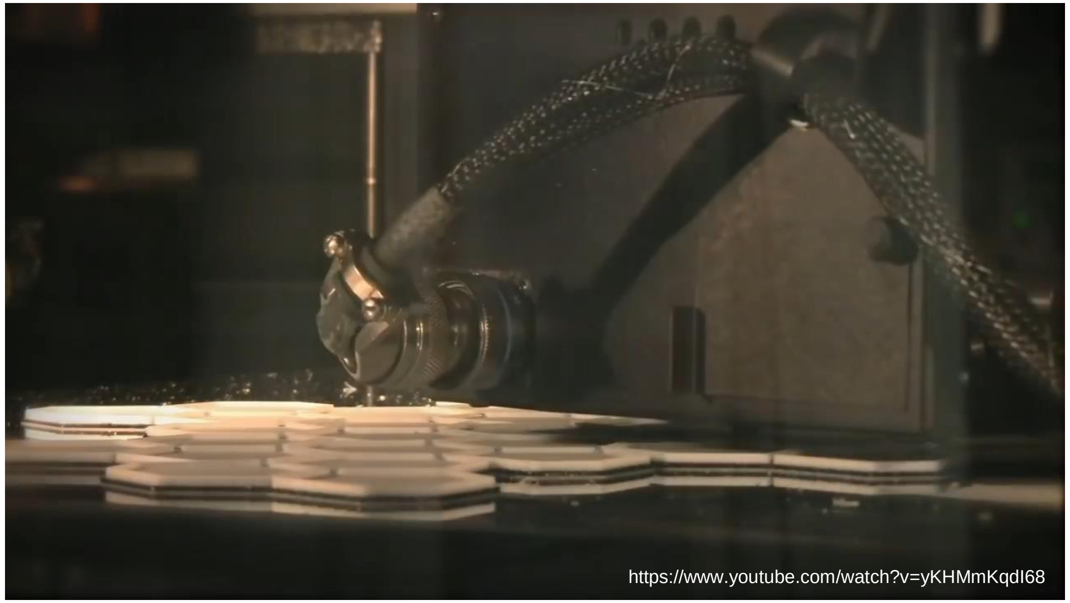
+

Thermoplastic filament




Post-Process

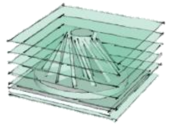
## Process in Action




- Thermoplastic filament is molten and extruded through a hot nozzle
- Support structures are required for overhangs
- Use in industry, but also huge open source and DIY community
- Many materials available (e.g, PLA, ABS, PP, PA, PC, TPE, TPC, TPU, PEEK, PEKK, PPSU, PEI)

# AM Technologies
# **Stereolithography (SLA)**

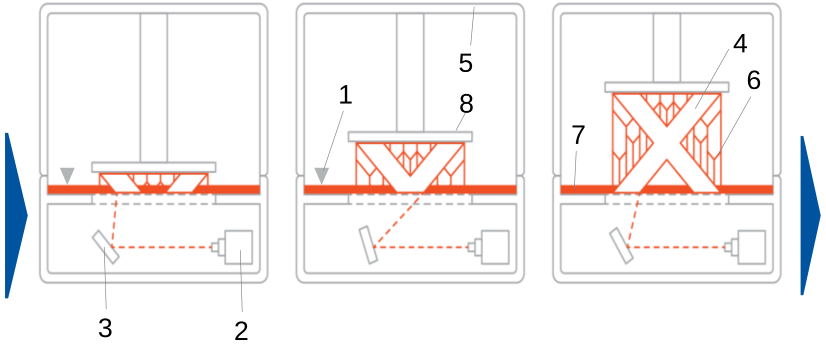
## Process Principle



**Digital Model**

+

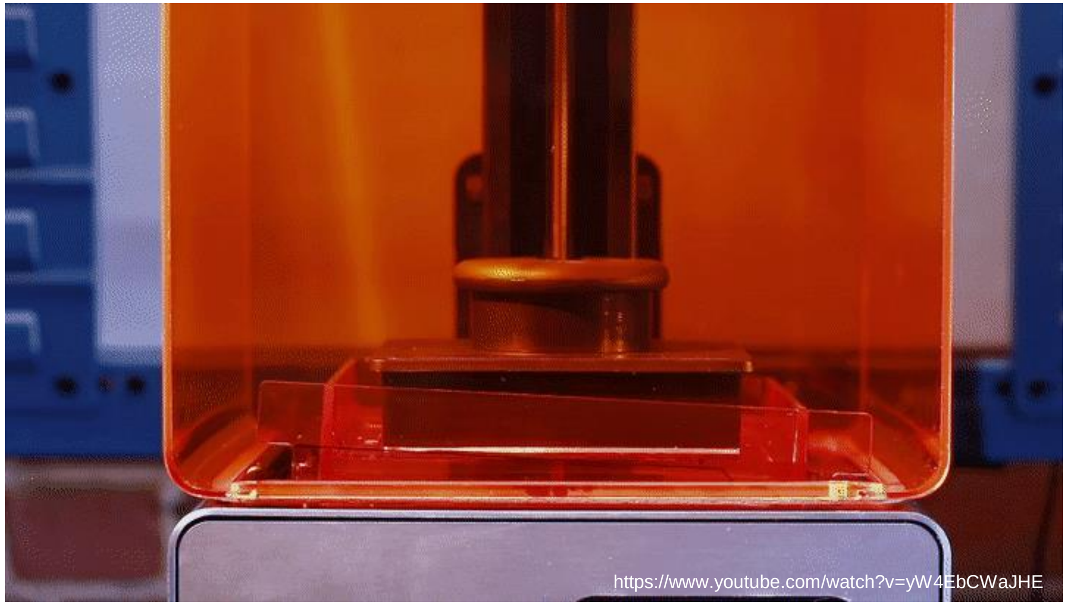
**Photo-reactive resin**




**Post-Process**

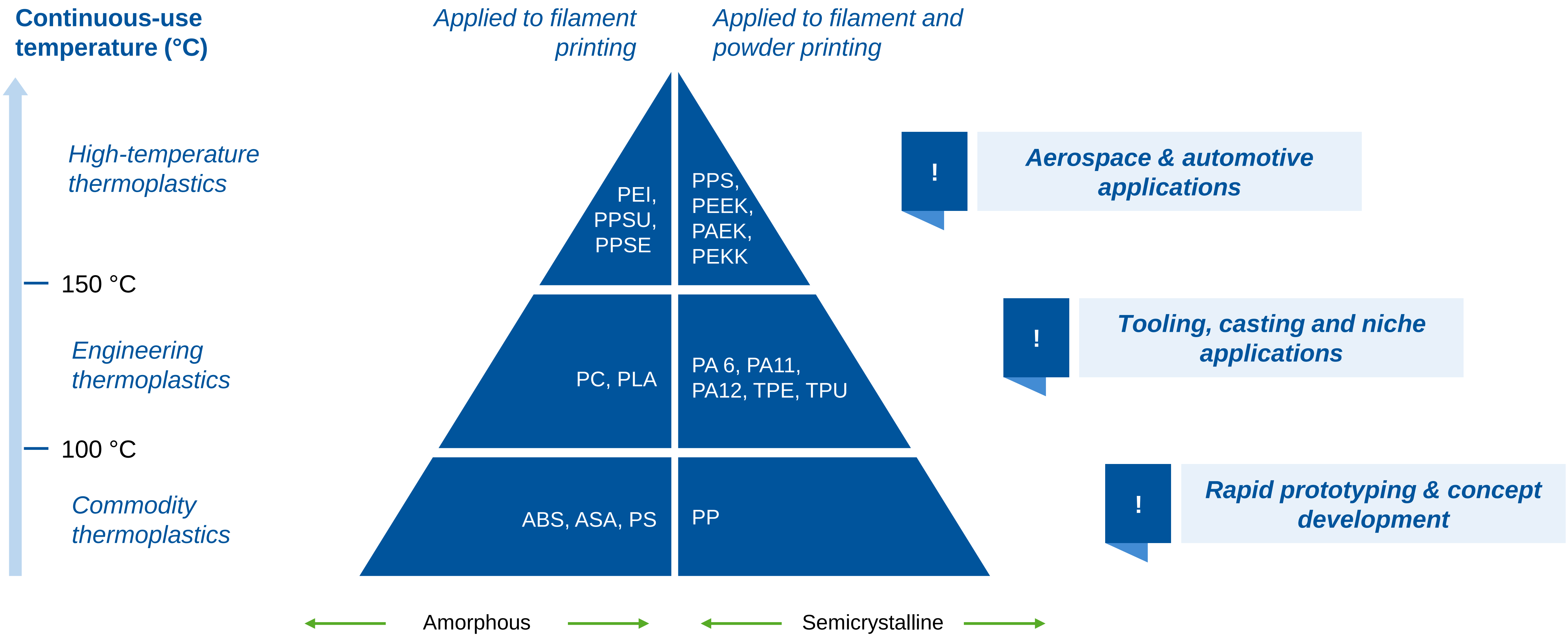
1. Surface of polymer bath
2. Laser
3. X-Y-scanner
4. Generated part
5. Housing
6. Support structure
7. Polymer batch
8. Build platform

## Process in Action




- Polymerization of photo-reactive resin by selective scanning with a UV laser beam (usually through transparent container from below)
- Requires support structures for overhangs
- Wide range of photo-reactive resins with different optical, thermal and mechanical properties

# AM Technology Overview
## Available Polymer Materials

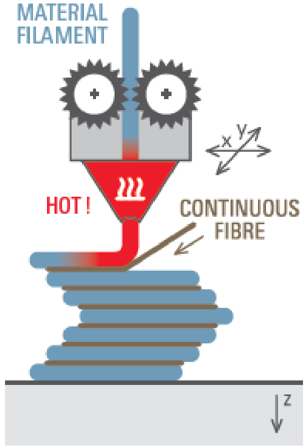


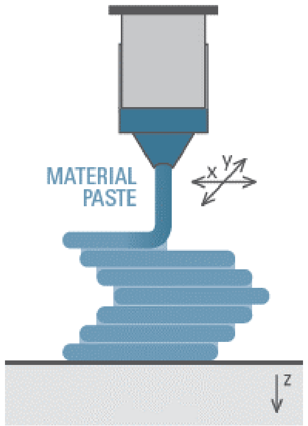

Source: 3DMaker Engineering, RapidMade, EOS, BigRep

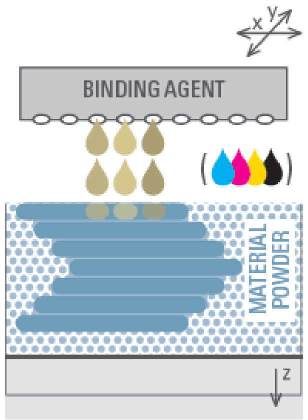
# AM Technology Overview
## Segmentation of Other AM Technologies

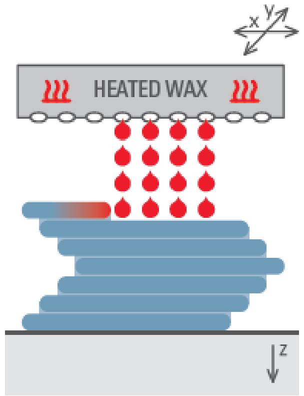
**Additive Manufacturing**

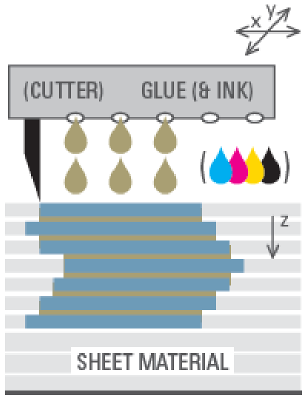
| Reinforced polymer fibers | Any material paste | Sand or gypsum | Wax | Composite or paper |
|---|---|---|---|---|
| *Material Extrusion* | *Material Extrusion* | *Binder Jetting* | *Material Jetting* | *Sheet Lamination* |
| Material extrusion of **composite** | Paste extrusion of **any material** | Joined **sand or gypsum** with bonding agent, | Selective application of **wax** droplets | Cured with projector |
| **CFF** Continuous Filament Fabrication | **PEM** Paste Extrusion Modeling | **BJ** Binder Jetting | **DOD** Drop on Demand | **SDL / LOM** Selective Deposition Lamination / Laminated Object Manufacturing |




Source: Derived from Fomrnnext AM Field Guide Compact and DIN EN ISO/ASTM Terminology

# Basic AM Seminar – Content

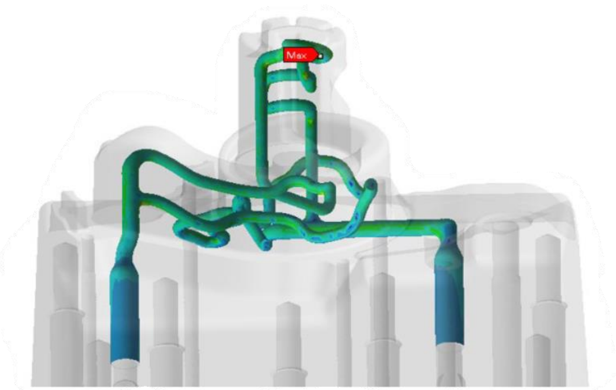
# AM Application Examples
## Sprue Distributors and Tool Inserts for Aluminum Die Casting

### Characteristics

- Sprue distributors and tool inserts for aluminum die casting
- Cooling channels impossible to manufacture conventionally
- Material: Tool steel alloy, adapted for LPBF
- AM technology: LPBF

### Utilized AM Benefits

- Economical and ecological sustainability though longer tool life and shorter cycle times
- Economical small quantities for tooling
- Short time and efficiency from idea to product




