AACHEN CENTER FOR ADDITIVE MANUFACTURING

Discover3DPrinting @ Formnext 2023

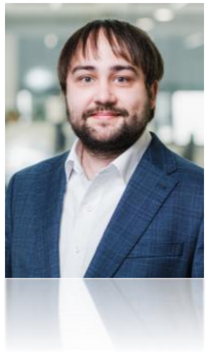
Basic AM Seminar

Jan Schenk| November 2023

formnext

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

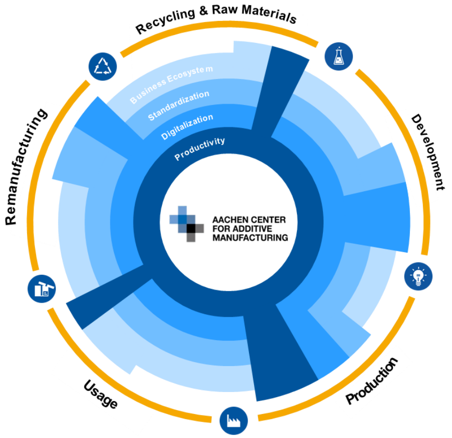
Your presenter



Jan Schenk, M.Sc.

- 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

BASIC Members

COOPERATION Members

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

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.“**

RWTH AACHEN CAMPUS

- **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

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**

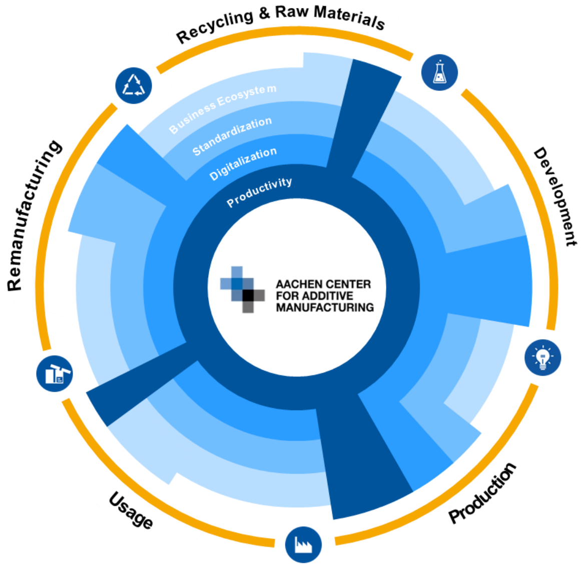
The world‘s most vivid and multifaceted AM ecosystem

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

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.

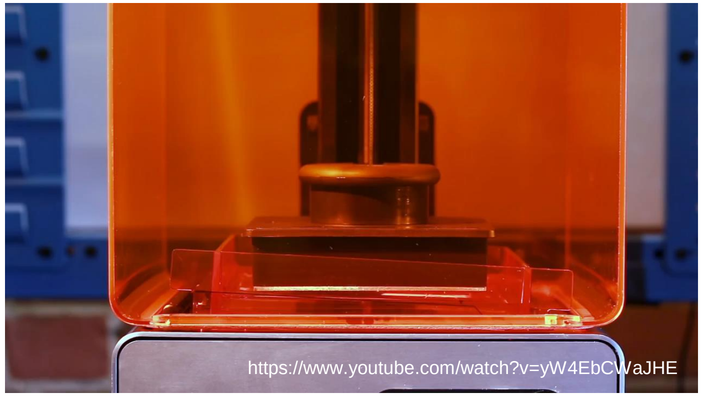
Basic AM Seminar – Content

Additive Manufacturing – Definition

Definition (ASTM 52900)

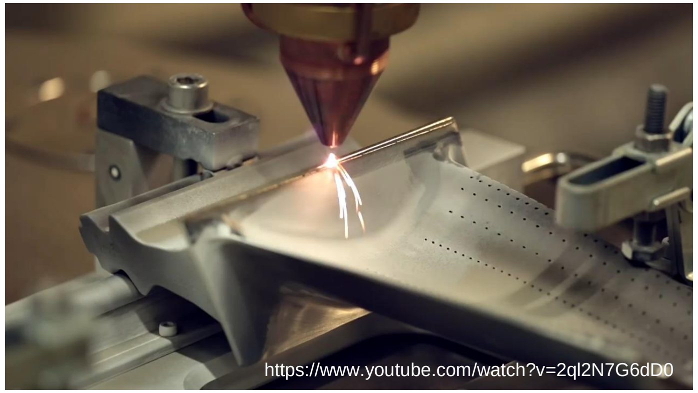
“Additive Manufacturing (AM) is defined as the process that

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



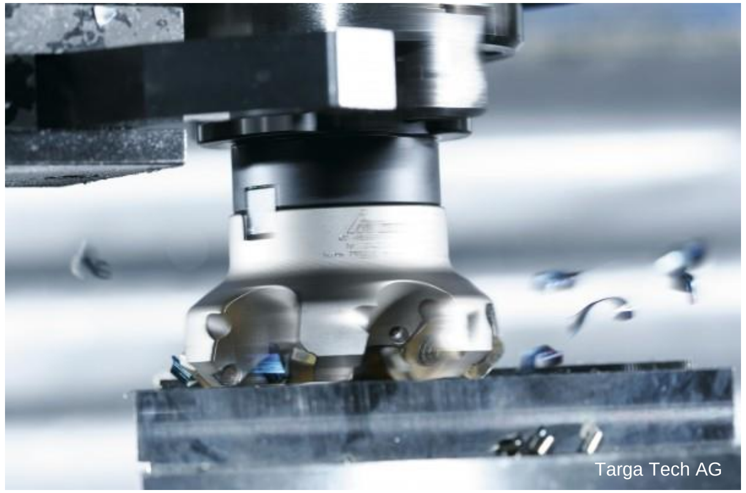
Definition (VDI 3405)

*“Manufacturing process in which the **workpiece is built up in successive layers or units**.”*



Subdivision of Manufacturing Technologies

Subtractive Manufacturing



Manufacturing of geometry by removing of defined areas from workpiece

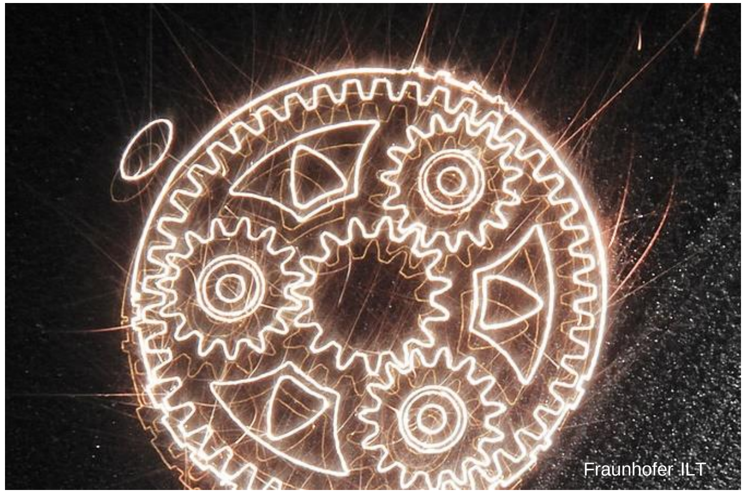
- Milling
- Turning
- …

Formative Manufacturing

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

- Deep Drawing
- Molding
- …

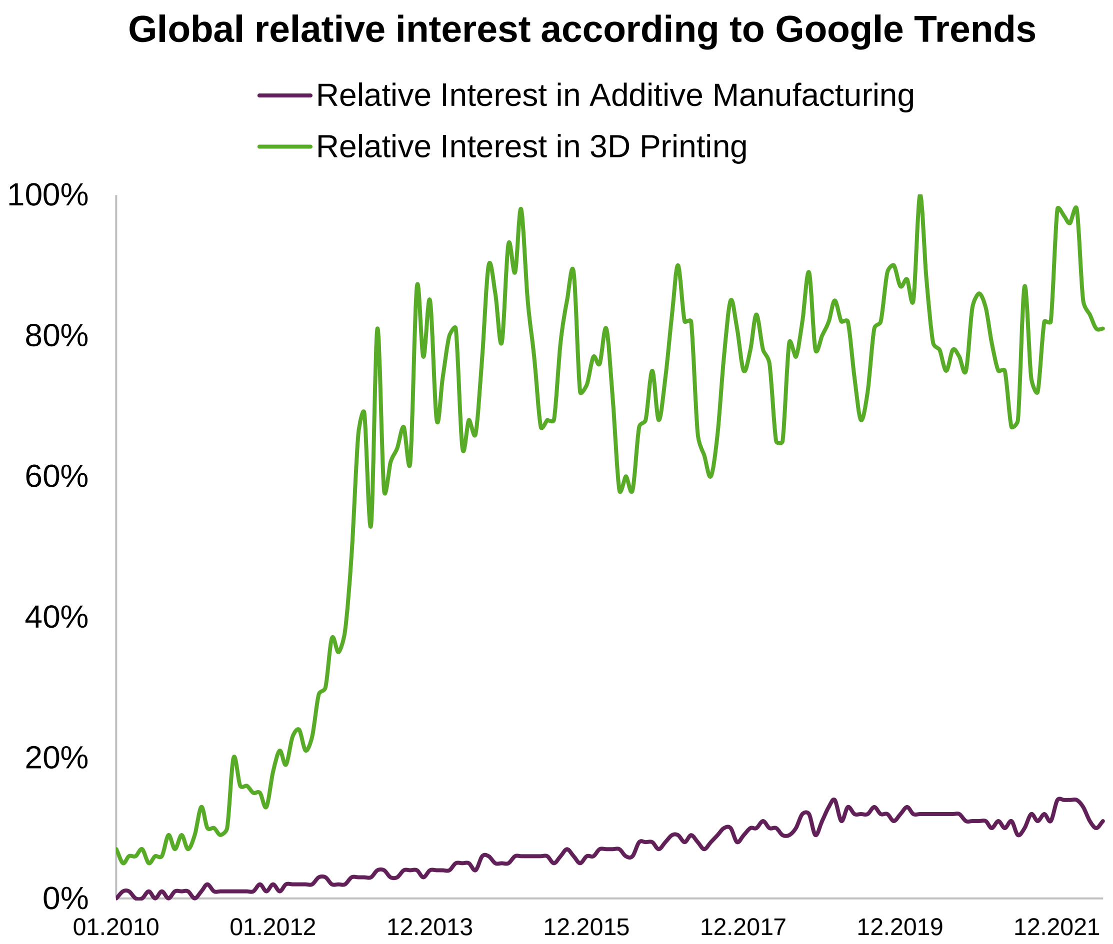
Additive Manufacturing



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**

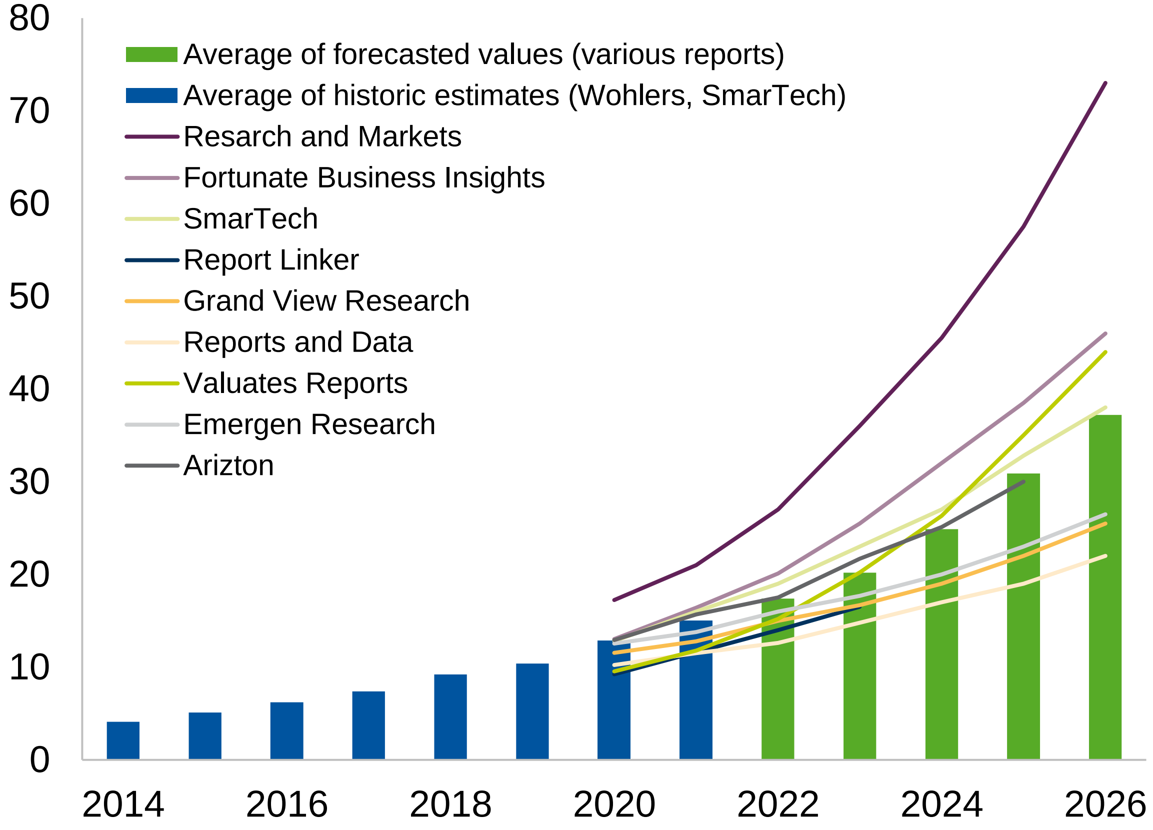
"3D Printing has the potential to revolutionize the way we make almost everything"