**Tool insert, optimized by:**
- Damage analysis
- Process simulation
- Load simulation


**Sprue distributor**
- Cycle time: -2.5 sec
- Tool lifetime: >200%


**Sprue distributor**
- Cycle time: -3 sec
- Tool lifetime: >150%

Source: Voestalpine

# AM Application Examples
## Series Part - BMW i8 Roadster Roof Mount

### Characteristics

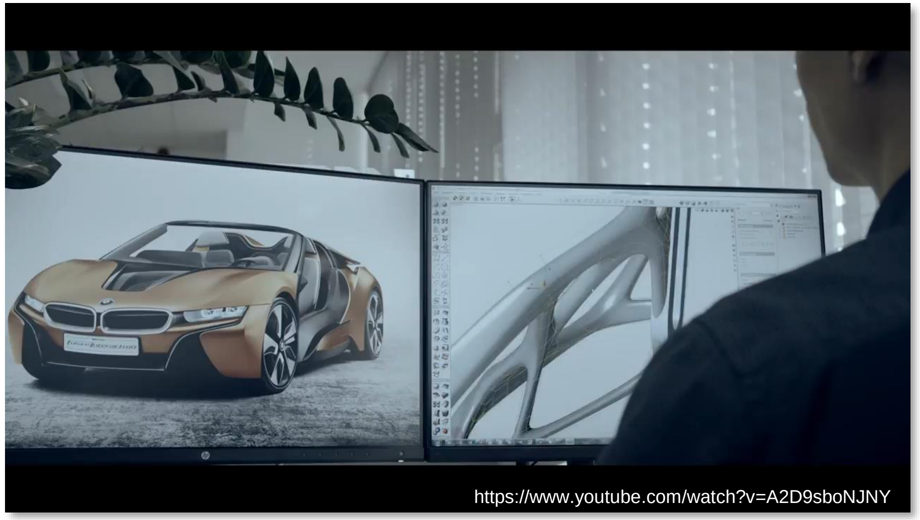
- Stiff part that holds the convertible roof of the BMW i8 roadster
- Small series end-use part
- AM Technology: Laser Powder Bed Fusion
- Material: Aluminum alloy (AlSi10Mg)


https://www.3dnatives.com/de/altair-enlighten-award-2018-220820181/#!


https://www.press.bmwgroup.com

### Utilized AM Benefits

- Algorithmic design (topology optimization)
- Flexible design iterations
- Lightweight design and material (44% weight reduction)
- Economical and ecological sustainability through material efficiency


https://www.youtube.com/watch?v=A2D9sboNJNY


https://www.youtube.com/watch?v=A2D9sboNJNY

# AM Application Examples
## Series Part – Fuel Nozzle for Jet Engines

### Characteristics

- Aviation industry predestined for AM: Weight reduction and functional integration
- More than 100.000 fuel nozzle tips made with AM
- AM technologies: LPBF
- Application type: Series part

### Utilized AM Benefits

- Monolithic design: 20 conventionally manufactured parts with need for assembly reduced to 1 AM part
- Complex lightweight design: 25% weight reduction
- Decrease of production cost and lead times


Pexels


GE Aviation


GE Aviation

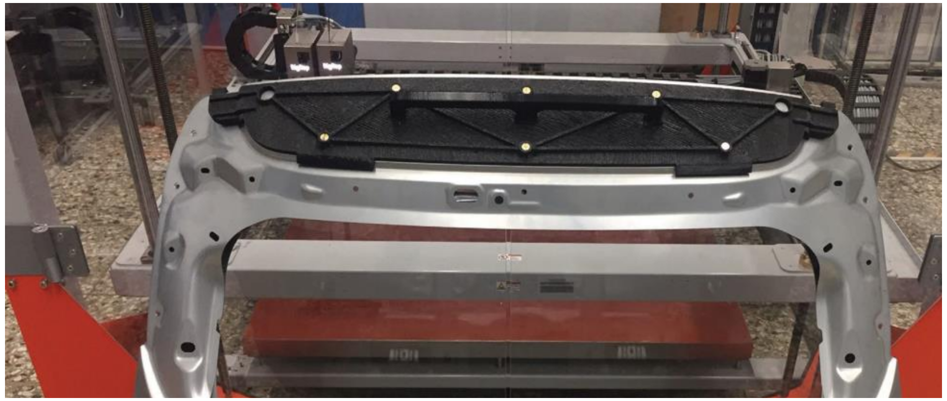

GE Aviation

Source: https://blog.geaerospace.com/manufacturing/manufacturing-milestone-30000-additive-fuel-nozzles/

# AM Application Examples
## Assembly and Manufacturing Aids by Ford

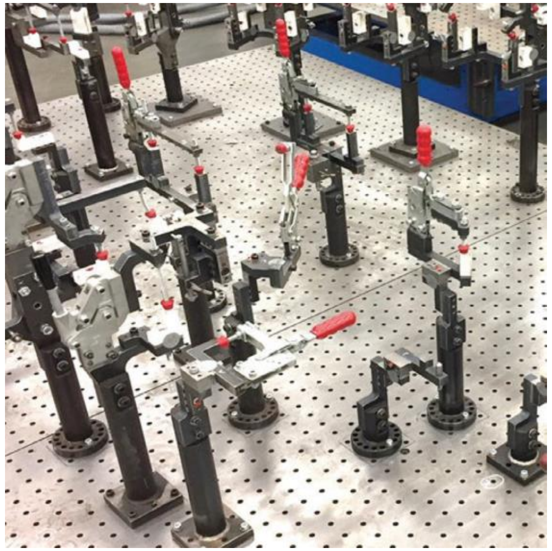
### Characteristics

- Frame for measuring gaps in assembly e.g. between body and the door of a vehicle
- Aids for manual positioning of badges
- Welding fixture
- AM technology: FDM (large format)



### Utilized AM Benefits

- Short time and efficiency from idea to product (e.g., 8-10 weeks to 2-3 days for seal gap frame)
- Economic small quantities
- Flexible design iterations & engineering changes



Source: https://bigrep.com/ebooks/ford-upscales-their-in-house-tooling-with-bigrep-3d-printers/

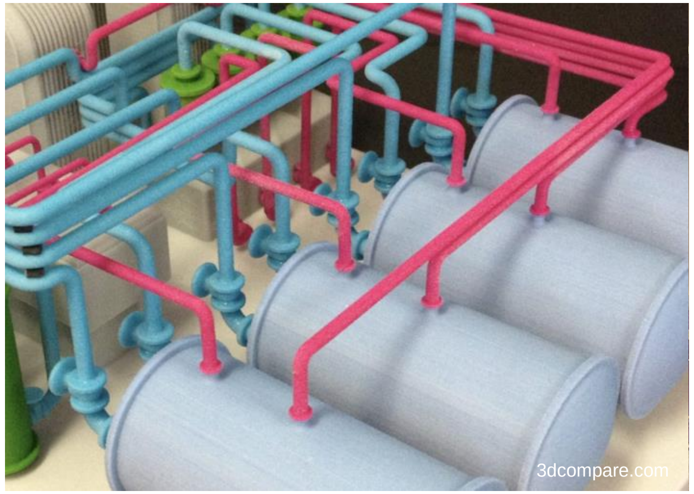
# AM Application Examples
## Visual Prototypes for Architecture

### Characteristics

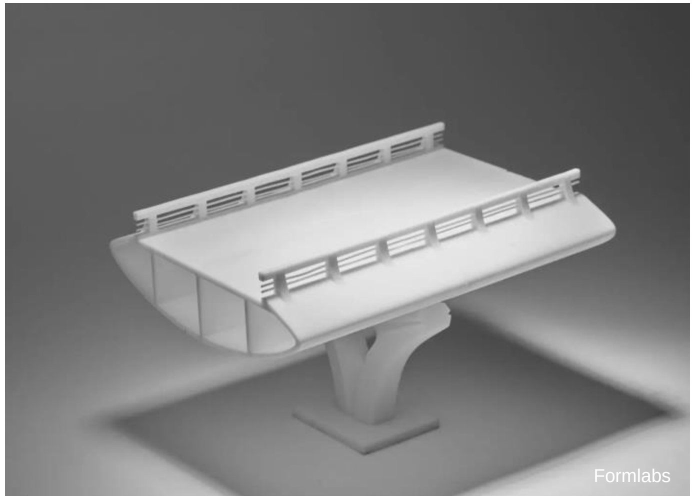
- Visualization of geometries using prototypes made with AM
- AM technologies: Various
- Application type: Visual prototype

### Utilized AM Benefits

- Fast design iterations and simplified adjustments through digital workflow
- Economic small quantities
- Realization of complex geometries
- Decrease of cost and time


3dcompare.com


Formlabs


Formlabs


Formlabs

Source: https://formlabs.com/blog/3d-printing-architectural-models/

# AM Application Examples
# **Series Part – Adidas Shoe Sole**

## Characteristics

- AM lattice structure shoe sole
- Partnership of Adidas and Carbon
- AM technology: DLP / CLIP

## Utilized AM Benefits

- Functional integration: Address needs of athletes for movement and cushioning
- Design freedom: Freedom to manufacture lattice structure according to digital opimization


Adidas


Adidas


Carbon


Carbon

Source: https://www.carbon3d.com/news/press-releases/adidas-unveils-industrys-first-application-of-digital-light-synthesis-with-futurecraft-4d

# Basic AM Seminar – Content

# Successful Adaption of AM
## Benefits Through an “Additive Mindset“

### Comparing Apples with Oranges…

***Successful AM adaption** requires **consideration of AM differences**. Without change of expectations, AM turns out as a poor substitute for established processes.*

### …Additive Manufacturing is different

**Different cost structure**

**Financial return** and **technological feasibility** must be considered in **identification of parts with positive business case**

Enables **new business models** such as mass customization or digital warehousing

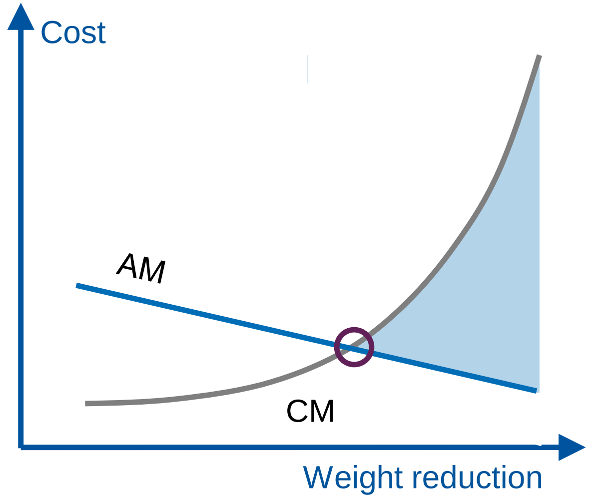
**Products and required expertise** along the product life cycle are different (e.g. Design for Additive Manufacturing)

Some AM technologies require complex **health & security measures**

Source: Effectory, TCT

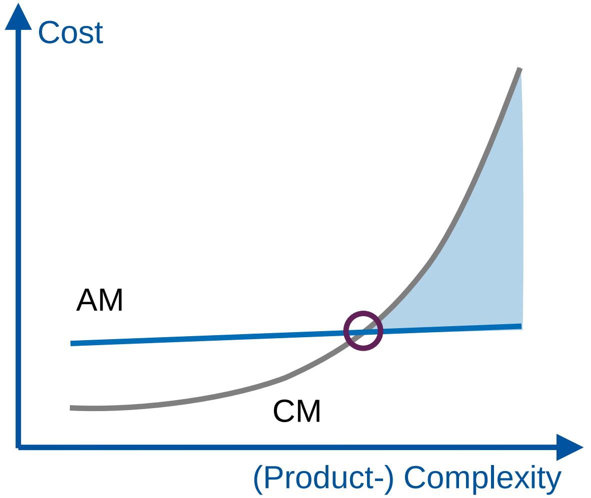
# Successful Adaption of AM
## Different Cost Structure of Conventional Manufacturing (CM) and AM

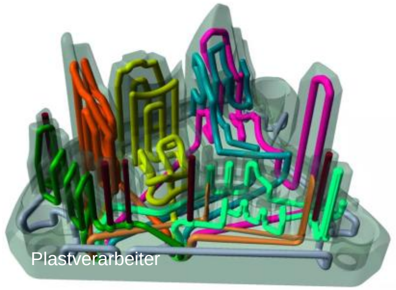
### Weight reduction means cost reduction