Barack Obama, State of the Union, Feb 2013

Source: Google Trends

Positive Historic and Future Development of the AM Market

Total AM market size according to different market reports [$ billion]

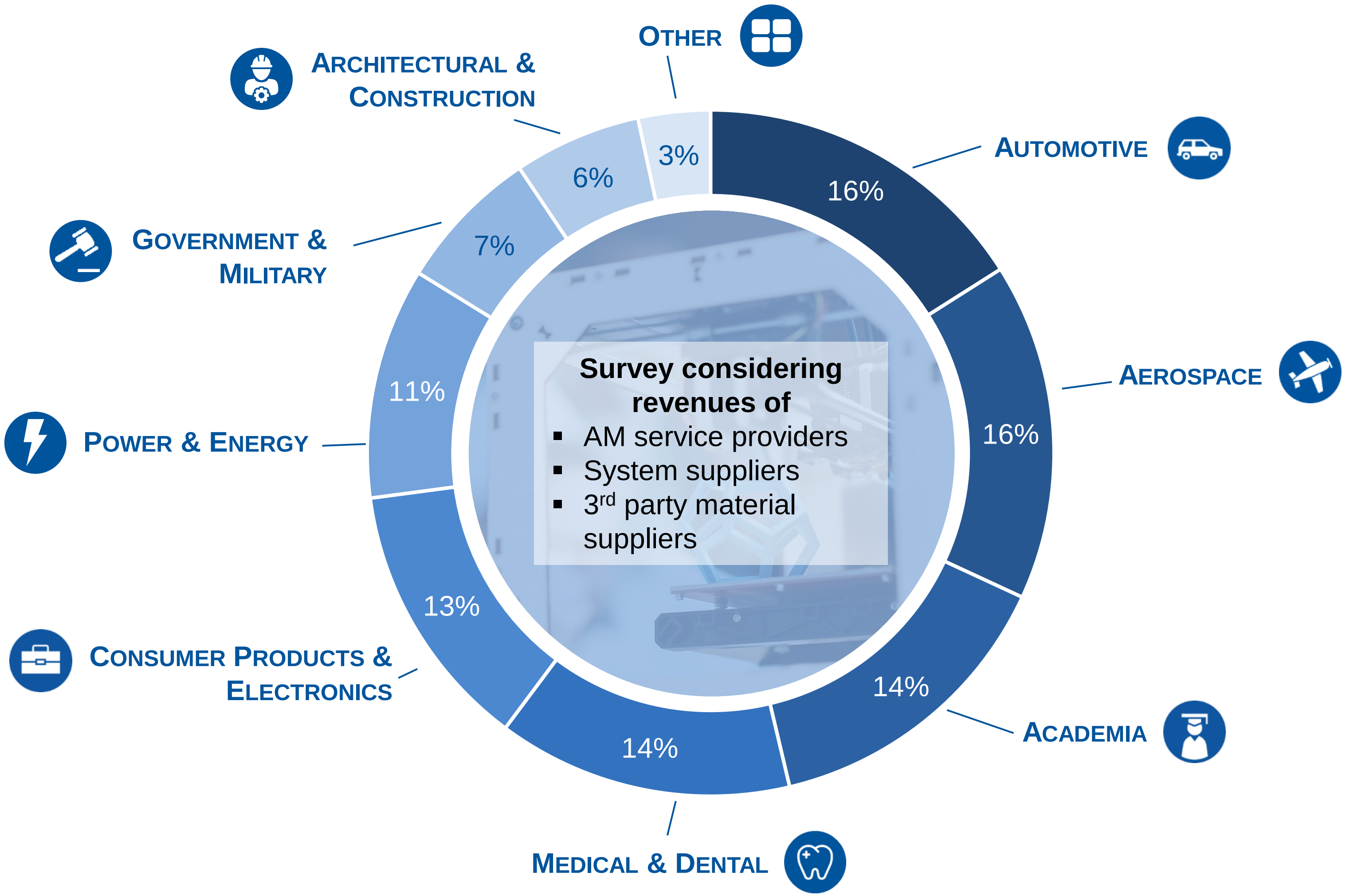


- **Overall positive** forecasted and historic growth rates in all reports
- **Diverging positive forecasts** indicate a **developing** volatile and uncertain market

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

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

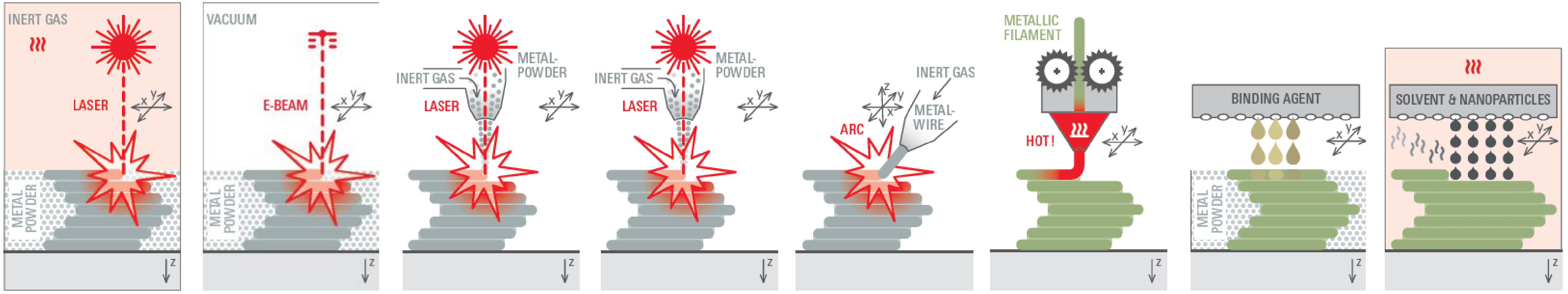
Basic AM Seminar – Content

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



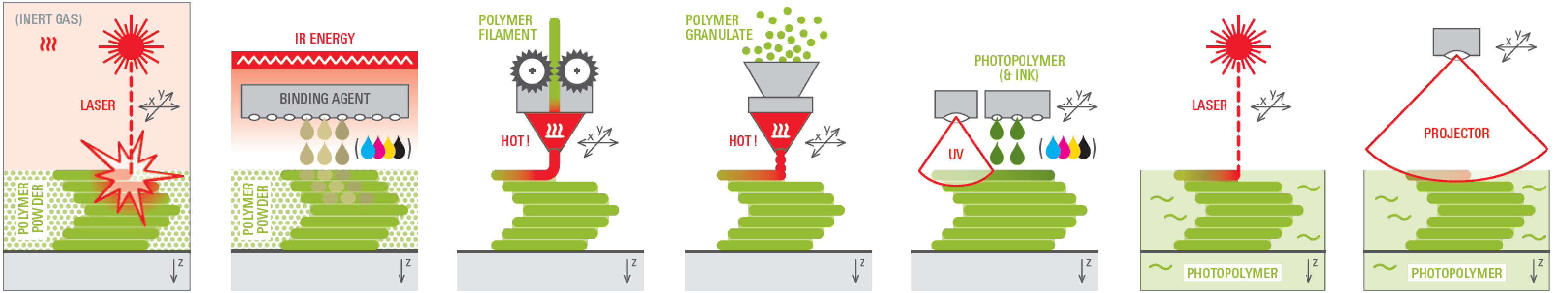
Source: Derived from Fomrnnext AM Field Guide Compact and DIN EN ISO/ASTM Terminology

AM Technology Overview
Segmentation of Established Polymer AM Technologies

Additive Manufacturing

Polymer

- ***Powder Bed Fusion***
  - Fused with laser → **SLS** Selective Laser Sintering
  - Fused with agent + energy → **MJF** Multi Jet Fusion
- ***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



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Additive Manufacturing

Metal

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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
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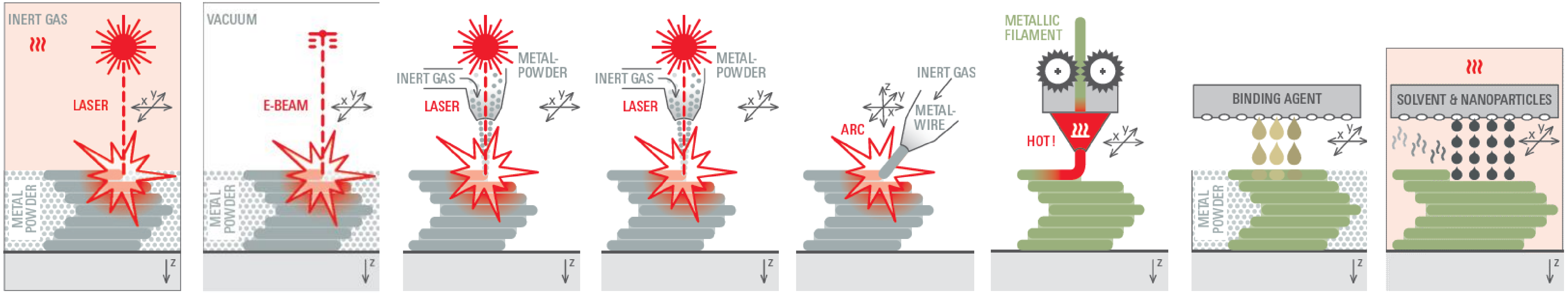
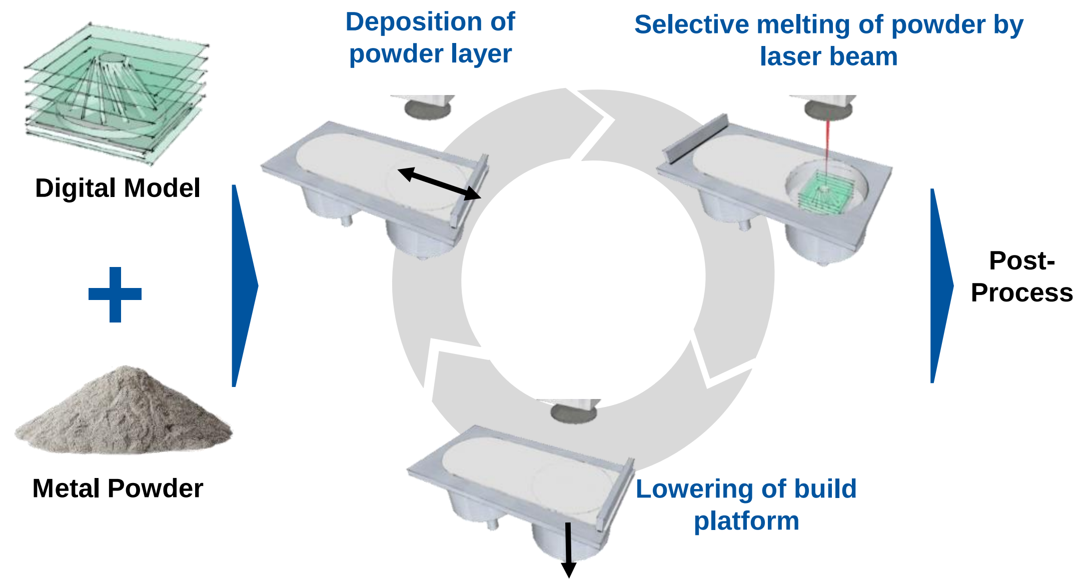


Source: Derived from Fomrnnext AM Field Guide Compact and DIN EN ISO/ASTM Terminology

AM Technologies
Laser Powder Bed Fusion of Metal (LPBF)