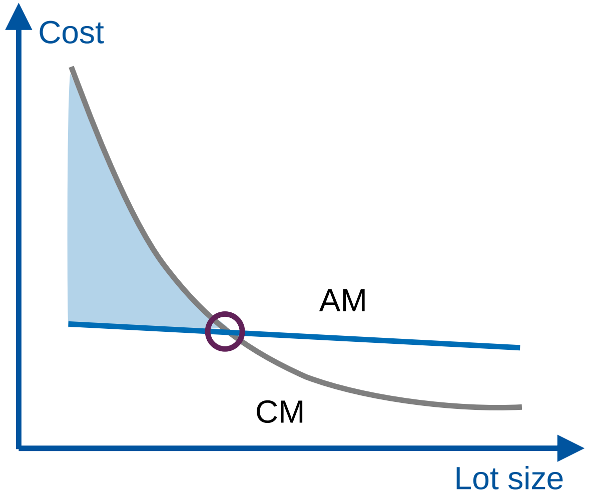


### Complexity (almost) for free



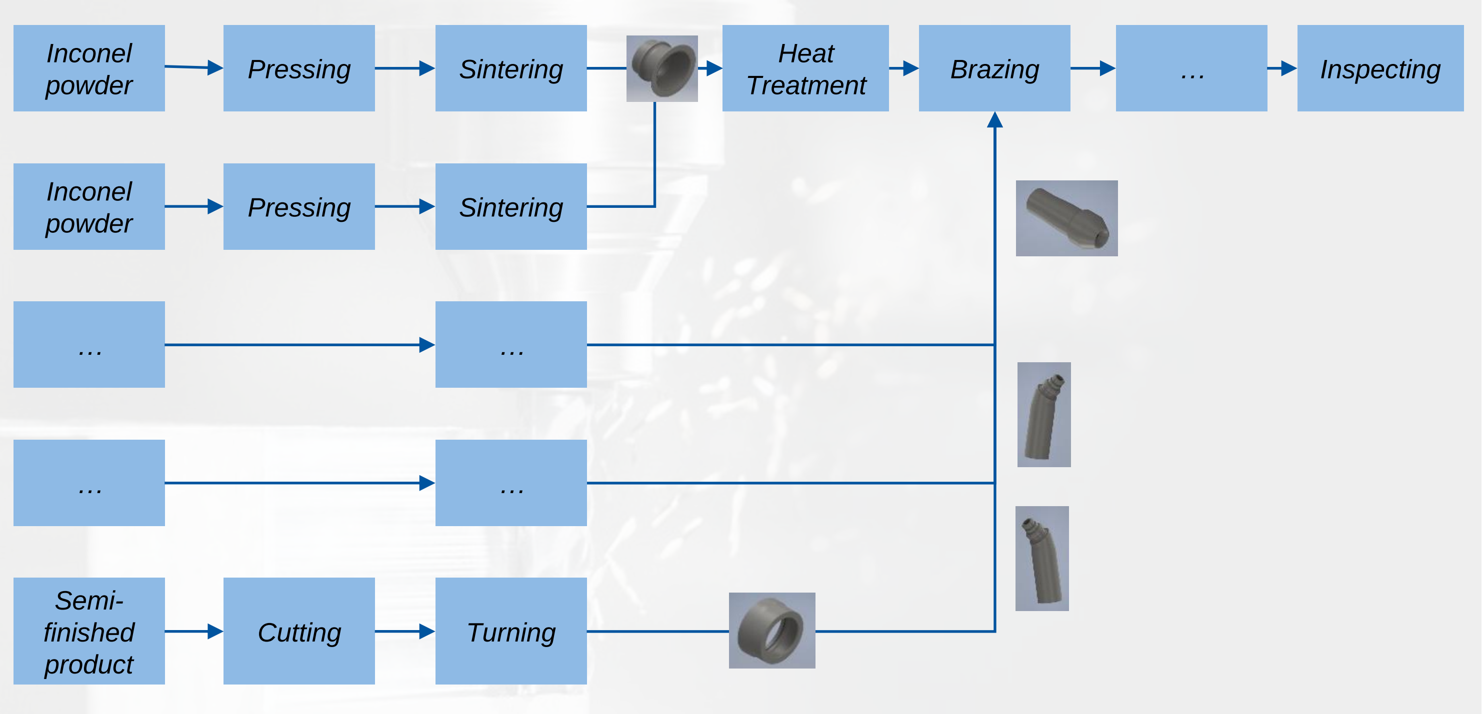




### Individualization (almost) for free

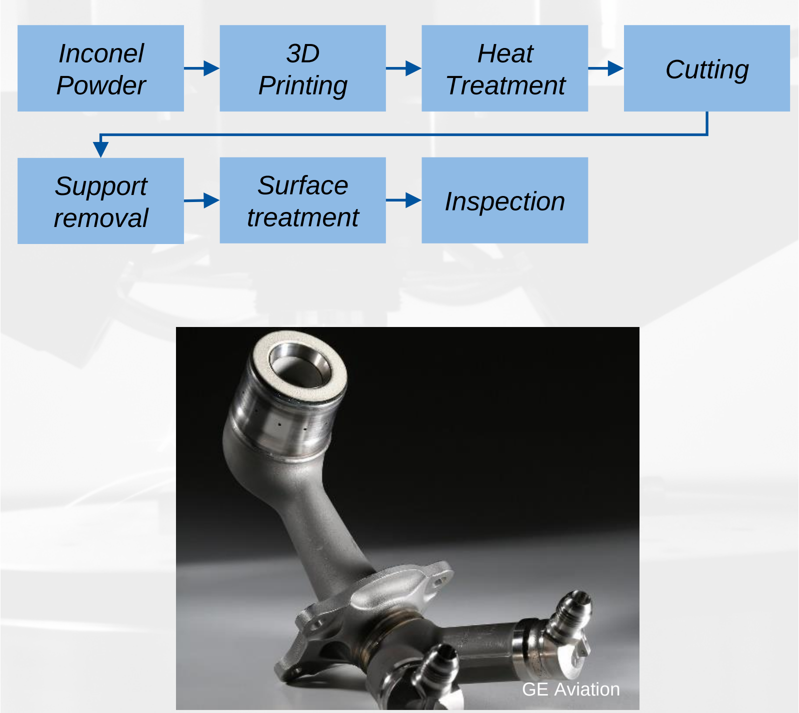



# Successful Adaption of AM
# Different Process Chains Result in Different Manufacturing Cost Structure

## Conventional process chain




## Additive process chain




**Additive Manufacturing allows to transfer process chain complexity to part design (e.g. through part consolidation)**

# Successful Adaption of AM
## **Benefits Through an “Additive Mindset“**

### Comparing Apples with Oranges…

***Successful AM adaption** requires **consideration of AM differences**. Without change of expectations, AM turns out as a poor substitute for established processes.*

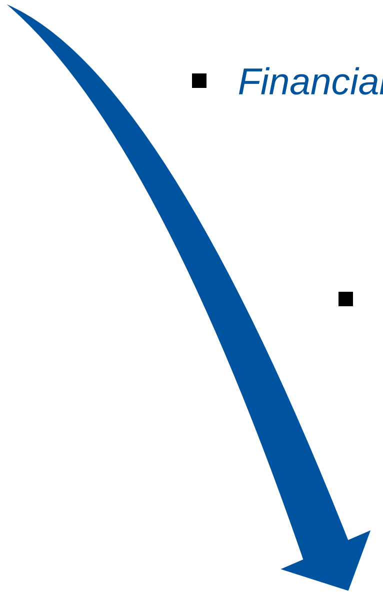
### …Additive Manufacturing is different

- **Different cost structure**
- **Financial return** and **technological feasibility** must be considered in **identification of parts with positive business case**
- Enables **new business models** such as mass customization or digital warehousing
- **Products and required expertise** along the product life cycle are different (e.g. Design for Additive Manufacturing)
- Some AM technologies require complex **health & security measures**

Source: Effectory, TCT

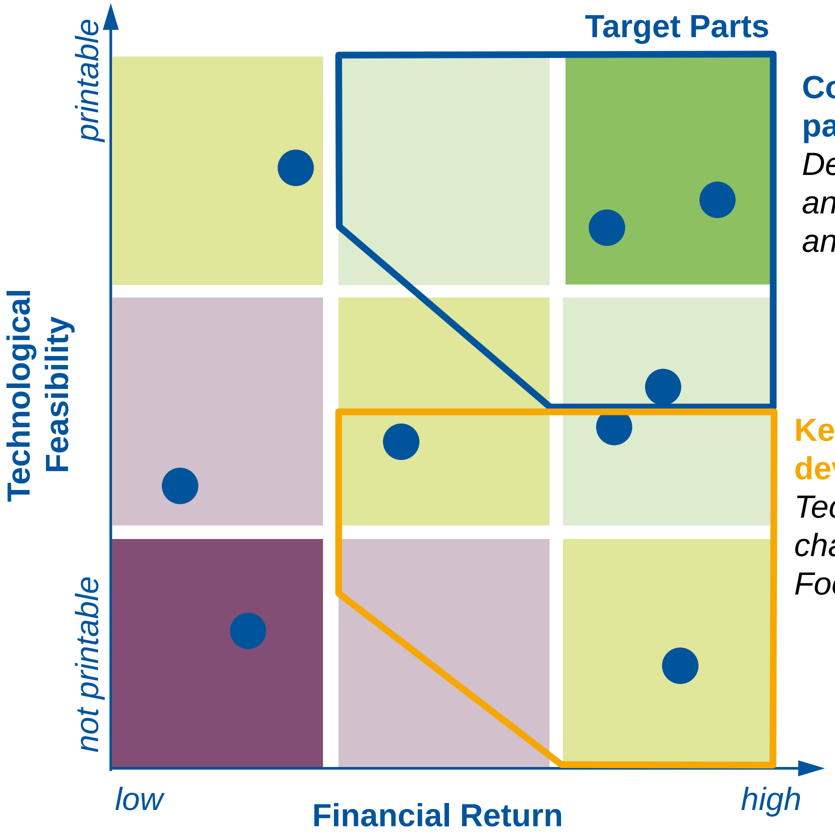
## Successful Adaption of AM
# **Benefits Through an "Additive Mindset"**

### Part identification process



- *Preliminary Selection*
- *Financial Assessment*
- *Technological Assessment*
- *Implementation*

### Mapping of possible candidates to find target parts for implementation




**Collaboration with technology partners:**
*Development of prototype components and processes to validate assumptions and prove AM feasibility*

**Keeping in backlog for future developments:**
*Technology and market evolution can change the feasibility status of parts. Focus on parts with high potential ROI*

Source: ACAM Webinar "Software or Expert? Part Identification for Additive" with RWTH DAP

Successful Adaption of AM

# Benefits Through an "Additive Mindset"

## Comparing Apples with Oranges…

***Successful AM adaption** requires **consideration of AM differences**. Without change of expectations, AM turns out as a poor substitute for established processes.*

## …Additive Manufacturing is different

- **Different cost structure**
- **Financial return** and **technological feasibility** must be considered in **identification of parts with positive business case**
- Enables **new business models** such as mass customization or digital warehousing
- **Products and required expertise** along the product life cycle are different (e.g. Design for Additive Manufacturing)
- Some AM technologies require complex **health & security measures**

Source: Effectory, TCT

# Successful Adaption of AM
# **Business Models Based on AM**

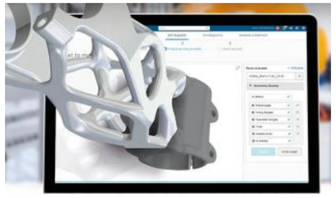
## AM Benefits

- **Design freedom**: Complex features, lightweight, monolithic
- **Flexible design** iterations and engineering changes
- **Integration of functions**
- Economic **small quantities** and **individualization**
- **Short time** and efficiency **idea to product**
- **Short supply chain**
- **Insourcing:** Appealing industrialized countries & high degree of automation
- **Sustainability** by material reduction or efficiency in performance

## Enabled business models for AM users (not conclusive)

*Digital spare part warehouse*

*Service provider*



*Online marketplace*

*Mass customization*

*Co-Production*

*Others …*

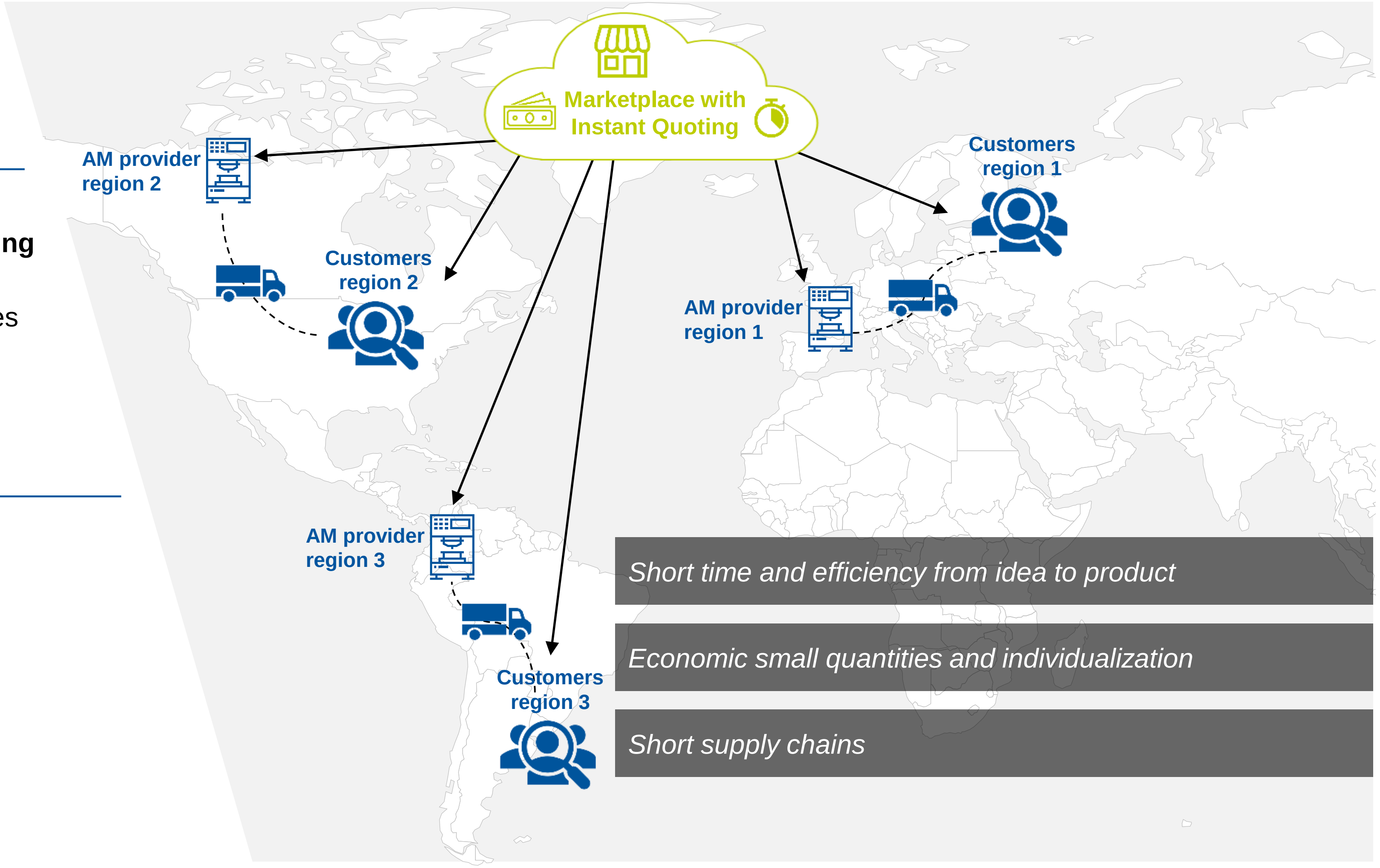
# Successful Adaption of AM
# Online Marketplaces with integrated AM Service Providers

## Online marketplace for AM

- Integration of **AM service providers**
- Platform for customers to **compare manufacturing services** of different providers
- **Instant quoting tool** with price and delivery dates based on CAD upload by customer
- **Automated design check** of uploaded models

## Exemplary AM marketplaces

- Protiq
- Xometry
- Hubs
- Jellypipe
- HP Digital Manufacturing Network
- …




*Short time and efficiency from idea to product*

*Economic small quantities and individualization*

*Short supply chains*

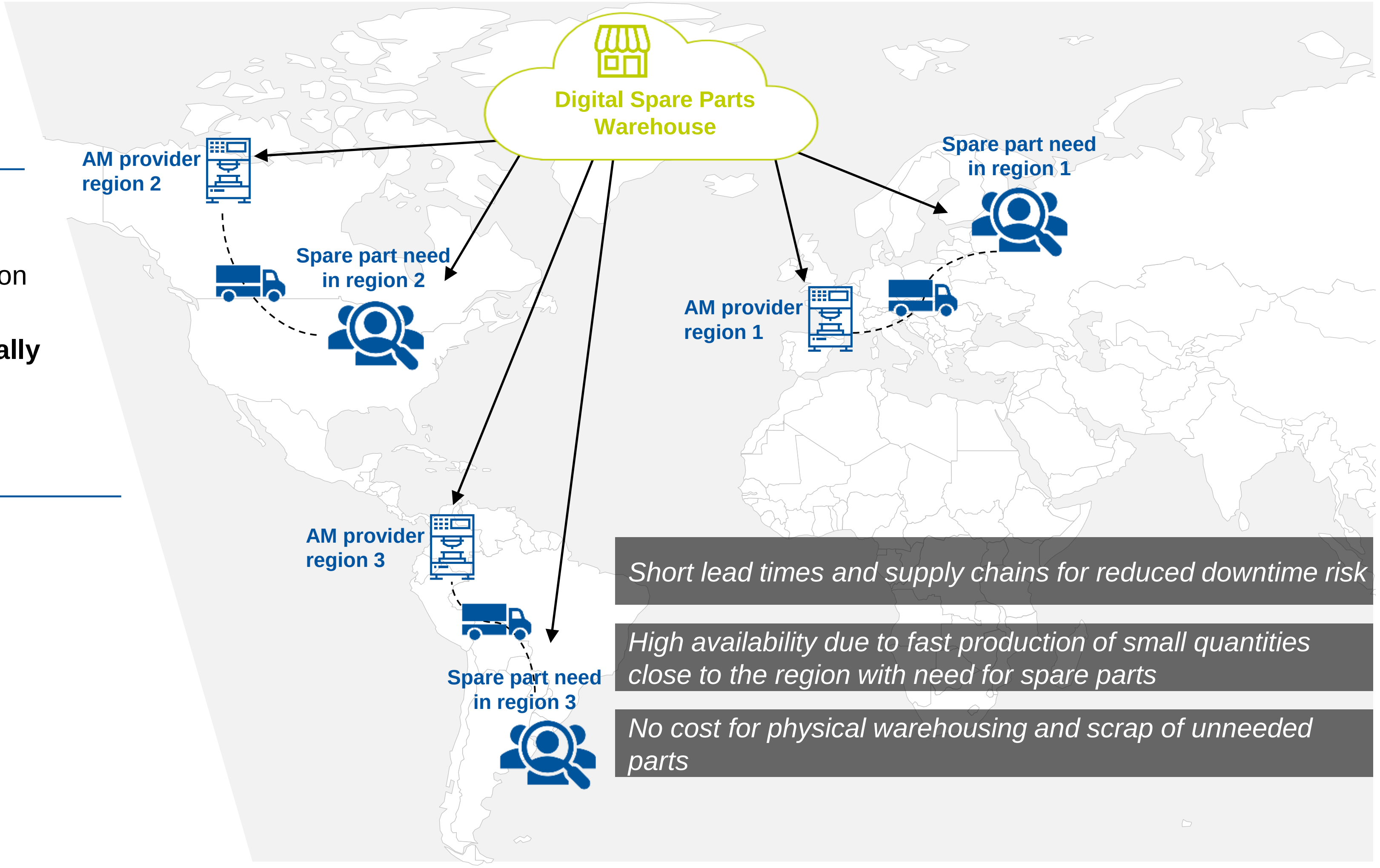
# Successful Adaption of AM
# **Digital Spare Parts Warehouse**

## Digital Spare Parts Warehouse

- **No physical warehousing**
- **Digitization** of additively manufacturable spare parts & backup in virtual warehouse Production "on demand”
- Also used to **supplement obsolete conventionally manufactured parts**

## Exemplary Digital Spare Parts Warehouses

- Wilhelmsen and thyssenkrupp
- FIT AG
- EvoBus GmbH, Daimler Group
- Shell
- …




*Short lead times and supply chains for reduced downtime risk*

*High availability due to fast production of small quantities close to the region with need for spare parts*

*No cost for physical warehousing and scrap of unneeded parts*

# Successful Adaption of AM
# **Co-Production**

WIESEMANN
1893

## Product design service

- Development and marketing for AM brands
- Aiming at companies striving towards digitization
- Design aimed to facilitate physical manufacturing **by end users**
- Monomaterial part design for circular economy

## Print@home applications

- **Inclusion of customers into value creation process** for better and more individualized products
- Shared value creation (**print@home application**)
- Reduced transport and waste through demand-oriented product supply
- Facilitated circular economy through monomaterial design
- Economic supply of small-series products


Source: Enable3D, Wiesemann 1893

# Successful Adaption of AM
# **Benefits Through an “Additive Mindset“**

## Comparing Apples with Oranges…

***Successful AM adaption*** *requires* ***consideration of AM differences****. Without change of expectations, AM turns out as a poor substitute for established processes.*

## …Additive Manufacturing is different

- **Different cost structure:** High upfront investment costs and high material prices, but not driven by economies of scale
- **Financial return** and **technological feasibility** must be considered in **identification of parts with positive business case**
- Enables **new business models** such as mass customization or digital warehousing
- **Products and required expertise** along the product life cycle are different (e.g. Design for Additive Manufacturing)
- Some AM technologies require complex **health & security measures**

Source: Effectory, TCT

Successful Adaption of AM

# Algorithmic Design for Additive Manufacturing – Generative Design

## How?

*Conventional design*

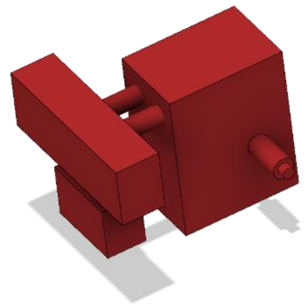
*Additive design*

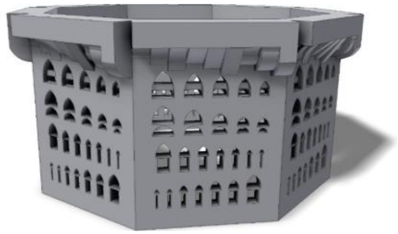
Source: RWTH DAP, e.GO

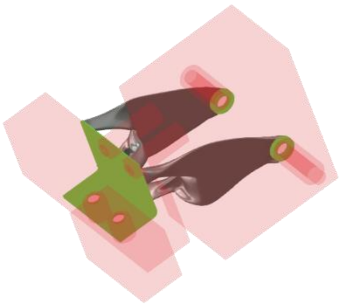
# Successful Adaption of AM

## Algorithmic Design for Additive Manufacturing – Generative Design

*Definition of design space* → *Definition of manufacturing constraints* → *Definition of loading and boundary conditions* → ***Algorithmic shape optimization*** → *Evaluation and adaption of generated options by engineer*







*Design and process know how engineer* | *Algorithmic optimization* | *Decision by engineer*

Source: RWTH DAP, e.GO

# Successful Adaption of AM
# **Benefits Through an “Additive Mindset“**

### Comparing Apples with Oranges…

***Successful AM adaption*** *requires* ***consideration of AM differences****. Without change of expectations, AM turns out as a poor substitute for established processes.*

### …Additive Manufacturing is different

- **Different cost structure**
- **Financial return** and **technological feasibility** must be considered in **identification of parts with positive business case**
- Enables **new business models** such as mass customization or digital warehousing
- **Products and required expertise** along the product life cycle are different (e.g. Design for Additive Manufacturing)
- Some AM technologies require complex **health & security measures**

Source: Effectory, TCT

# Successful Adaption of AM
# **Health & Safety Risks and Measures for Prevention**

## Risks of Metal Powder

**GHS05:** Corrosive

**GHS01:** Explosive

**GHS02:** Flammable

**GHS03:** Oxidizing

**GHS06:** Toxic

**GHS07:** Harmful

**GHS08:** Health hazards

**GHS09:** Environmental hazards

## Health & Safety Measures

### Standard PPE

- Protective gloves
- Work protective clothing
- Respirator mask
- Tight-closing safety goggles
- Anti-static work shoes

### Extended PPE

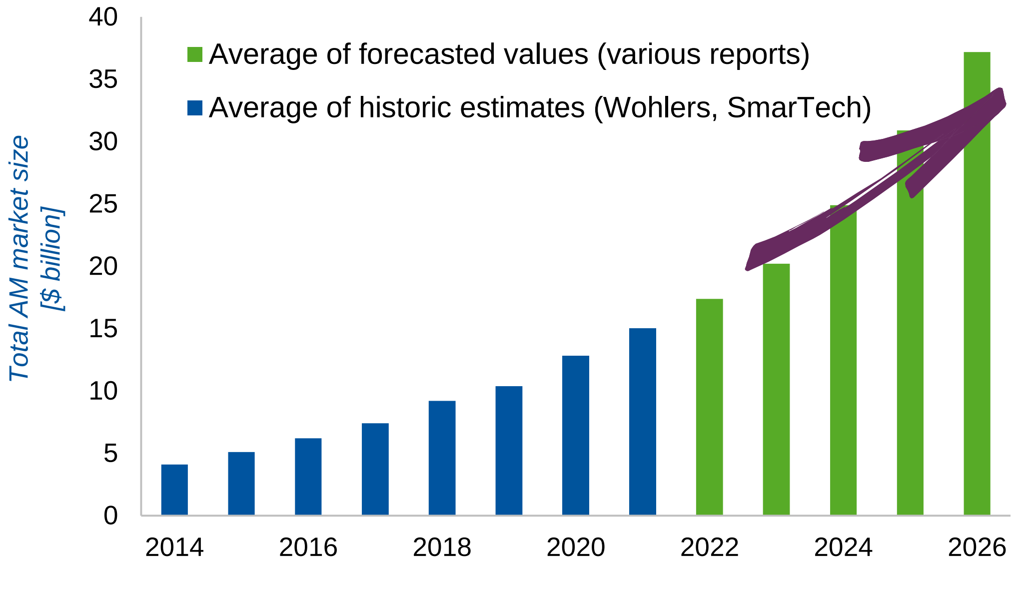
- Heat-protective gloves
- Flameproof clothing
- Full respiratory mask
- Protective shield
- ESD wristband

**Prevention of health hazards requires implementation of specific safety measures**

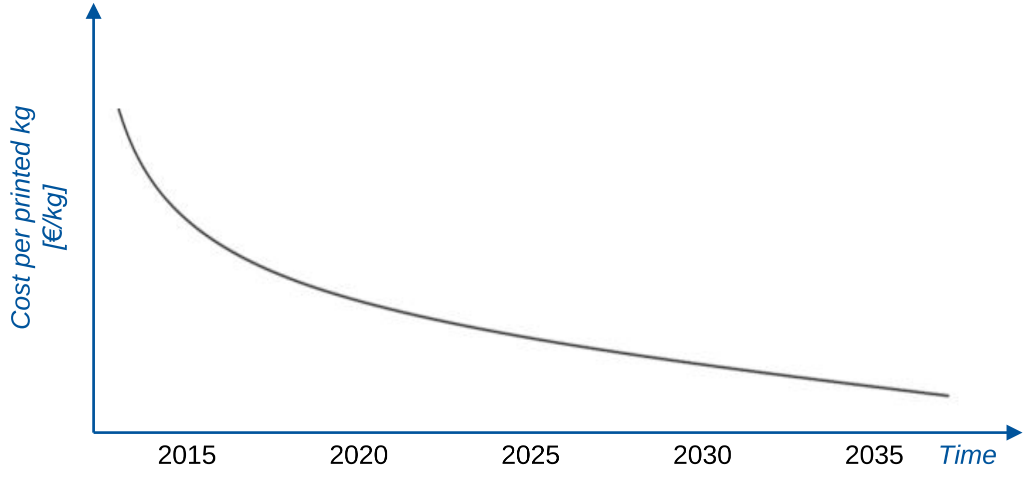
# Basic AM Seminar – Content

# Future Perspective of AM
# What Does the Future Hold for Additive Manufacturing?

## Expected market development




## Expected cost development




- *Increase of machine productivity*
- *Decrease of material prices*
- *Higher technology readiness level*
- *Higher degree of automation*

Forecasted continuous strong growth and reduced costs.
Current barriers of AM are addressed in industry and ongoing research and development.