Process Principle

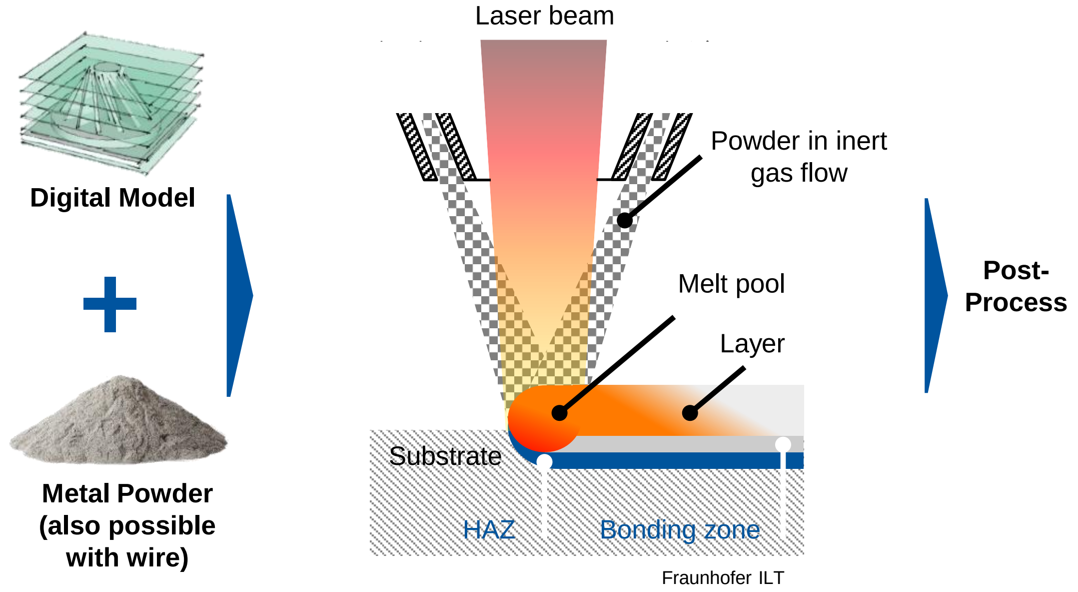


Process in Action

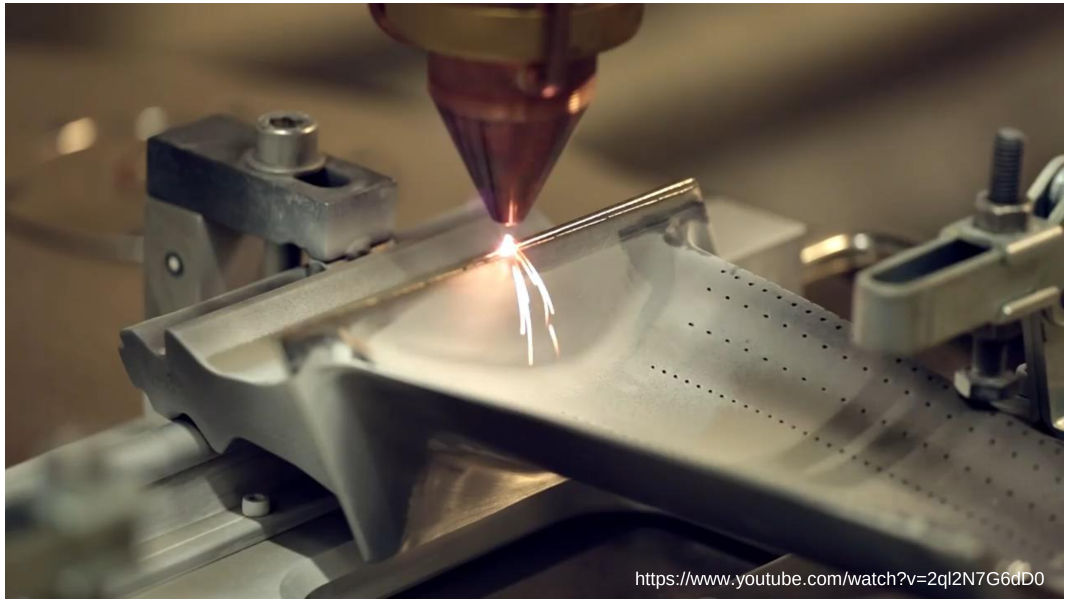
- Selective melting of metal powder layer-by-layer with one or more lasers
- Requires support structures for overhangs
- General suitability for weldable materials, comparably many alloys are qualified (e.g., steels, Ni based alloys, CoCr, copper and alloys, Ti and alloys, Al alloys, refractory metals,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

AM Technologies
Laser Metal Deposition (LMD)

Process Principle



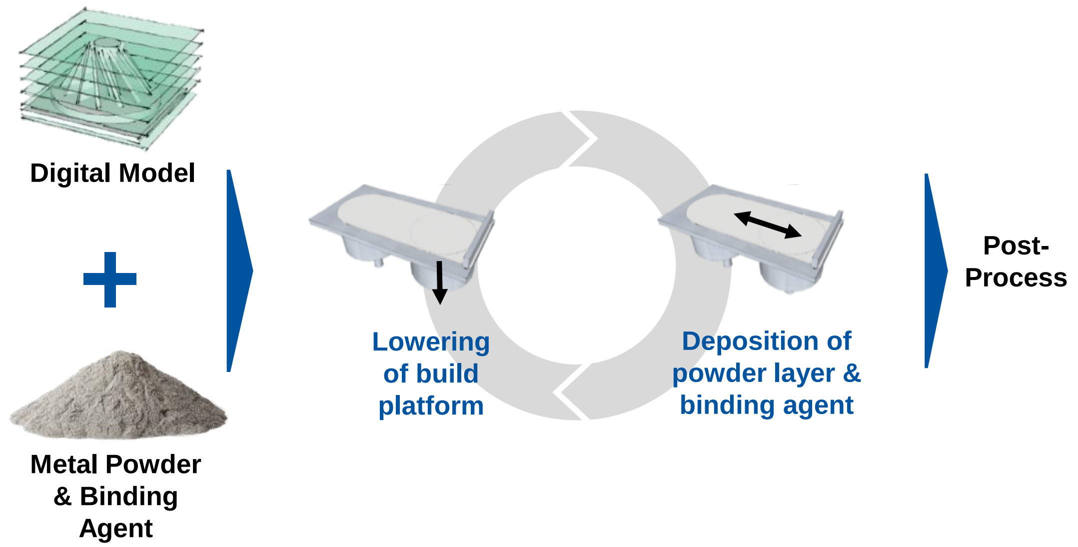
Process in Action



- 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
Binder Jetting (BJ)

Process Principle



Process in Action

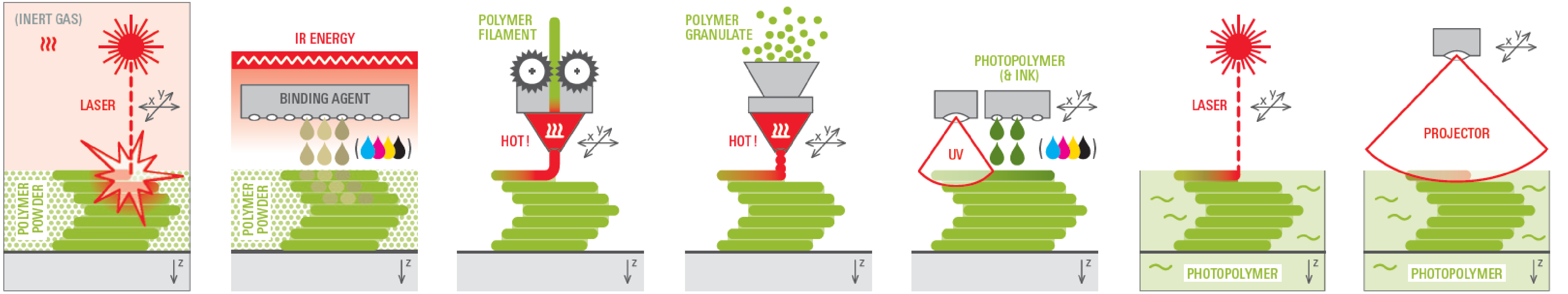
- Production of complex geometries by selective deposition of binder agent on metal powder layer by layer
- As-built part is in green state and requires further processing steps for functionality (e.g., curing, depowdering, sintering)
- Compared to LPBF lower technological maturity and less materials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

AM Technology Overview
Segmentation of Established Polymer AM Technologies

Additive Manufacturing

Polymer

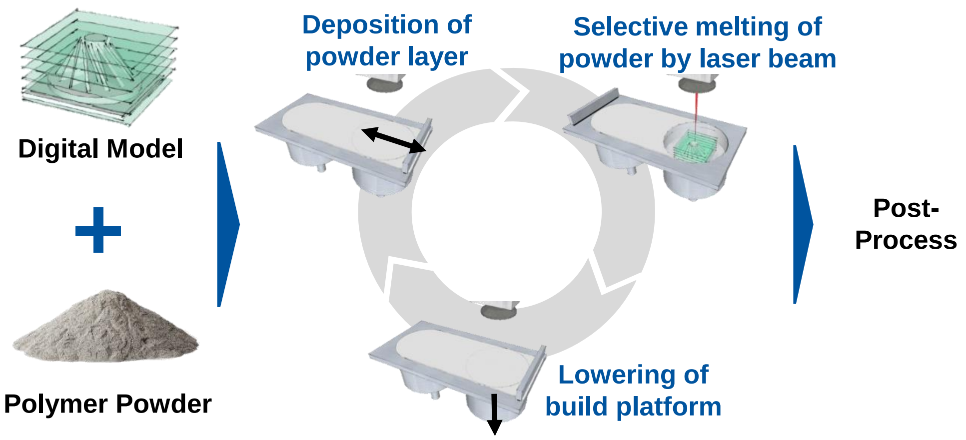
Powder Bed Fusion		*Material Extrusion*		*Material Jetting*	*Photopolymerization of Resins*	
Fused with laser	Fused with agent + energy	With filament	With granulate	Cured with UV light	Cured with laser	Cured with projector
SLS Selective Laser Sintering	**MJF** Multi Jet Fusion	**FDM** Fused Deposition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



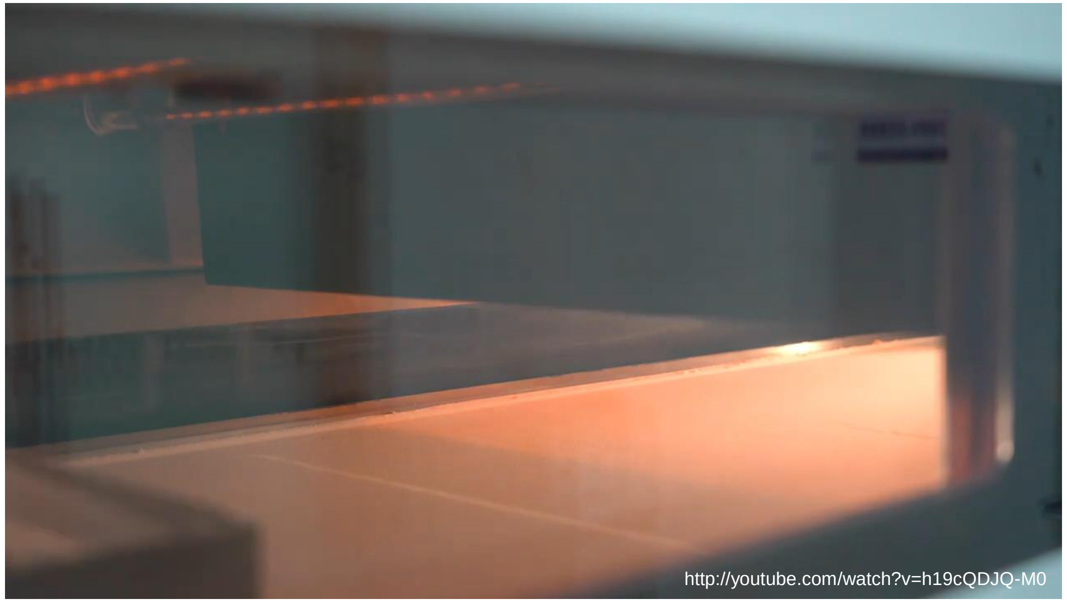
Source: Derived from Fomrnnext AM Field Guide Compact and DIN EN ISO/ASTM Terminology

AM Technologies
Selective Laser Sintering (SLS)

Process Principle



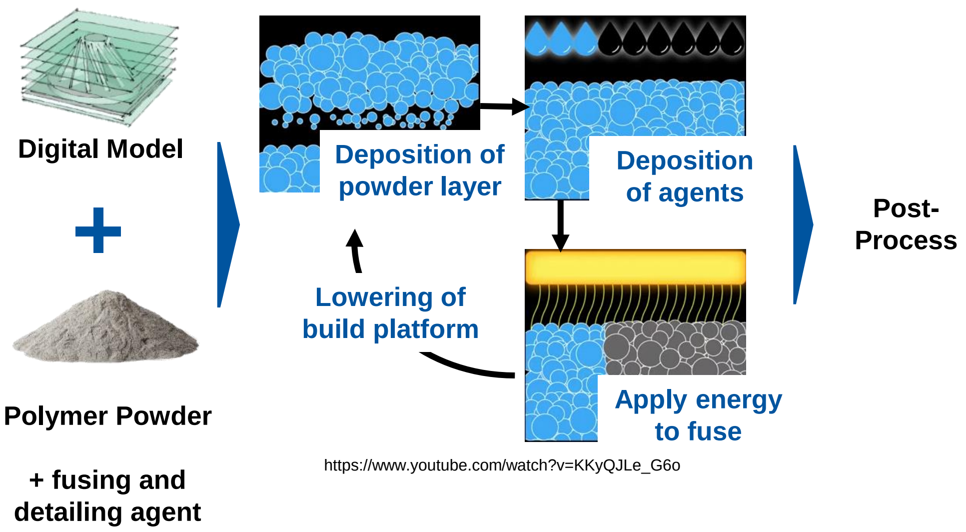
Process in Action



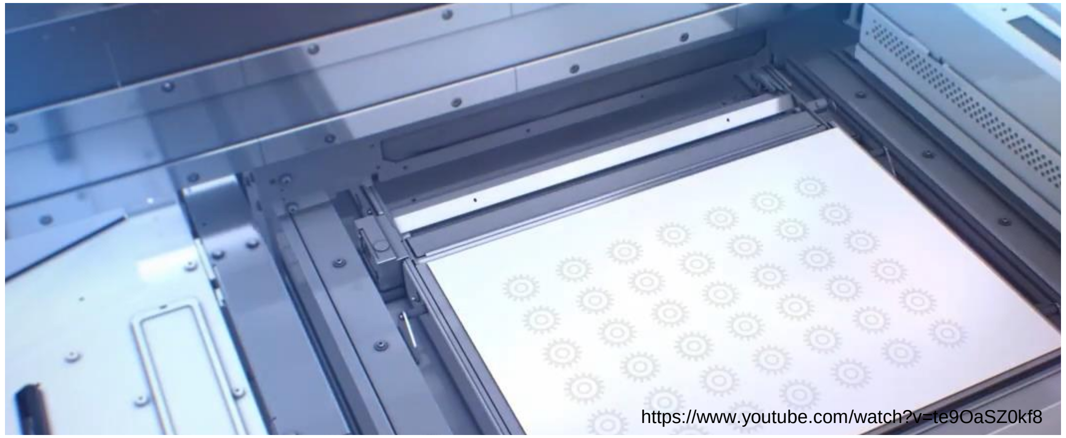
- Production of complex geometries by selective melting of polymer powder with one or more lasers
- As-built parts are usually white (polymer color)
- Many different materials available (e.g., PA11, PA12, TPU, PEEK, TPE, PP)