Source: Audi AG, Hubs, Wohlers, SmarTech, Metal-AM

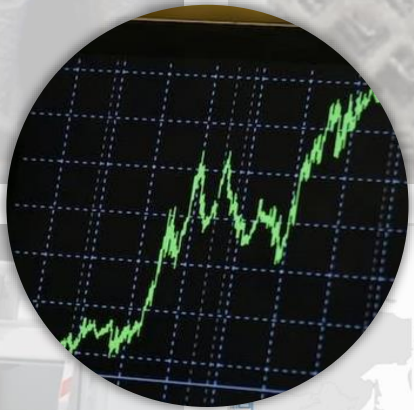
# Future Perspective of AM
## Key Aspects

## Emerging AM Technologies

RWTH DAP

## Digital Materials

Altair Enlighten




## Automation & Line Integration

IDAM, BMW


## Digital & Sustainable Business Models

RWTH DAP

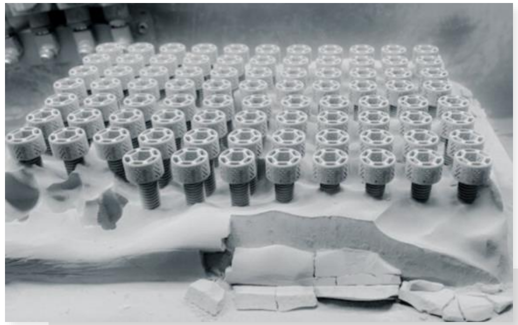
# Future Perspective of AM
## Emerging AM Technologies – Metal Binder Jetting for Mass Production

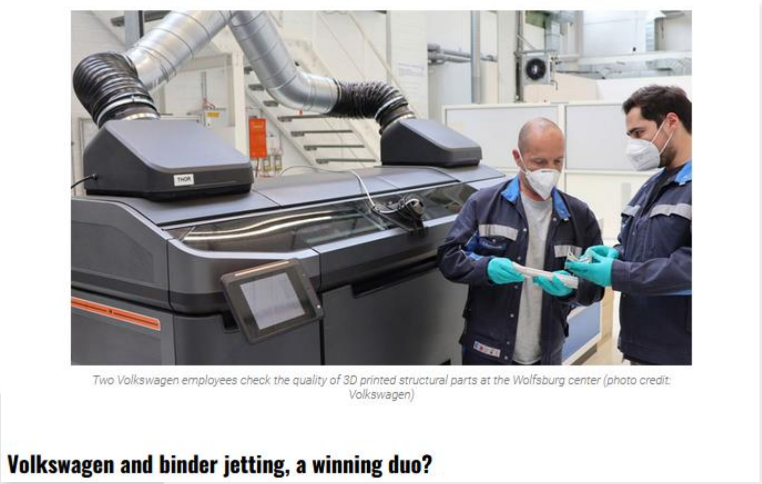
### Expectations in productivity

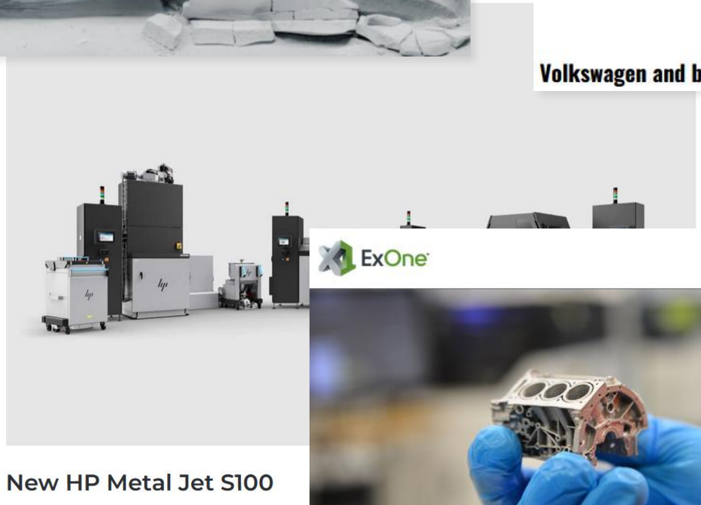
- More parts per build job due to 3D nesting compared to 2D nesting with LPBF
- Faster printing speed especially with high filling degree

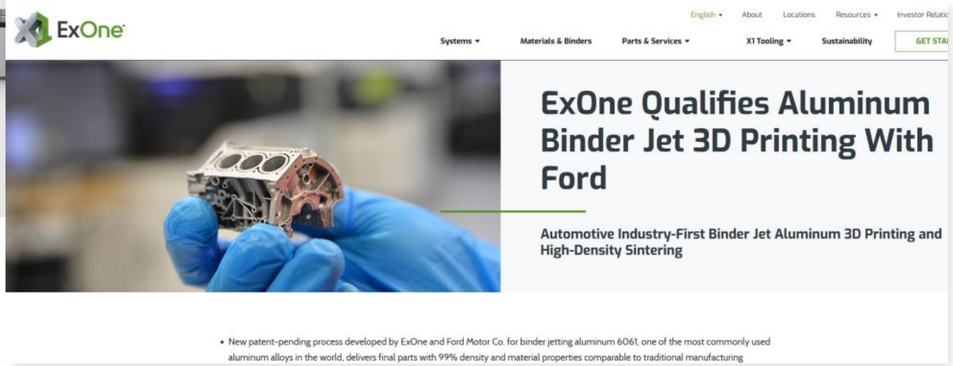
### Barriers for realization

- Additional process steps: Debinding & Sintering
- Automation, e.g., removal of green parts from powder cake
- Comparably low technology maturity compared to LPBF





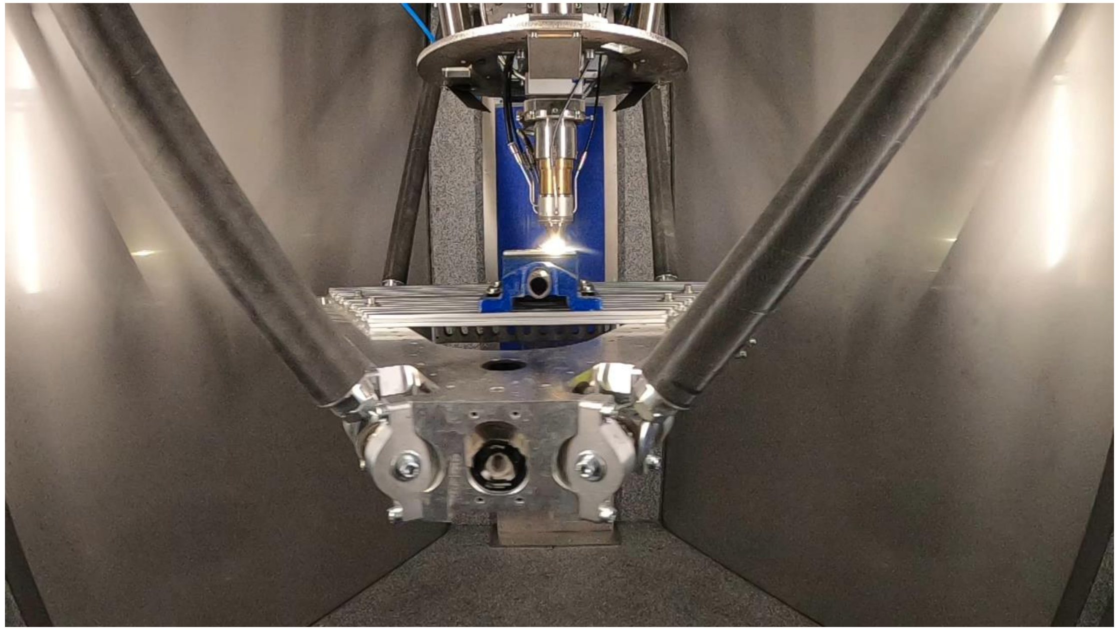



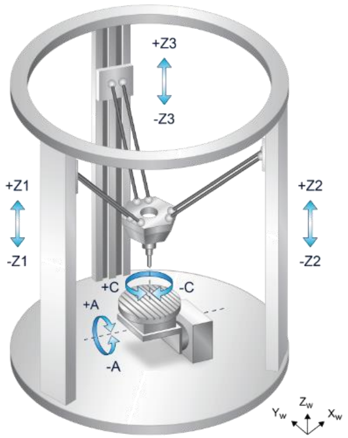

Source: ExOne, 3Dnatives, AFMG, HP

# Future Perspective of AM
# **Emerging AM Technologies – EHLA for Non-Rotational Symmetric Parts**

## Characteristics of the 3D EHLA Process

- Additive coating and manufacturing of components
- Non-rotationally symmetric components possible
- Complex surfaces can be coated locally
- Wide variety of materials
- Develop and process new types of alloys



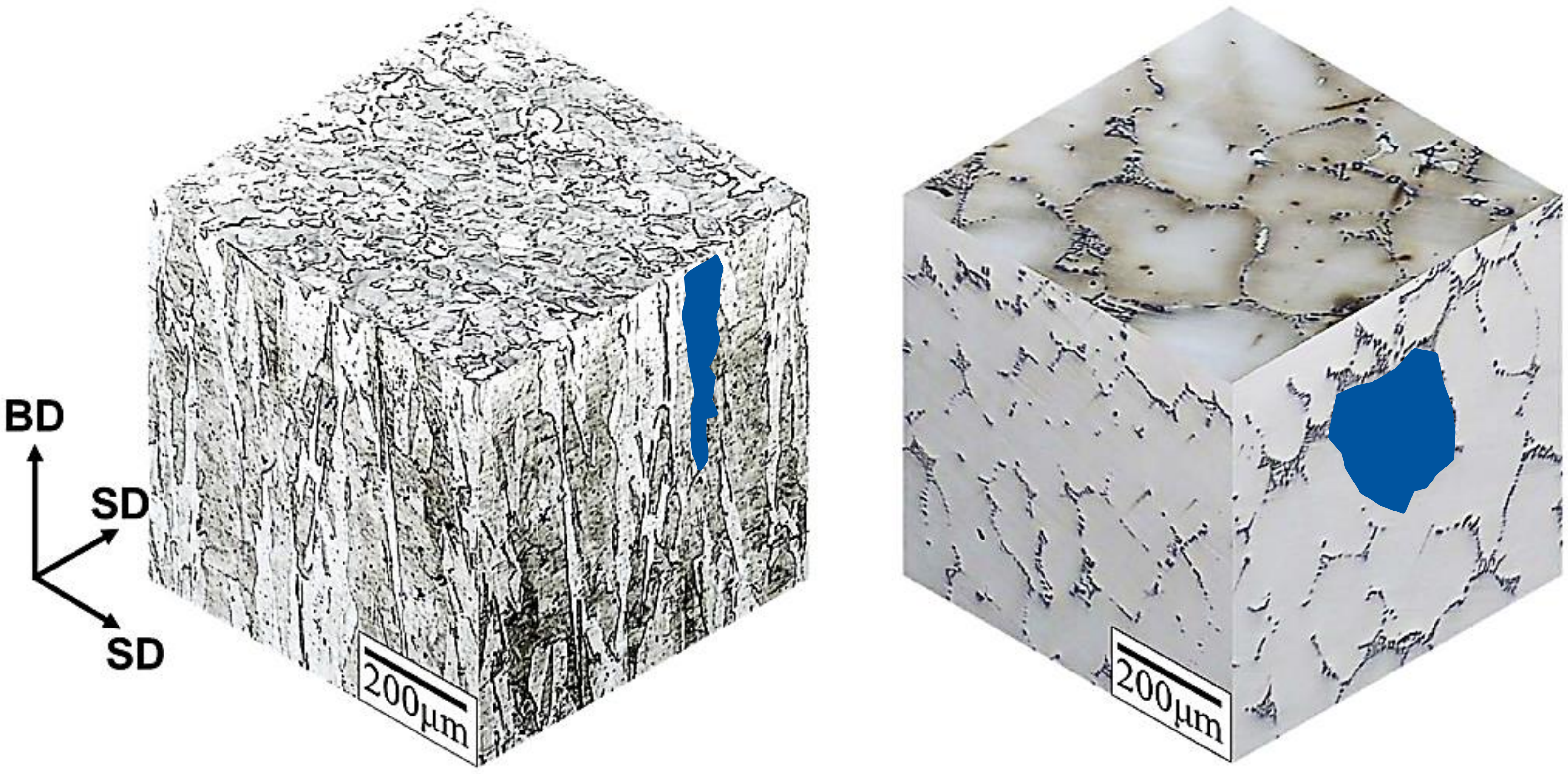



Tripod Kinematics

Source: Courtesy of Ponticon

# Digital Material – Different Microstructure with Influence on Mechanical Properties

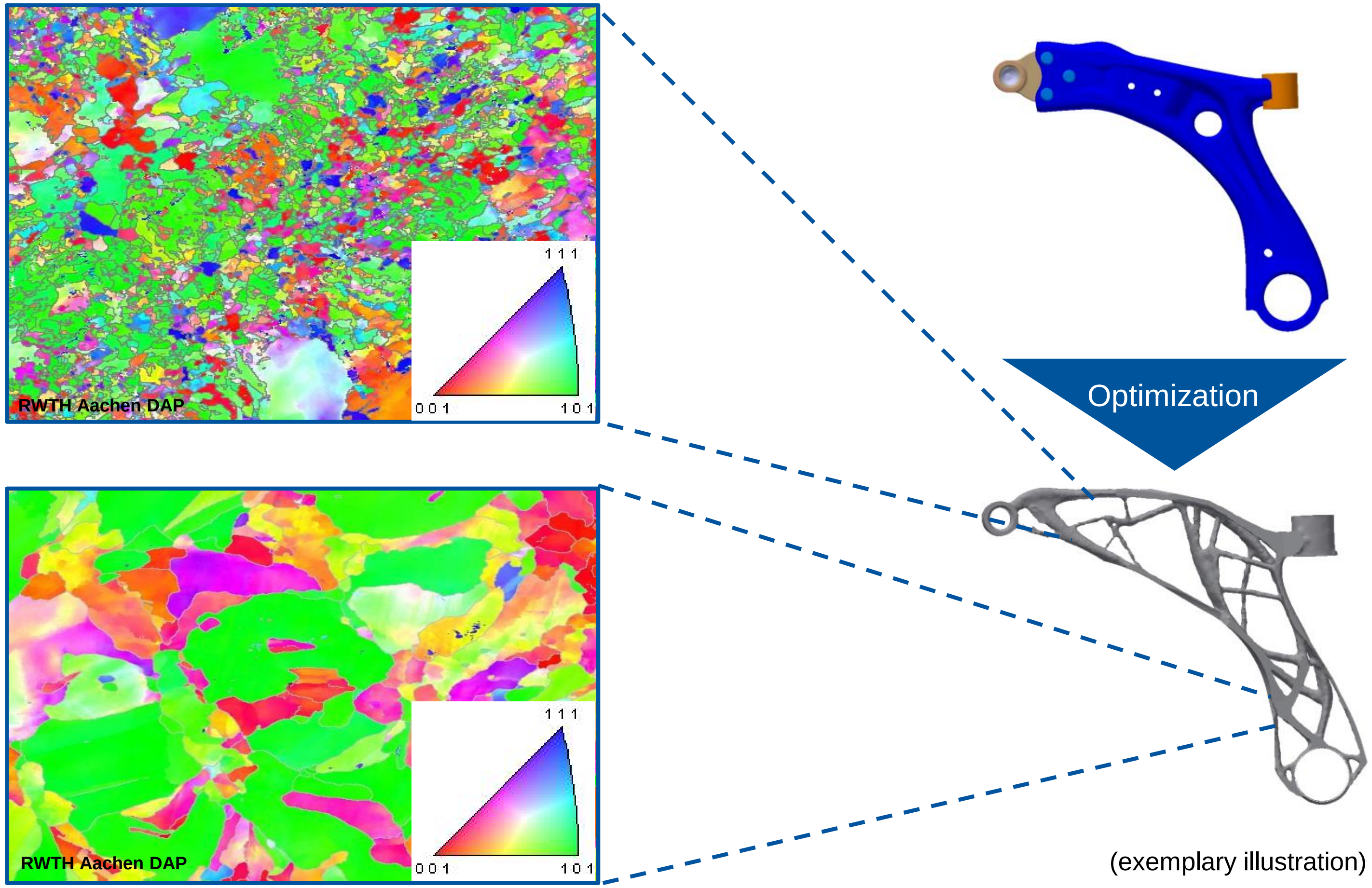
BD: build direction
SD: side direction




**Microstructure after LPBF** **Microstructure after casting**

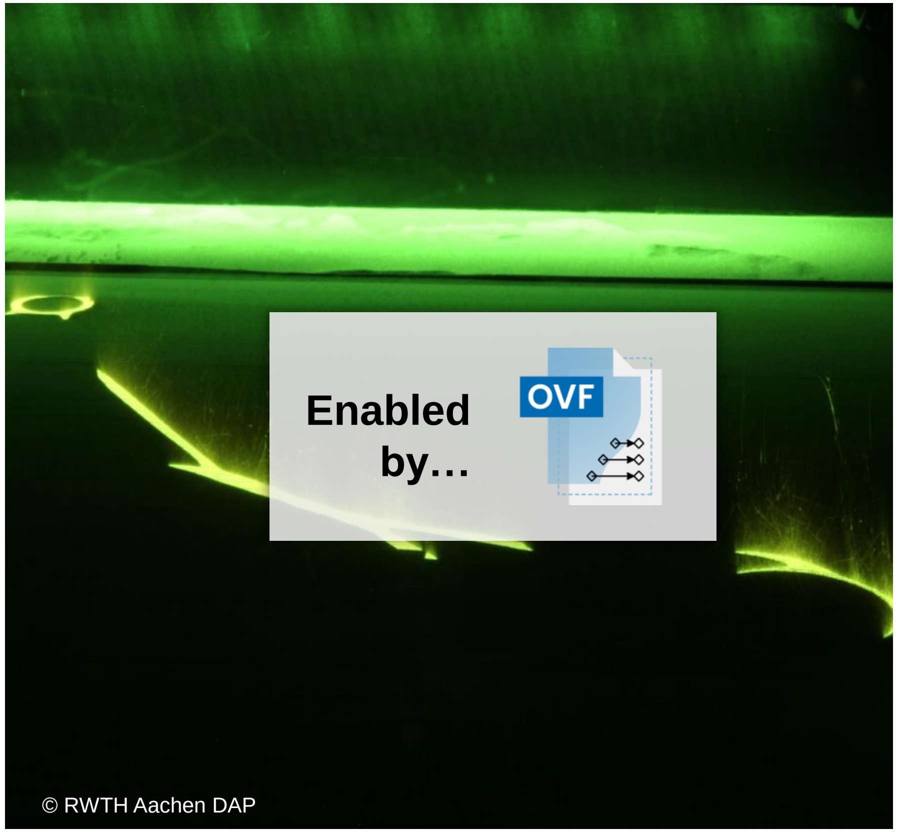
Source: Manfredi, D., & Bidulský, R. (2017). Laser powder bed fusion of aluminum alloys. *Acta Metallurgica Slovaca*, *23*(3), 276-282.

# Future Perspective of AM
## Digital Material - 4D Design Approach (3d-Geometry and Local Microstructure)



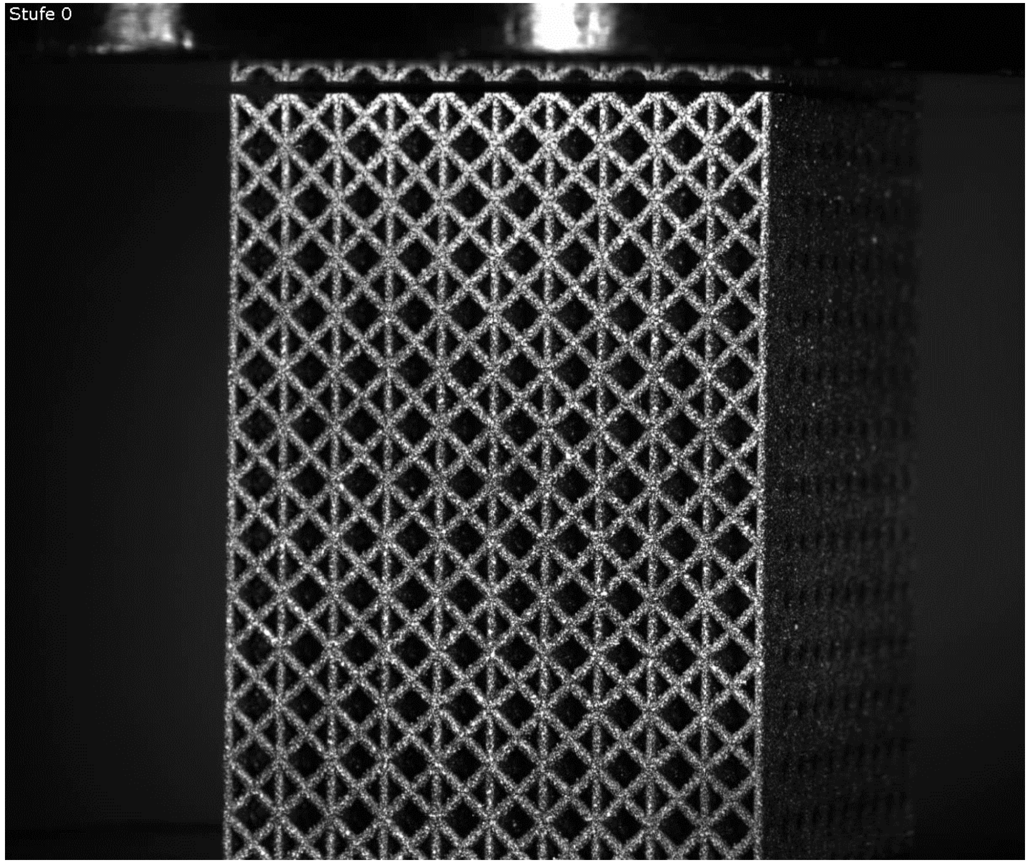

(exemplary illustration)

**LPBF**

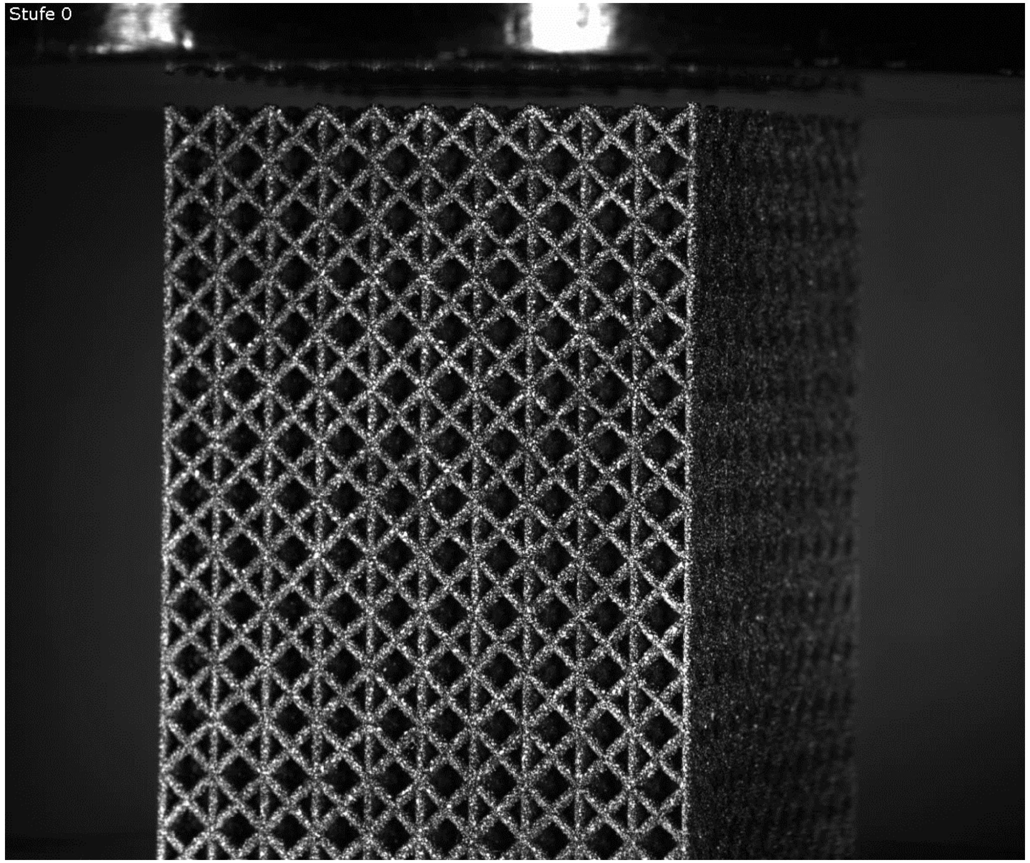


Future Perspective of AM

# Digital Material – Illustration of the Effect of Locally Adapted Microstructure




**Conventional**



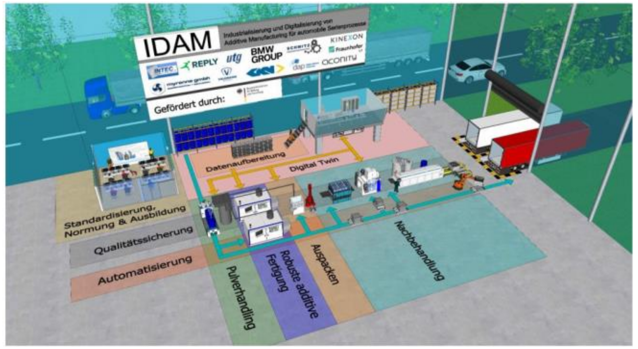

**Locally adapted microstructure (digital material)**

# Future Perspective of AM
## Automation and Line Integration – Joint Research Project IDAM

### *Initial Situation*

- High costs
- Low productivity
- High material prices
- Inadequate connection of enterprise IT systems
- High manual labor efforts
- Lack of consistent end-to-end quality assurance

- *Material systems: Aluminum and steel*
- *Production volumes: > 10,000 components/year (@GKN)*
- *Production volumes: > 50,000 components/year (@BMW)*