AM Technologies
Multi Jet Fusion (MJF)

Process Principle



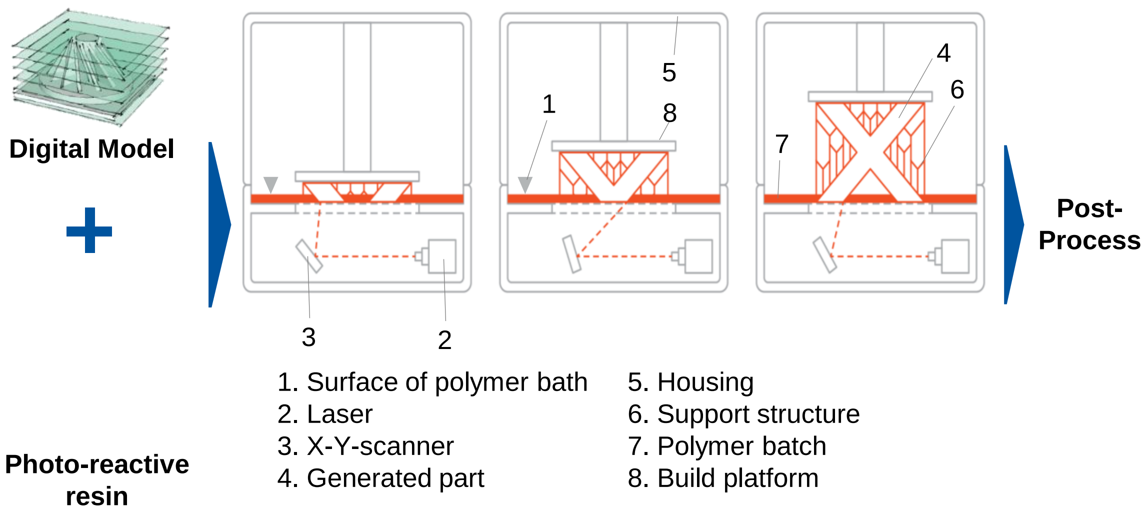
Process in Action



- 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

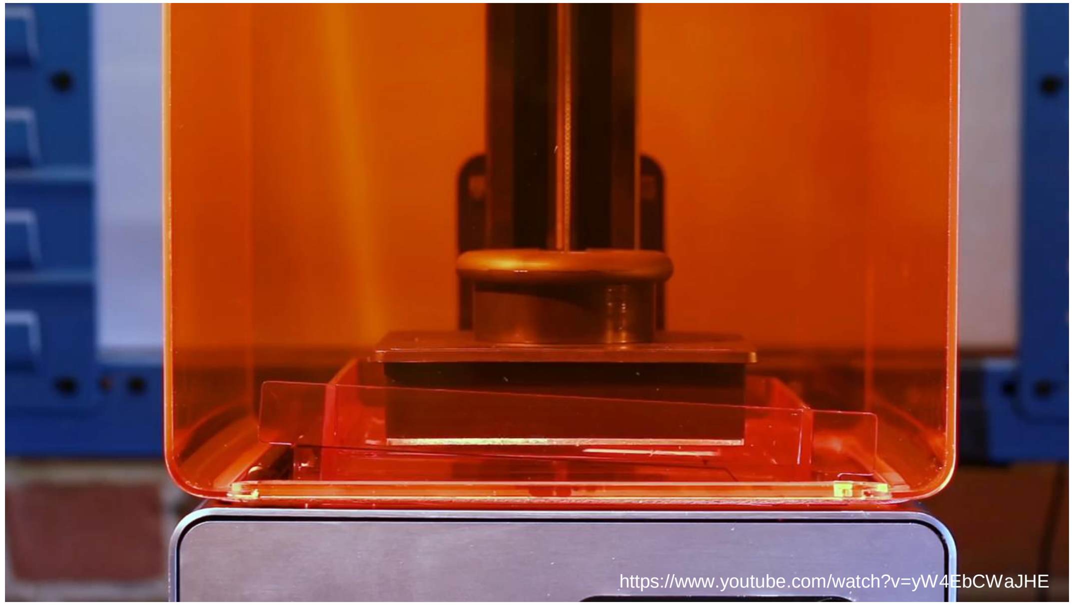
AM Technologies
Stereolithography (SLA)

Process Principle



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

Basic AM Seminar – Content

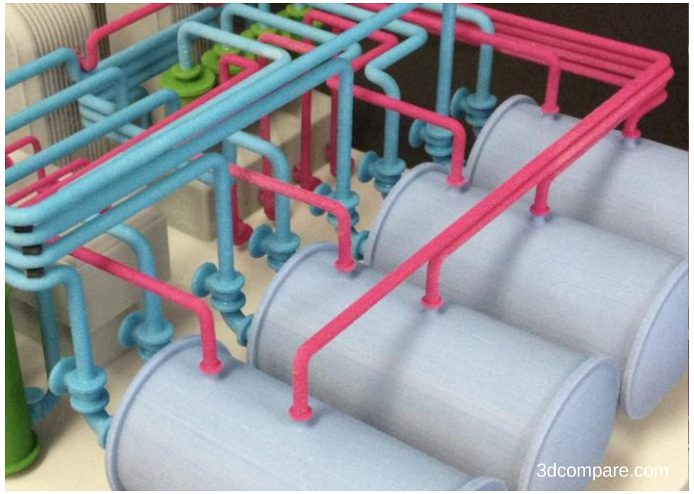
AM Application Examples
Visual Prototypes for Architecture

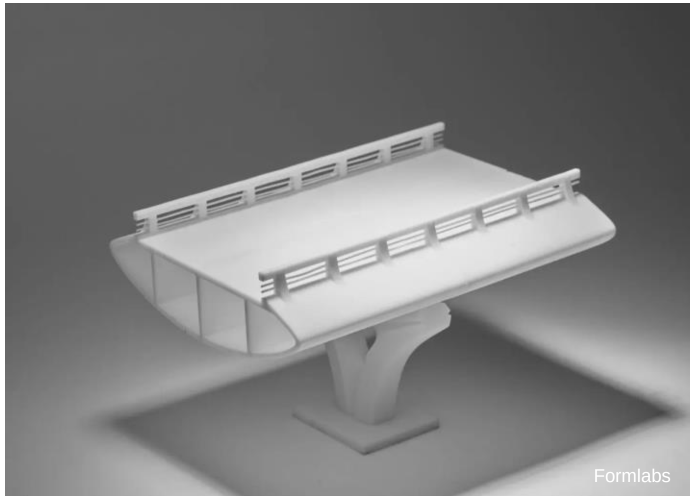
Characteristics

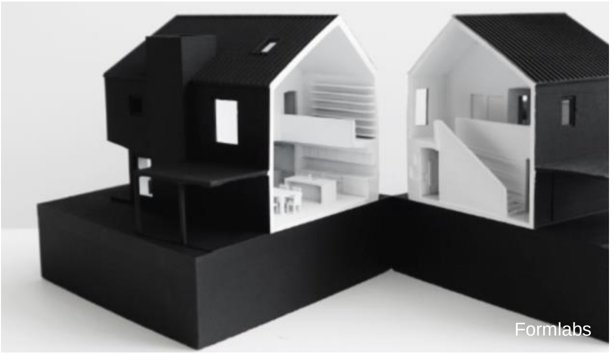
- Visualization of geometries using prototypes made with AM
- AM technologies: Various
- Application type: Visual prototype

Utilized AM Benefits

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







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

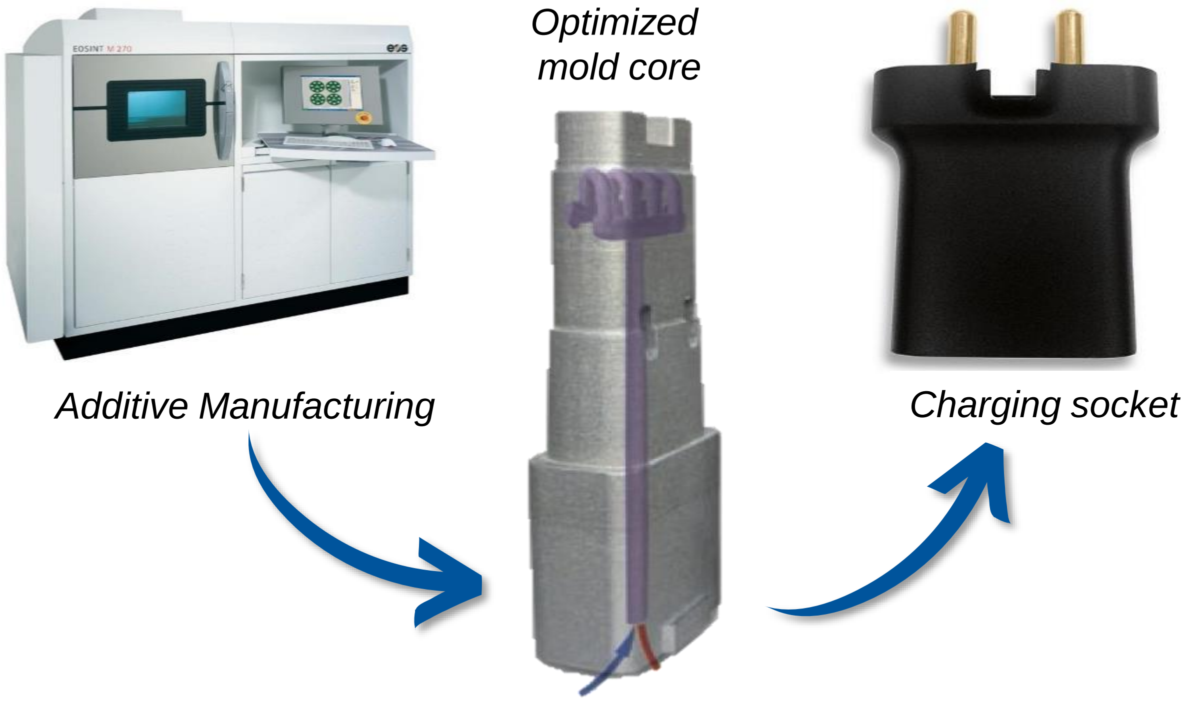
AM Application Examples
Reduction of Cycle Time in Injection Molding

Characteristics

- Conventional tool for charging socket with 14 seconds cycle time and 2 % reject rate
- AM technology: LPBF
- Application type: Tooling

Utilized AM Benefits

- Cycle time reduced down to 8 seconds
- Reject rate reduced to 1,4 %
- Realization of internal cooling geometries
- Cost saving of 20.000 €



Source: Eos GmbH, Salcomp PLC

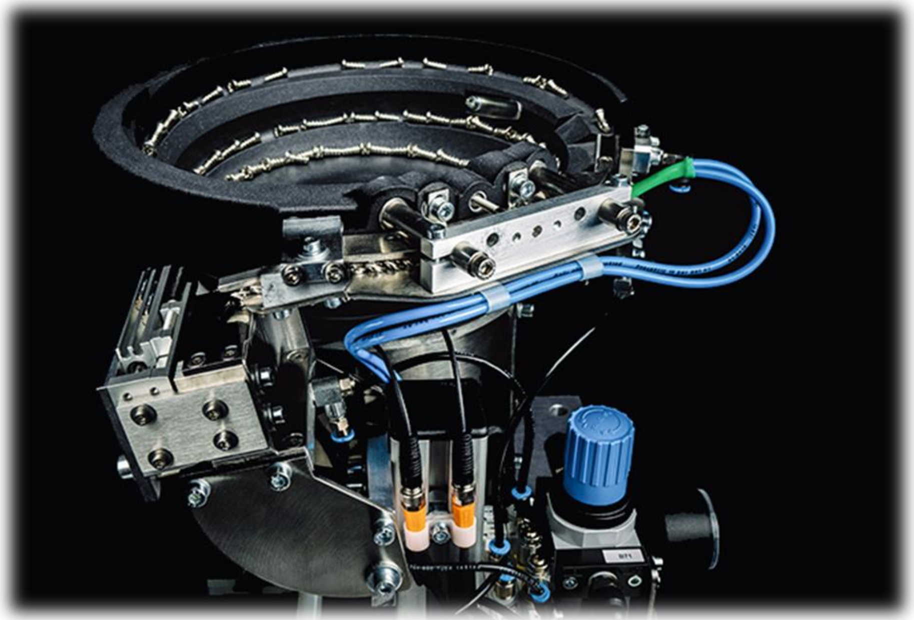
AM Application Examples
RNA GmbH Vibratory Conveyors