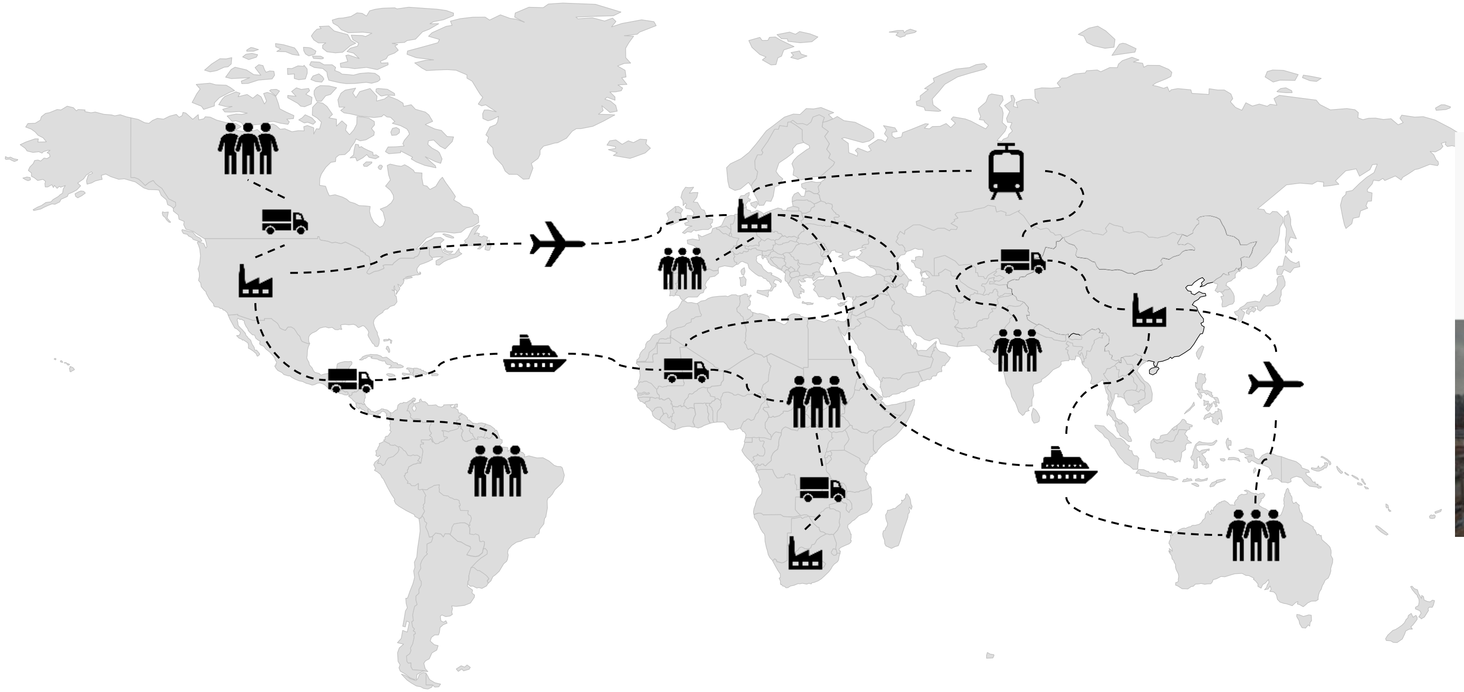

### *Results*

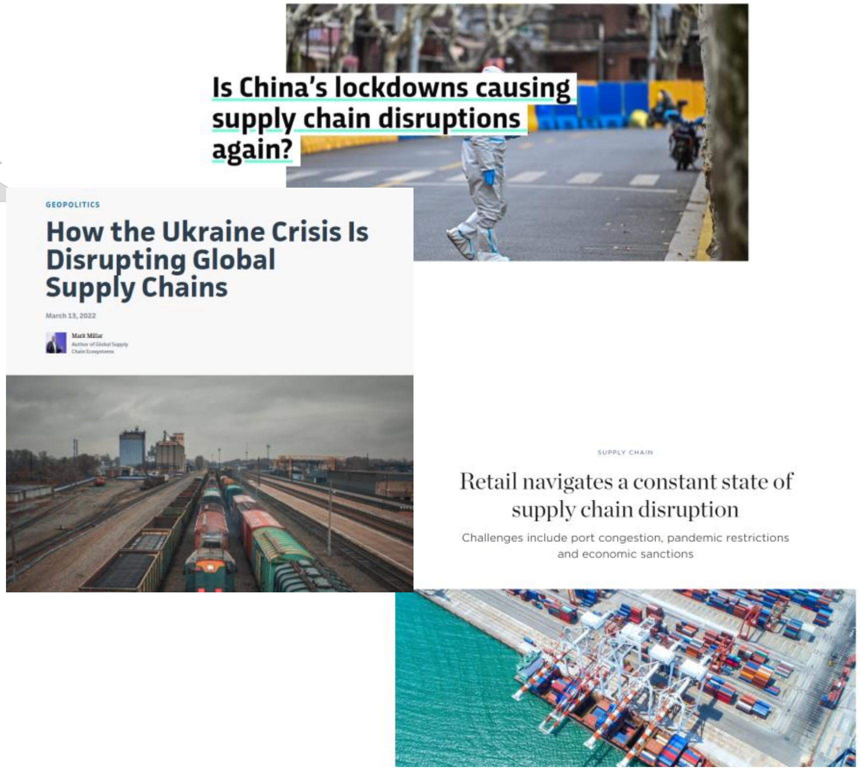
- Line integration of LPBF 3D printing
- Digital connection of all systems
- Reduction of manual work from 35% to 5%
- Continuous end-to-end digital quality assurance

Source: RWTH DAP, Photonikforschung

# Future Perspective of AM

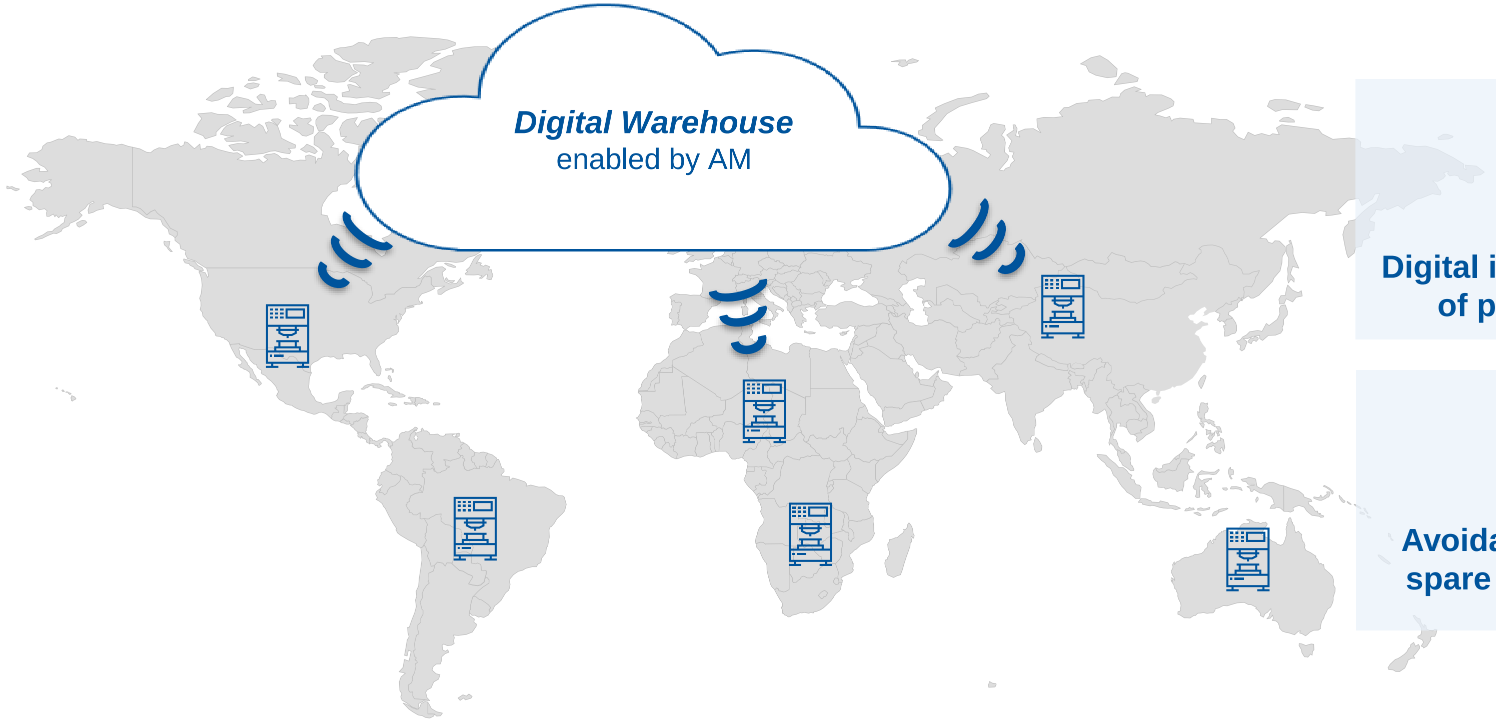
## Current State: Globalized, Complex, and Vulnerable Supply Chains






Recent crises have shown the vulnerability of global supply chains. Resilience is a key element to competitiveness.

# Future Perspective of AM
## Digital Spare Parts Warehouses as New Business Models Enabled by AM




**Digital inventory instead of physical stock**

**Short & fast transport routes**

**Avoidance of scrap if spare parts not used**

**Avoid obsolescence and costly idle times**

But how to ensure secure data handling and quality with different part designers and suppliers?

Source: RWTH DAP, WIBU, BMBF

# Future Perspective of AM
## Research Project ProCloud3D – Data Security by Layer-wise Streaming

**Customer**

**Cloud Marketplace**

**AM Supplier**

Customer Order to Cloud Marketplace

Encrypted CAD Model

Automatic Build Job Preparation in Cloud

**Data security?**

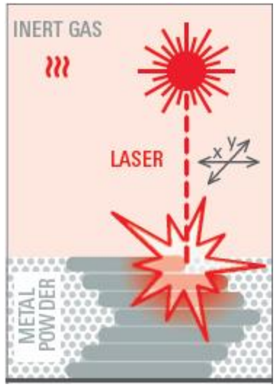
**Control how often this part is printed?**

**Secure print quality?**

Layerwise streaming of OVF Workplane

OVF

e layer n




Parts

**CAD data is not shared with supplier**

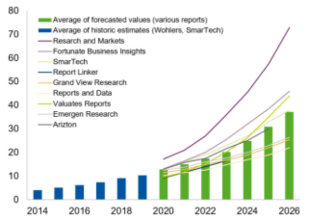
**Control how often this part is printed**

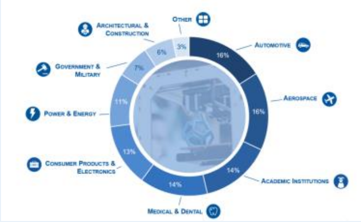
Sources: RWTH DAP, WIBU, BMBF, Formnext

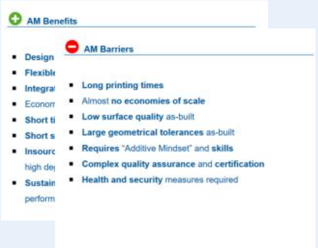
# Basic AM Seminar – Content

# Basic AM Seminar
# **Summary**

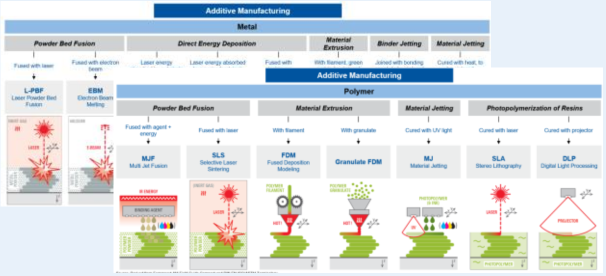
## *Introduction to Additive Manufacturing*




## *Overview of AM Technologies*




- High variety of established and emerging AM technologies
- Varying technology readiness
- Technology-specific characteristics, advantages and disadvantages
- Material choice according to application

## *Future Perspective*

- Expected continuous market growth
- Cost decrease due to increased technology readiness level, productivity and industrialization
- Technological and economical challenges are addressed through industry and R&D

## *Successful Adaption of AM*

***Successful AM adaption** requires **consideration of AM differences**. Without change of expectations, AM turns out as a poor substitute for established processes.*

## *AM Application Examples*

- Various applications along the product lifecycle
- Differentiation in rapid prototyping, rapid tooling and AM of end use parts
- Taking advantage of different AM benefits according to application

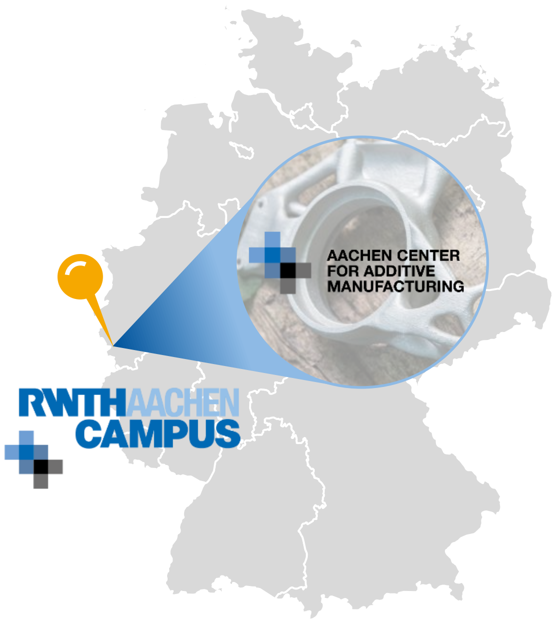
# Aachen Center for Additive Manufacturing
## Connecting the Best of Science and Industry to Shape the Future of AM

dap Digital Additive Production | RWTH Aachen University
IWM Institut für Werkstoffanwendungen im Maschinenbau | RWTH Aachen University
KEX Knowledge Exchange
MSE
FH Aachen University of Applied Sciences
Fraunhofer IPT
WZL | RWTH Aachen University
Institut für Kunststoffverarbeitung in Industrie und Handwerk an der RWTH Aachen
ika Institut für Kraftfahrzeuge | RWTH Aachen University
access
IWF An-Institut der FH Aachen
Fraunhofer ILT