Characteristics

- SLS-3D printed vibratory conveyors
- The high-performance magnets used enable a high load-independent conveying capacity
- 3D deep learning AI technology helps optimization of geometry

Utilized AM Benefits

- Completely reproducible
- Flexible and can be quickly converted for other workpieces
- Different parts from the same part family can be fed



3D printed vibratory conveyor drive

Source: RNA

AM Application Examples
Series Part - BMW i8 Roadster Roof Mount

Characteristics

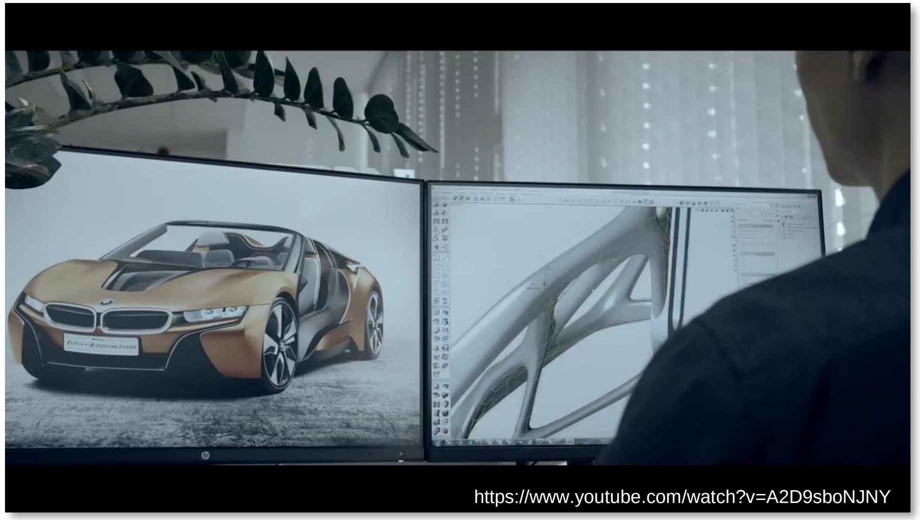
- Stiff part that holds the convertible roof of the BMW i8 roadster
- Small series end-use part
- AM Technology: Laser Powder Bed Fusion
- Material: Aluminum alloy (AlSi10Mg)


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)
- Economic and ecologic sustainability through material efficiency


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


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

AM Application Examples
Series Part – Adidas Shoe Sole

Characteristics

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


Adidas


Adidas

Utilized AM Benefits

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


Carbon

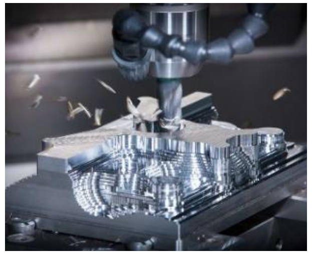
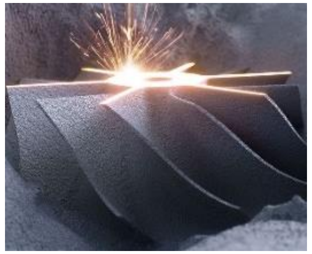

Carbon

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

AM in Comparison to Conventional Manufacturing

	Process	Internal Structure	Dimensional Accuracy (ISO)	Surface Quality Rz (µm)	Material Variety	Integration of Functions	Productivity [cm³/h]
Formative		++	++ *IT8 – IT16*	++ *4 – 1000*	+++	++	+++
Subtractive		+	+++ *IT5 – IT16*	+++ *0,04 – 250*	+++	+	++ *< 300.000*
Additive		+++	+ *IT10 – IT13*	+ *20 – 70*	+(+)	+++	+ *1 – 700*

Additive Manufacturing processes open up new technological possibilities - these must be used effectively and integrated into process chains

Legend: **+**: suitable **+(+)**: suitable in future; **++**: well suited; **+++**: very well suited

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.*

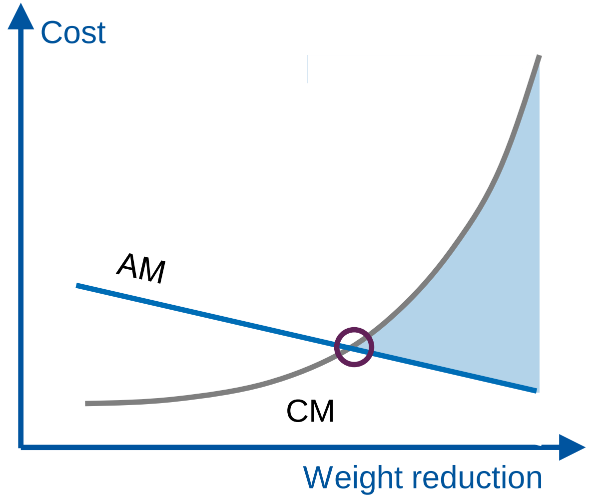
…Additive Manufacturing is different

- **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**

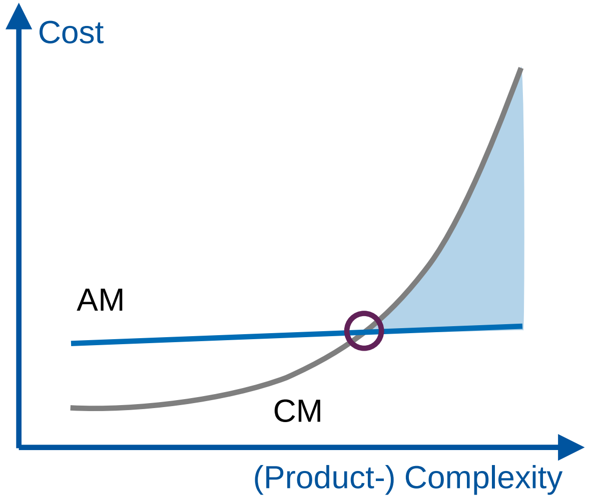
Source: Effectory, TCT

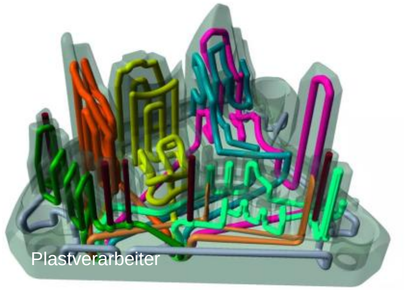
Successful Adaption of AM
Different Cost Structure of Conventional Manufacturing (CM) and AM

Weight reduction means cost reduction

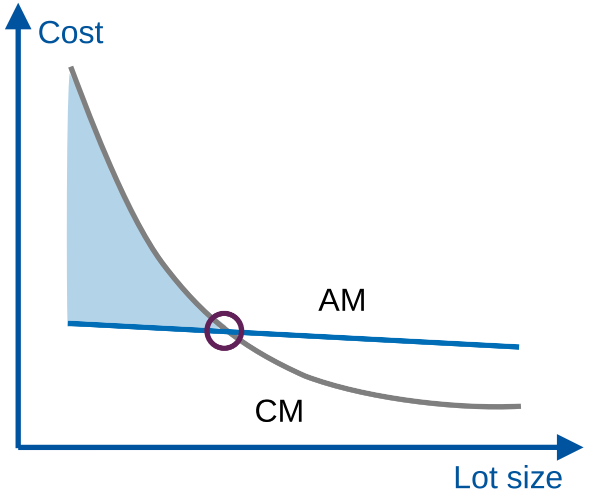


Complexity (almost) for free





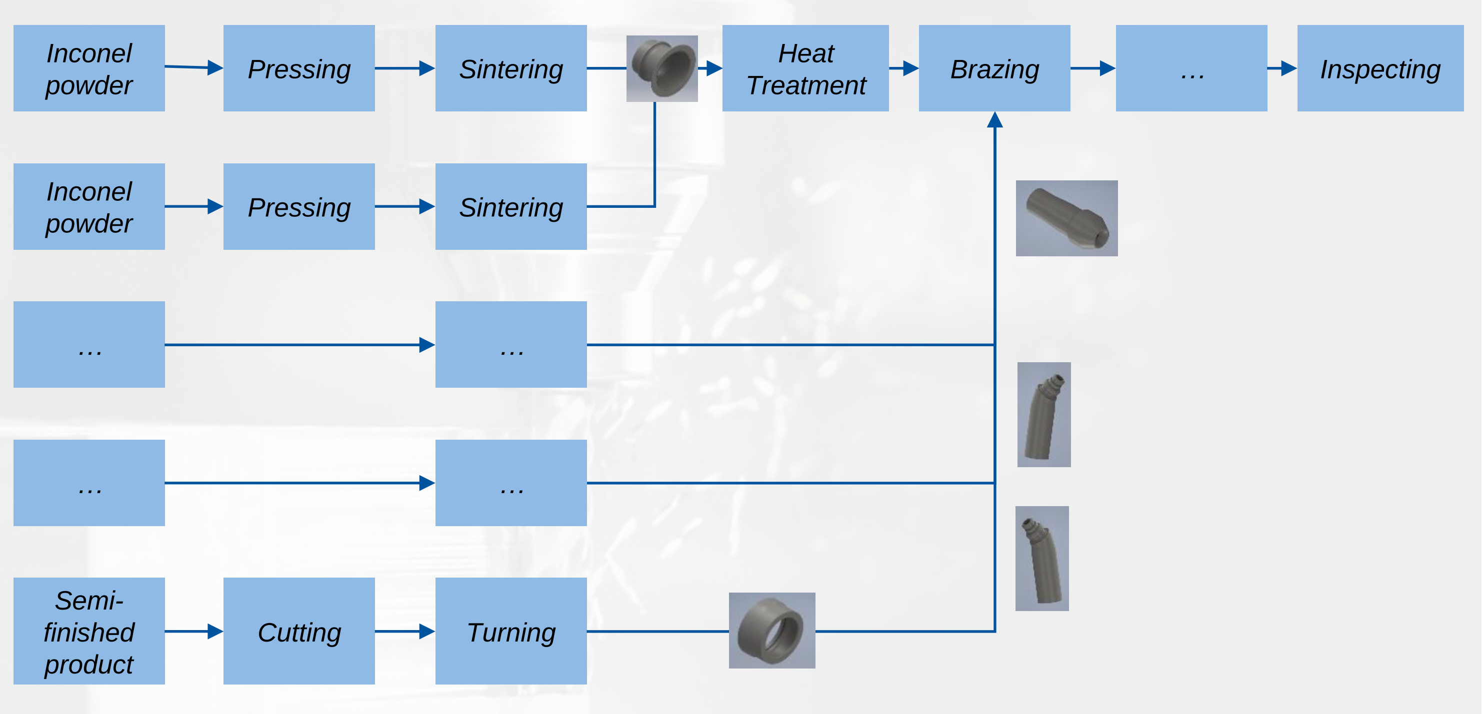
Individualization (almost) for free



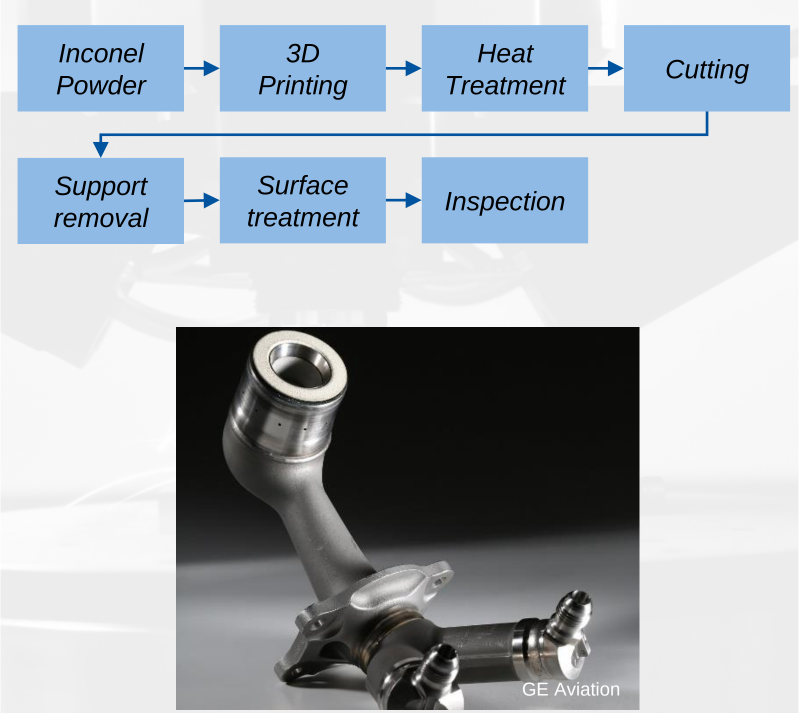
Successful Adaption of AM

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**

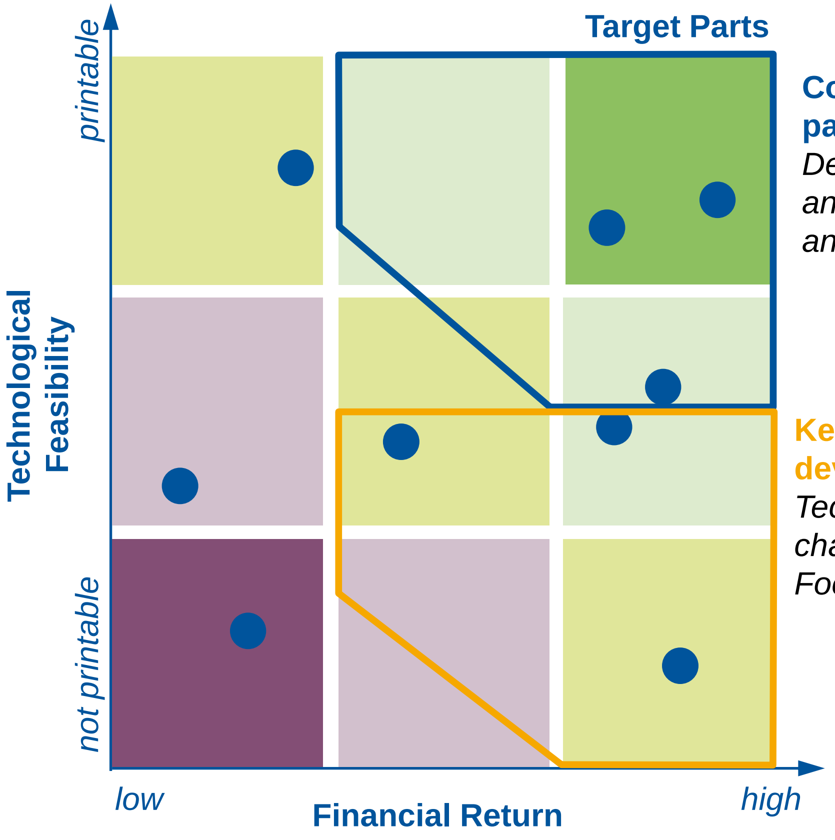
Source: Effectory, TCT

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

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Successful Adaption of AM
Business Models Based on AM

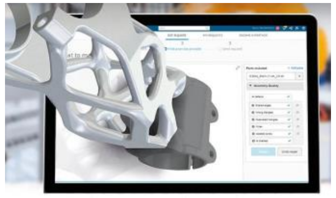
AM Benefits

- **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 for staff in 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
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**
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Source: Effectory, TCT

Successful Adaption of AM
Algorithmic Design for Additive Manufacturing – Generative Design

How?