**Embraced Research & Knowledge**

AACHEN CENTER FOR ADDITIVE MANUFACTURING

**Industry Network**




**BUSINESS Members**

oerlikon, TOYOTA, GMH GRUPPE, ZOLLERN, GRÄNGES, MTDG

**BASIC Members**

Materials Magic Hitachi Metals, PROTIQ, TÜV, DAIDO STEEL, SCHAEFFLER, LMT Tools, NISSAN, Hydro, MESSER, voestalpine, Danfoss, The Aviation AM Centre, SCHÄFER, toolcraft, AMEXCI, APPLIED MATERIALS, DENSO Crafting the Core, kurtz ersa, AddUp, VDM Metals, GE Additive, OTTO FUCHS, Linde, GEA, AUBERT & DUVAL

**COOPERATION Members**

Efficient Elements, LUNOVU Integrated Laser Solutions, ACUNITY, stratasys, ENABLE3D, IUN, formnext, 3YOURMIND

# Consulting
# Enabling Manufacturing Companies

Market & Customer Analysis

Product & Service Program

Intelligent Collaboration & Innovation Networks

*Increase customer value (external)*

Competitive Strategy

*Increase productivity (internal)*

Lean, Process- & Project management

Supplier Analysis & Screening

Industry 4.0 & Digital Transformation

Structural & Process Organization

Internal Support Processes

Inquiry-To-Order

Order-To-Delivery

Sustain and Retain

Demand Generation & Part Identification

Engineering, Design, Software Tool Chain

Production Planning & Scheduling

Layout Planning

Life-Cycle Assessment & Re-X Chains

Calculation & Pricing

Technology Assessment

Process Chain Design

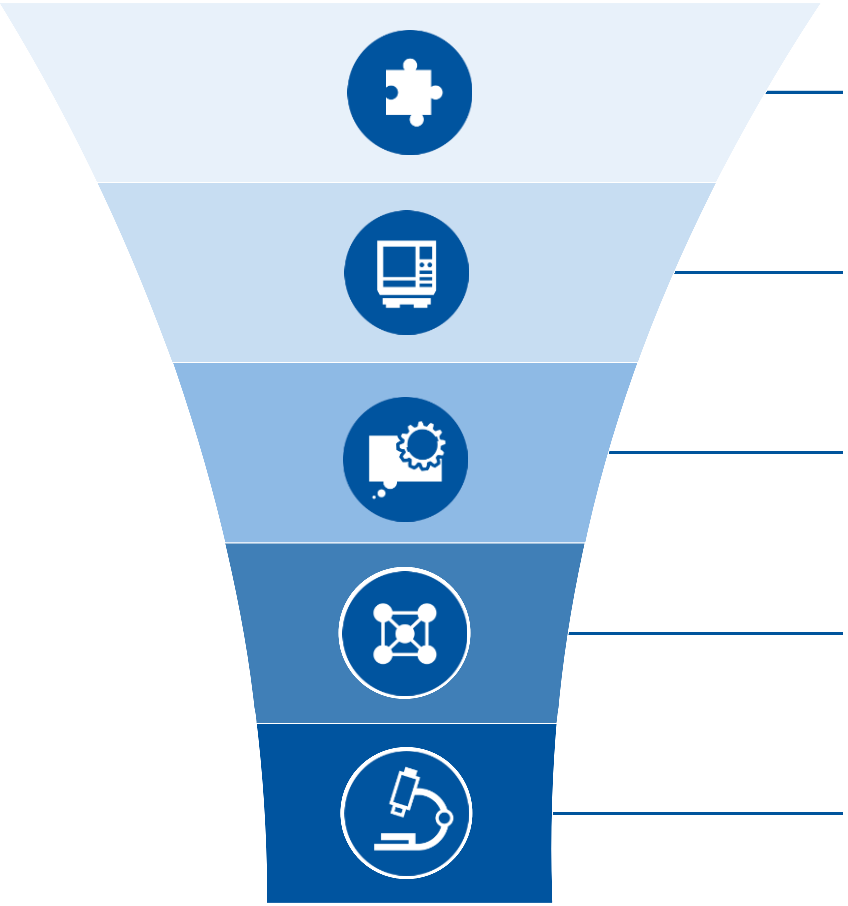
Material Flow & Automation

Certification & Auditing

Market & Customer | Top-Level Business Processes | Support Processes

# Research & Development
# The Future of Additive Manufacturing

## Driving Additive Manufacturing Forward



- Methods and Models for AM Application & Implementation
- Developing Machines and Tools for AM and Post-Processes
- Creation of Process Principles
- Designing of Materials for AM
- Understanding the Physical Phenomena

## Connecting Industry and Research

### Consortial ACAM Projects

- Annual R&D projects from research partners exclusive for ACAM members
- Quick knowledge boost by collaboration

### Bilateral R&D Projects

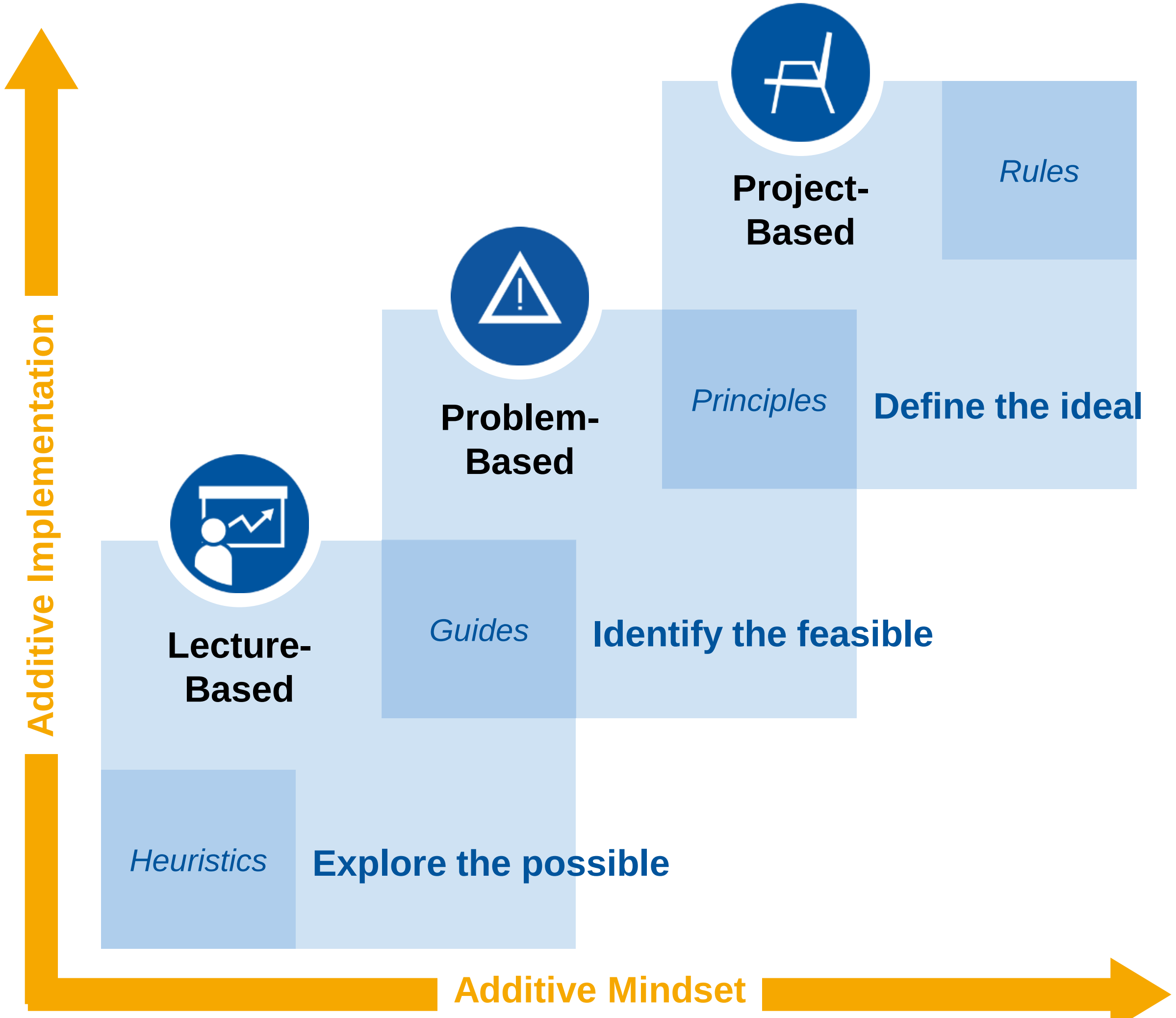
- Address contemporary challenges in R&D projects
- Overcome risks by fast results from leading-edge research

### Public-funded R&D Projects

- Take part in shaping the future of Additive Manufacturing
- Benefit from public funding to reach long-term goals

## Education

# Implementing an Additive Mindset




Source: Schleifenbaum and Schuh et al. (2020): Structured Approach for Changing Designer's Mindset Towards Additive Manufacturing

### Targeting Continuous Learning

**Project-based Approach**

- Starting with predefined goals
- Structuring the design process and integrating existing knowledge
- Focus on discussions about solutions

**Problem-based Approach**

- Starting with selected examples
- Understanding theoretical fundamentals of design problems
- Focus on the perception of problem indicators

**Lecture-based Approach**

- Starting with heuristic information
- Summary of experiences and theoretic knowledge
- Structured lectures transporting information
- Focus on existing knowledge of audience

← Groundplan

## Hall 11.0, C69

### Main exhibitor

ACAM Aachen Center for Additive Manufacturing GmbH

11.0, C69

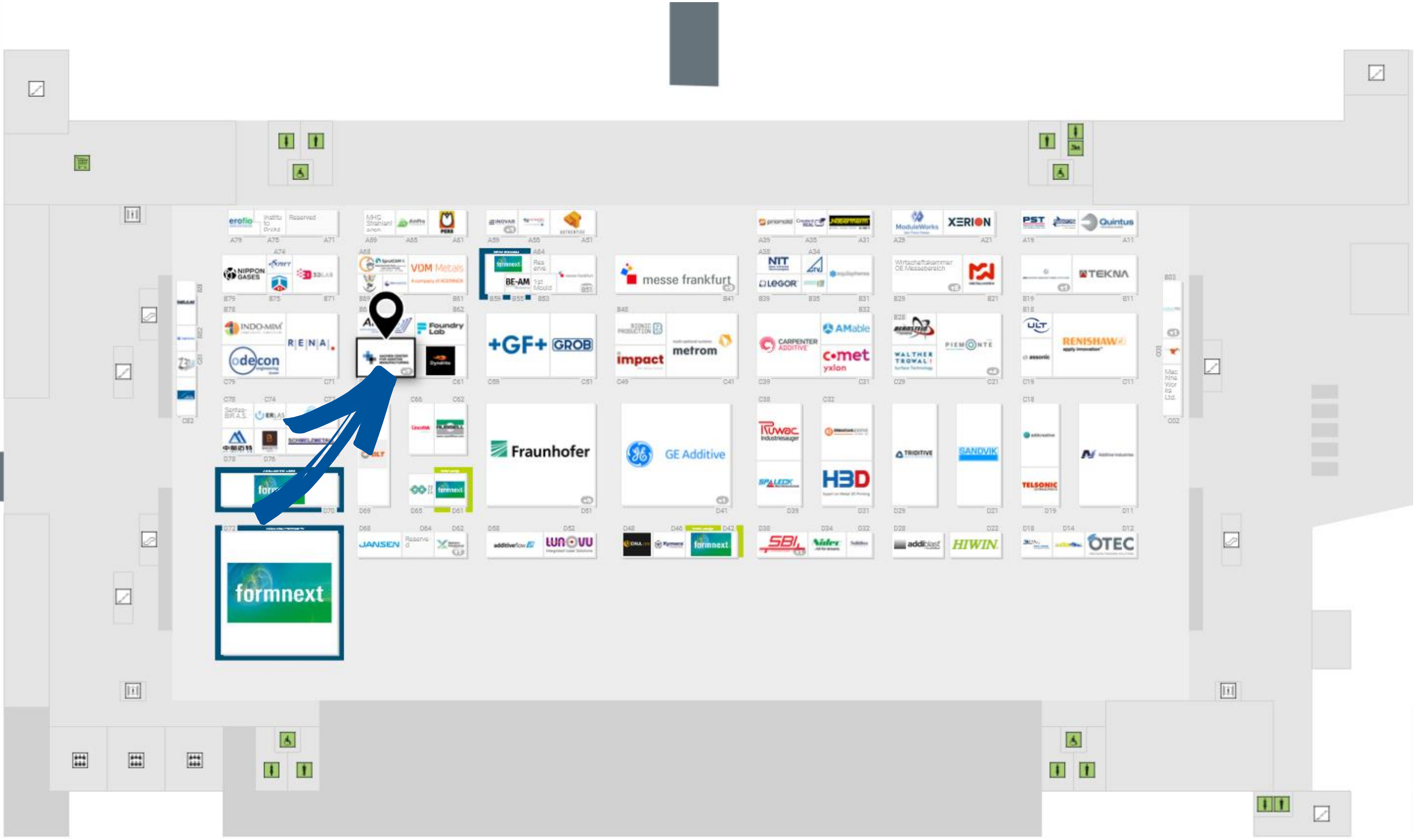
### Co-exhibitors: 2 Exhibitors

Hitachi Metals Europe GmbH

☆ 11.0, C69

Schäfer GmbH & Co. KG

☆ 11.0, C69



# Get in touch!

**Viktoria Krömer**
Consultant

ACAM Aachen Center for Additive Manufacturing GmbH
Campus-Boulevard 30
52074 Aachen

Email v.kroemer@acam-aachen.de

**Get in touch with our experts and become a part of Europe‘s most vivid AM and engineering ecosystem!**