Conventional design

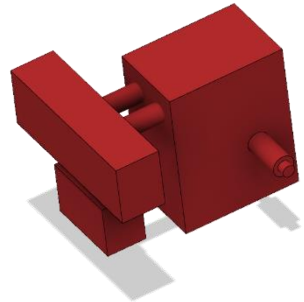
Additive design

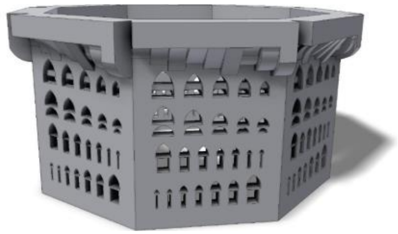
Source: RWTH DAP, e.GO

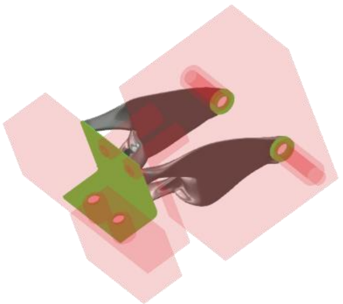
Successful Adaption of AM

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"

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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

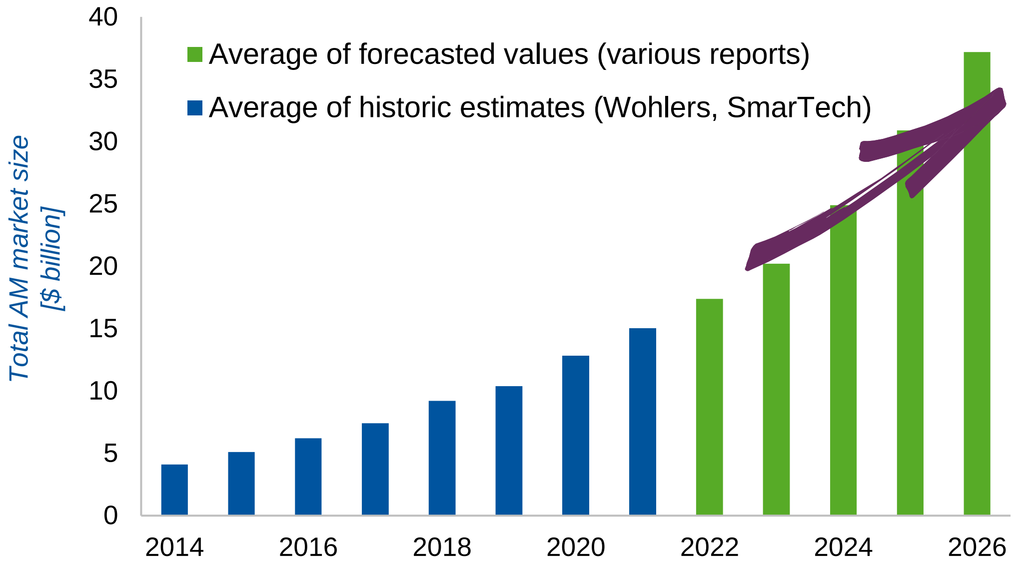
- Heat-protective gloves
- Flameproof clothing
- Full respiratory mask
- Protective shield
- ESD wristband

Prevention of health hazards requires implementation of specific safety measures

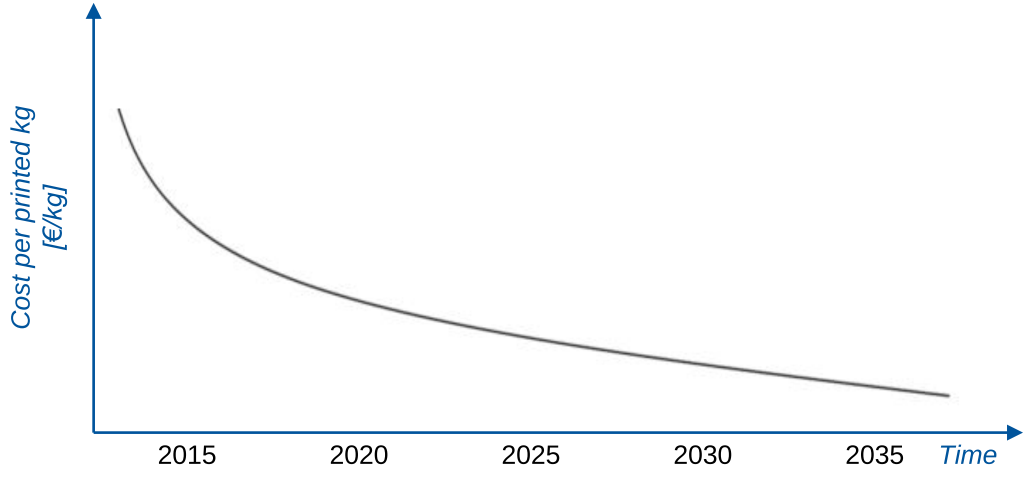
Basic AM Seminar – Content

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

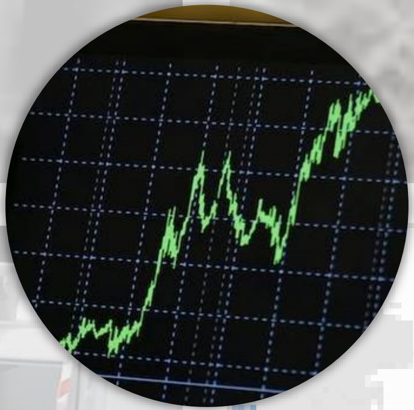
Future Perspective of AM
Key Aspects

Emerging AM Technologies

RWTH DAP

Digital Materials

Altair Enlighten



Automatization & Line Integration

TruPrint 5000

IDAM, BMW

Digital & Sustainable Business Models

RWTH DAP

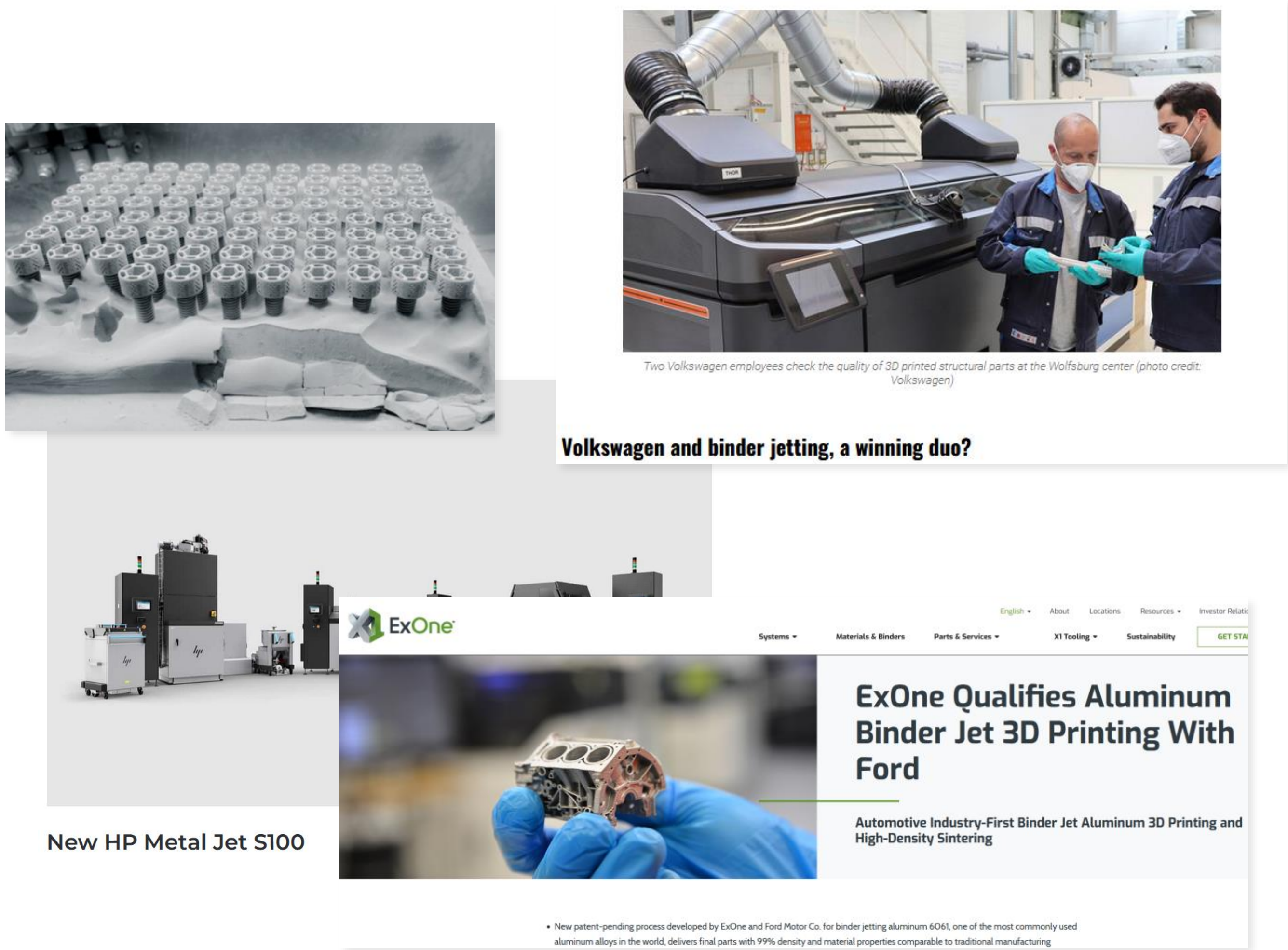
Future Perspective of AM
Emerging AM Technologies – Metal Binder Jetting for Mass Production

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

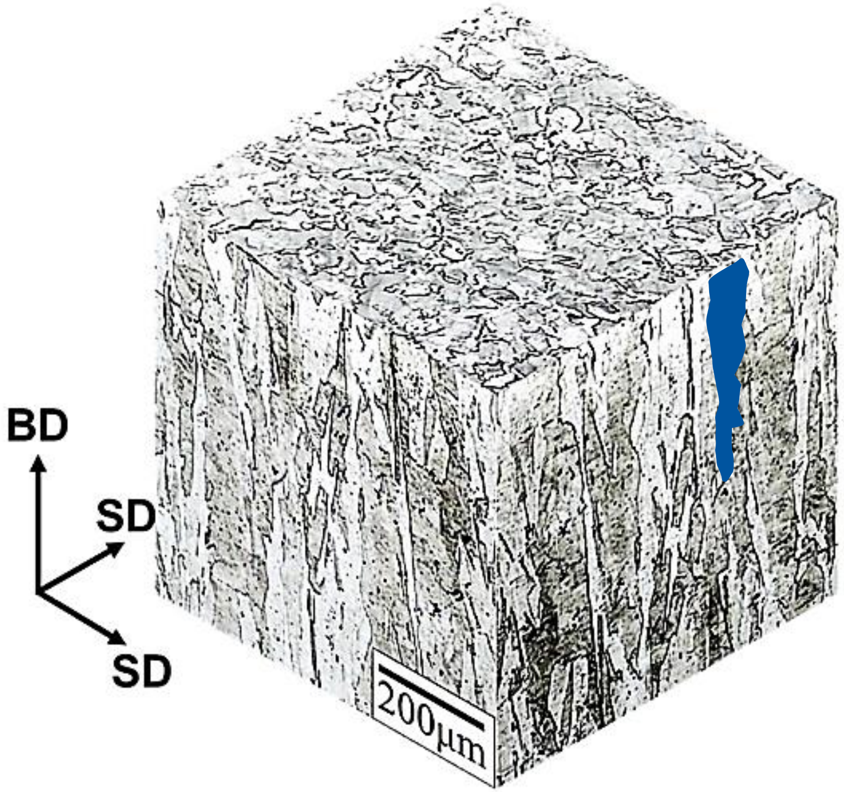
- Additional process steps: Debinding & Sintering
- Automation, e.g., removal of green parts from powder cake
- Comparably low technology maturity compared to LPBF



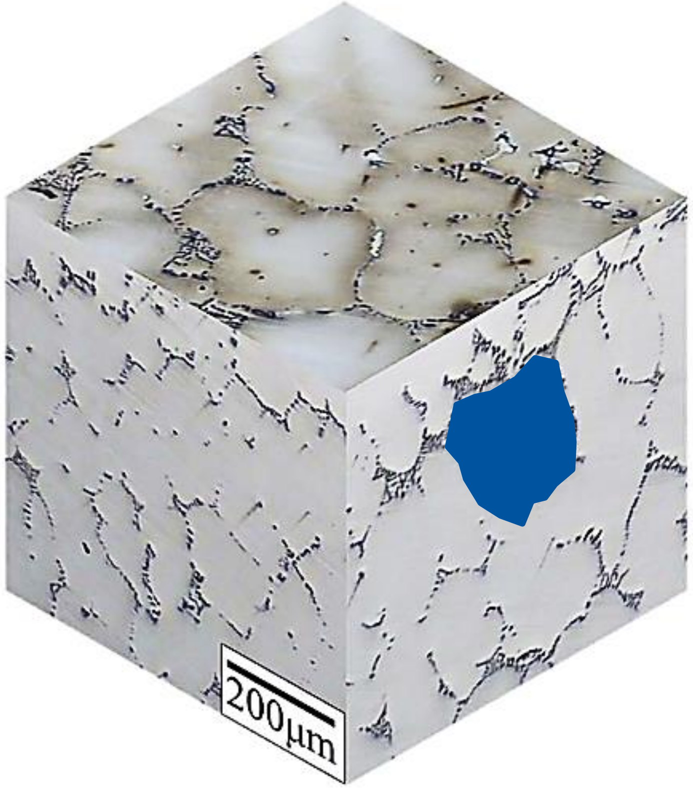
Source: ExOne, 3Dnatives, AFMG, HP

Future Perspective of AM
Digital Material – Different Microstructure with Influence on Mechanical Properties

BD: build direction
SD: side direction



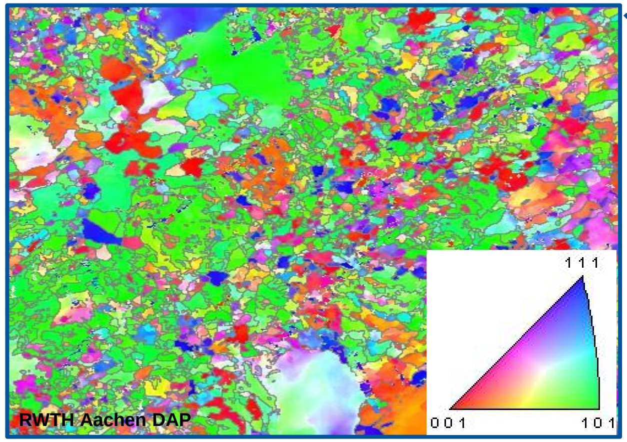
Microstructure after LPBF

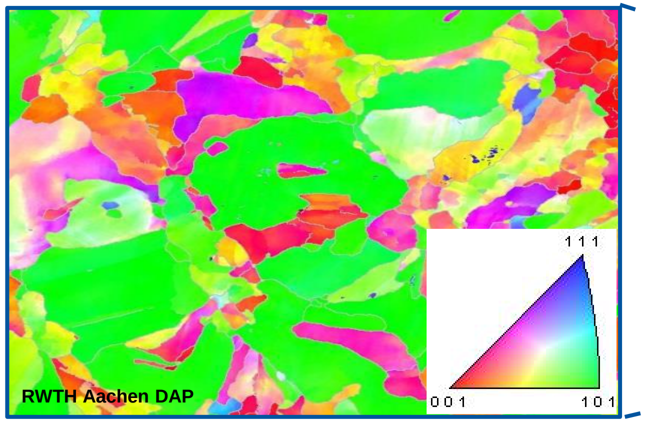


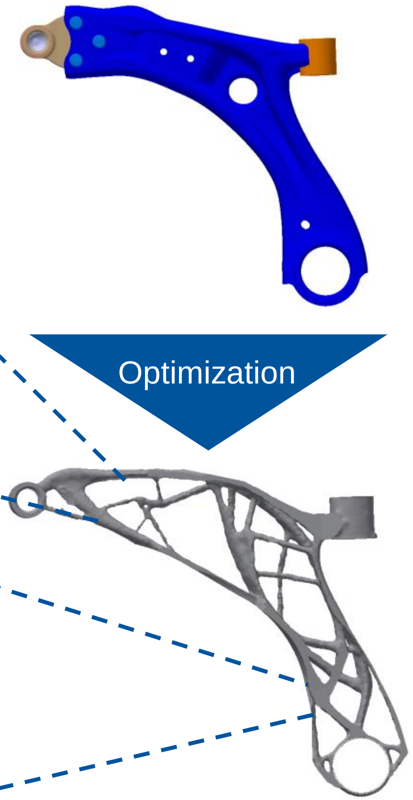
Microstructure after casting

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)

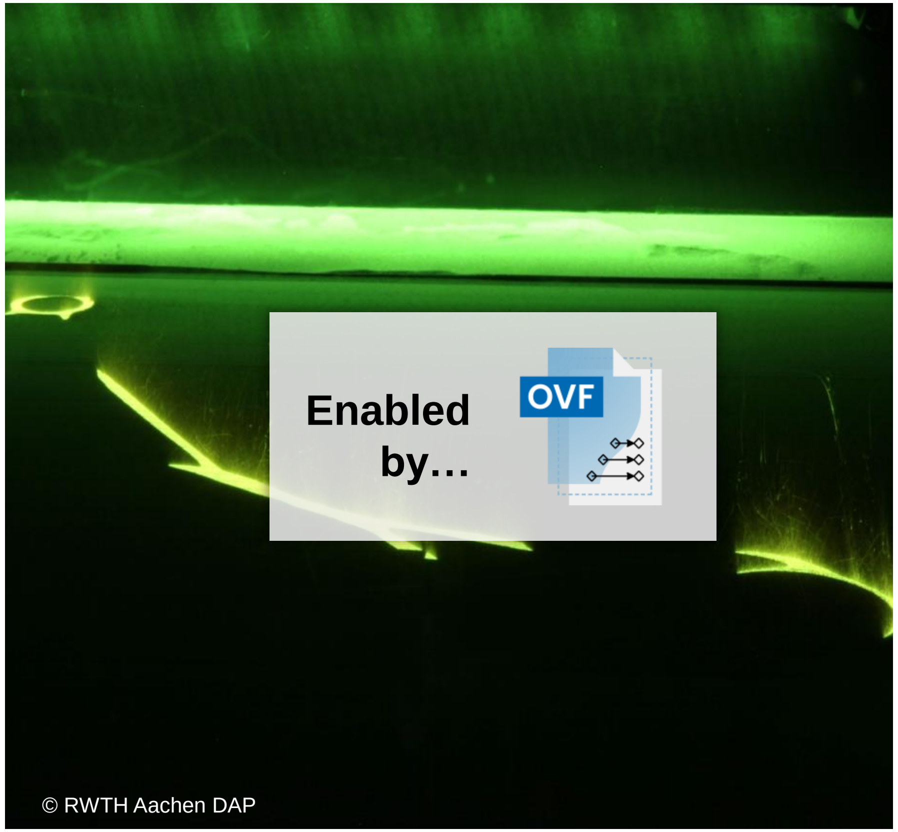






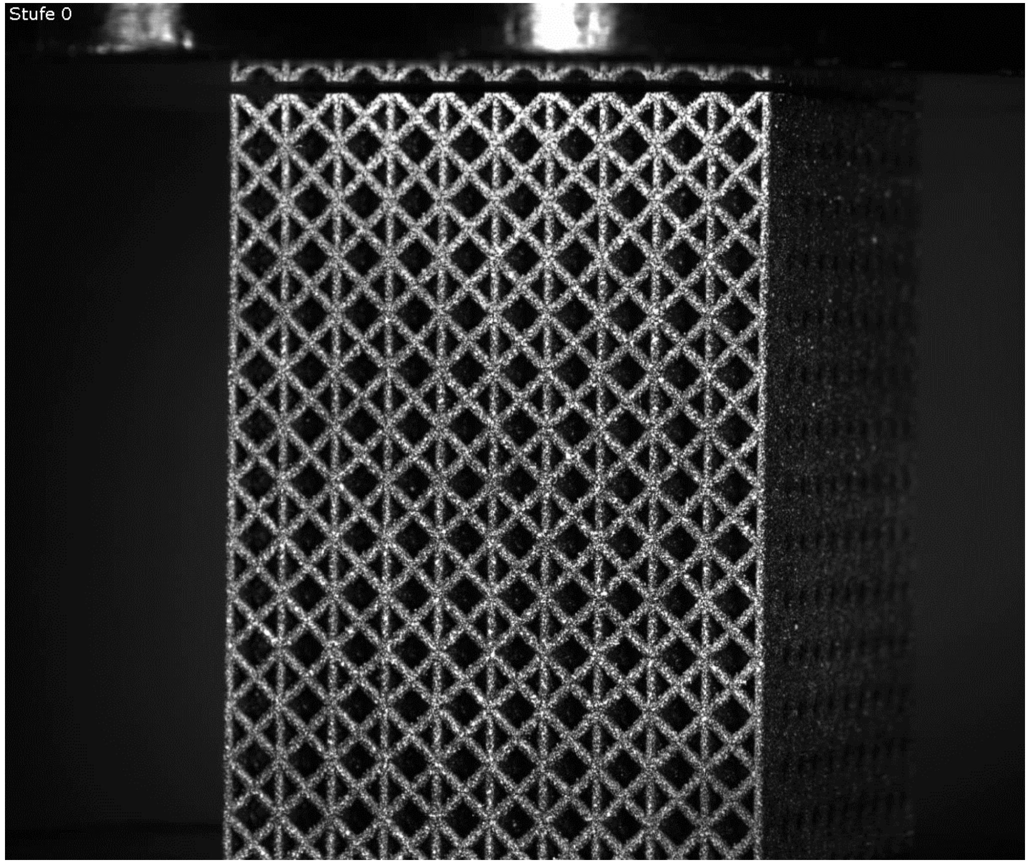
(exemplary illustration)

LPBF

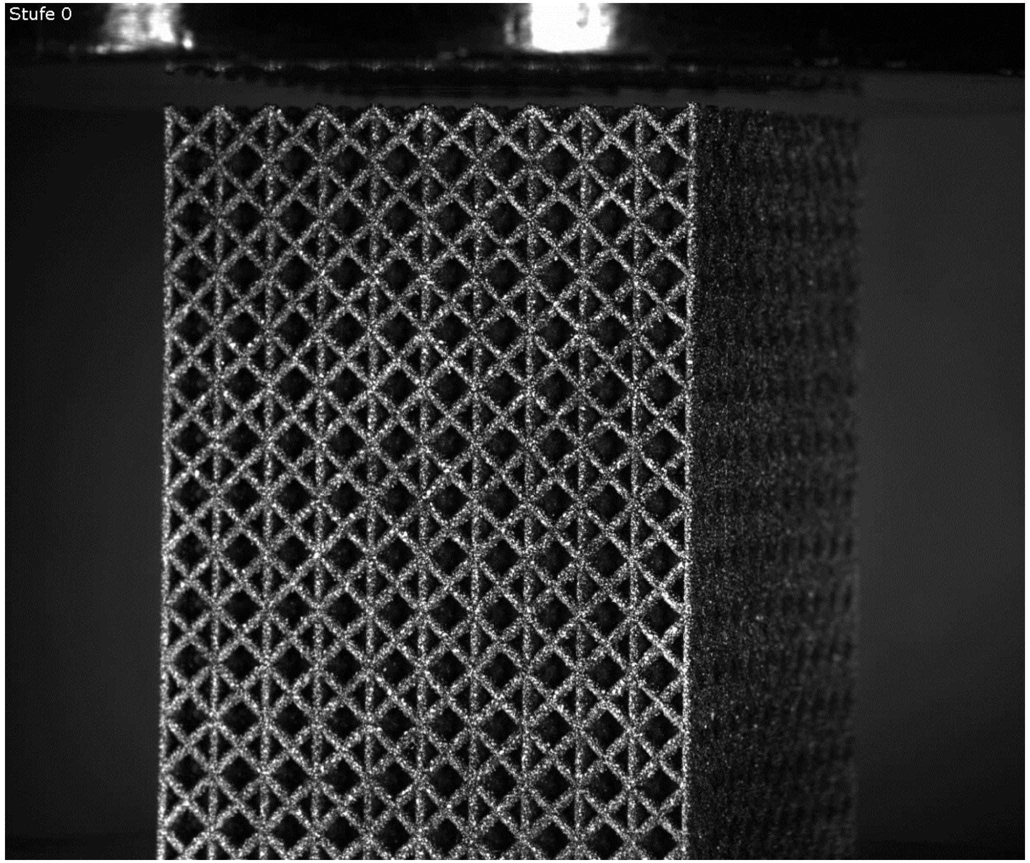


Future Perspective of AM

Digital Material – Illustration of the Effect of Locally Adapted Microstructure



Conventional



Locally adapted microstructure (digital material)

Future Perspective of AM
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

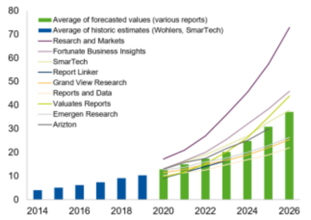
Recent crises have shown the vulnerability of global supply chains. Resilience is a key element to competitiveness.

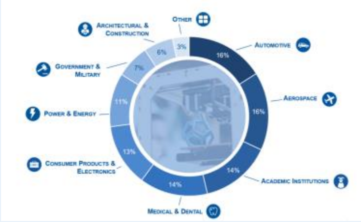
Source: RWTH DAP, WIBU, BMBF

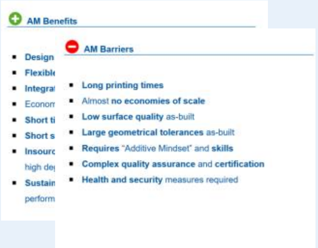
Basic AM Seminar – Content

Basic AM Seminar
Summary

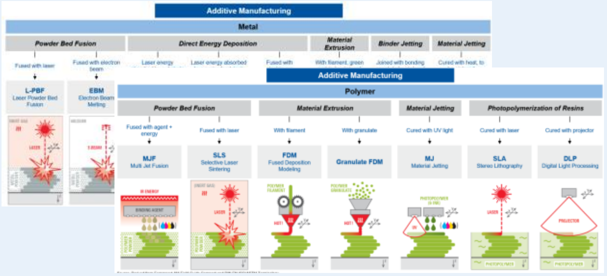
Introduction to Additive Manufacturing







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

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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 of 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
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IWF An-Institut der FH Aachen
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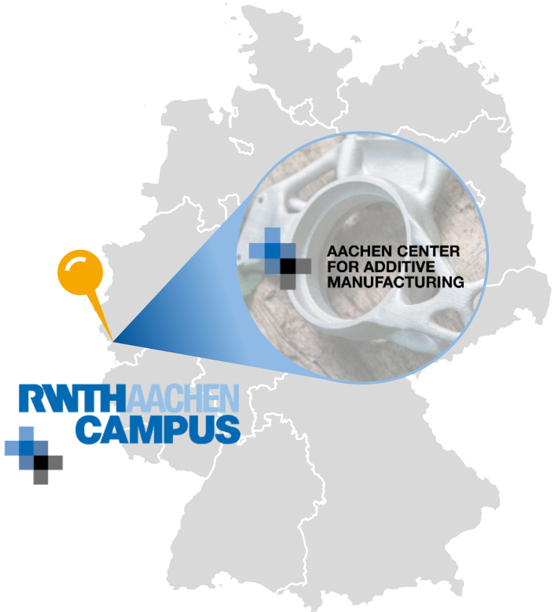
Embraced Research & Knowledge

AACHEN CENTER FOR ADDITIVE MANUFACTURING

Industry Network



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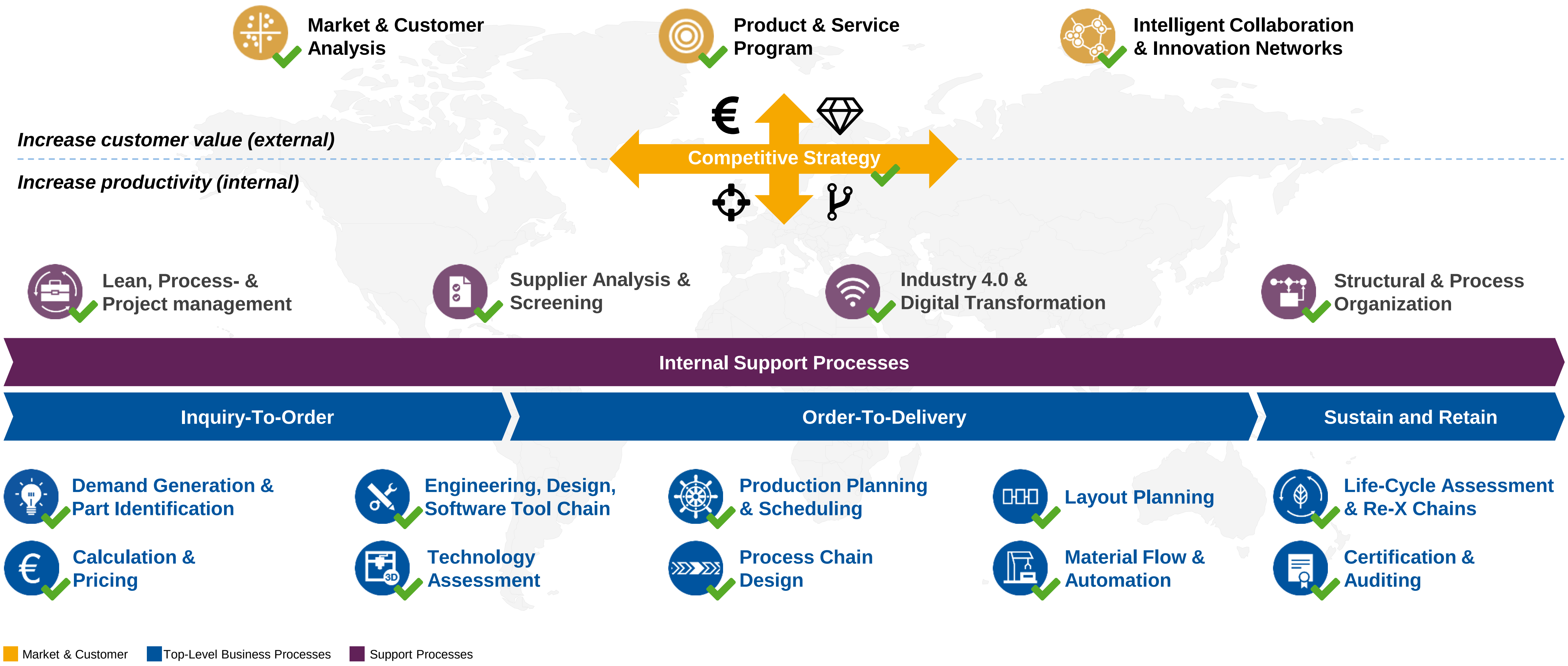
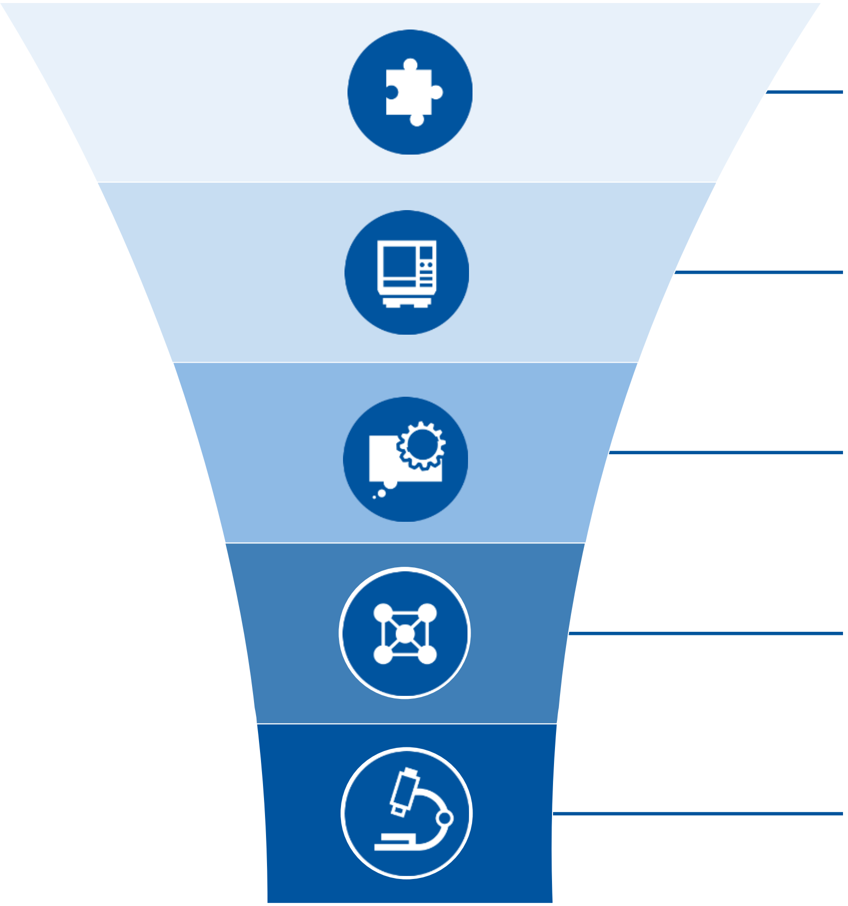
Enabling Manufacturing Companies



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

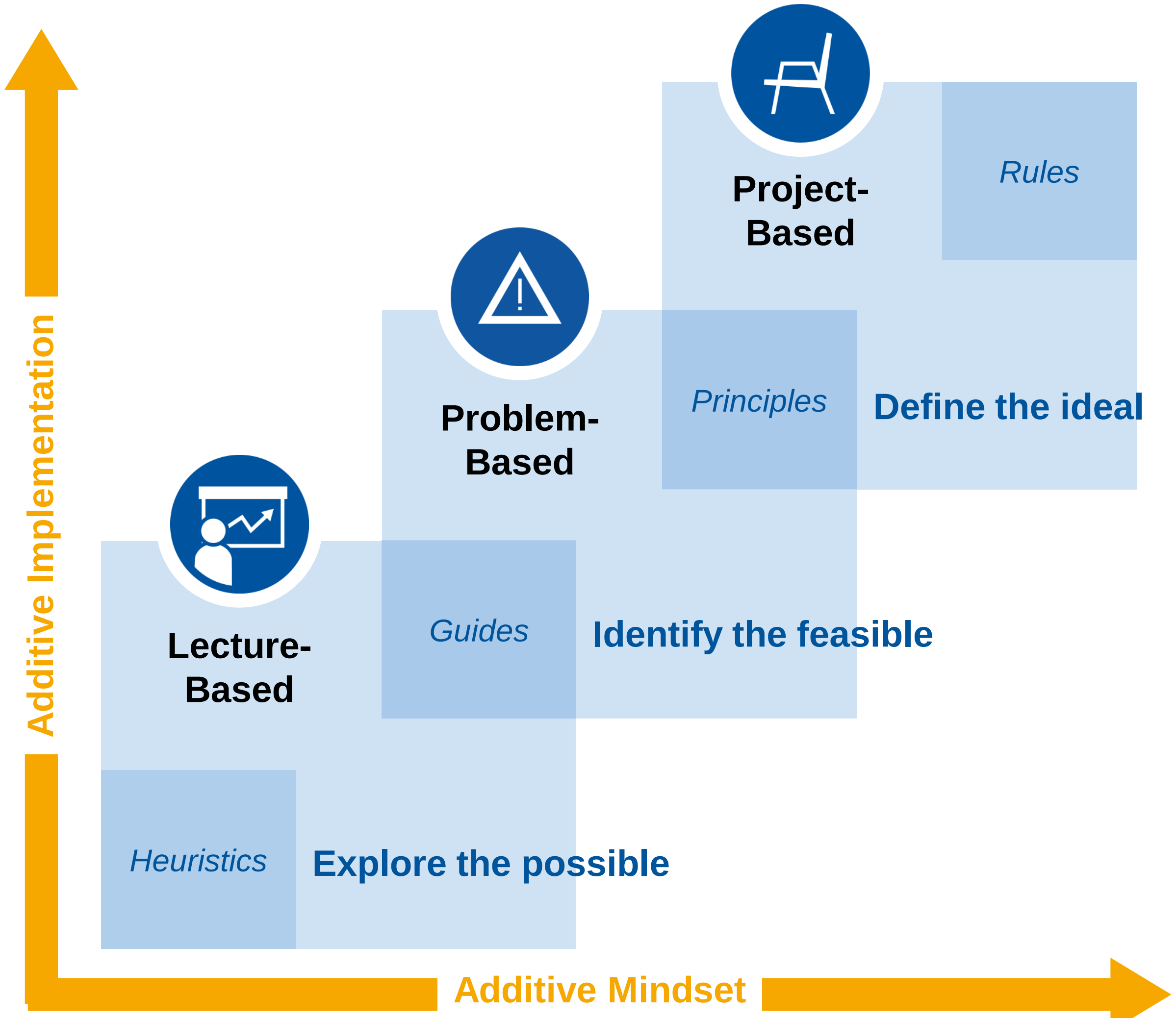
Bilateral R&D Projects

- 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

Get in touch!

← Hall 11.0

Hall 11.0, E43

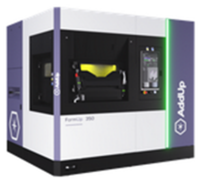
Main exhibitor

ACAM Aachen Center for Additive Manufacturing GmbH

11.0, E43

Co-exhibitors: 3 Exhibitors

AddUp



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Get in touch!

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