Tampere University

FITech Summer Boost: Additive Manufacturing and 3D printing

Additive Manufacturing Processes & Application Areas

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17 May 2019, Turku

Who am I?

Hossein Mokhtarian

Specialist in Additive manufacturing,

Product development & Systems engineering.

Postdoctoral researcher and lecturer at Tampere University

- **Education**
  - PhD in Mechanical Engineering, 2016 - 2019 *(Tampere University, Finland)*
  - PhD in Industrial Engineering, 2016 - 2019 *(Université Grenoble Alpes, France)*
  - Master of Science, 2014 - 2015 *(Université Joseph Fourier, France)*
  - Bachelor of Science, 2007- 2012 *(IAUN, IRAN)*

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Manufacturing Research Team

Additive manufacturing

Hybrid manufacturing

Modeling and simulation

Automatic robotic path planning

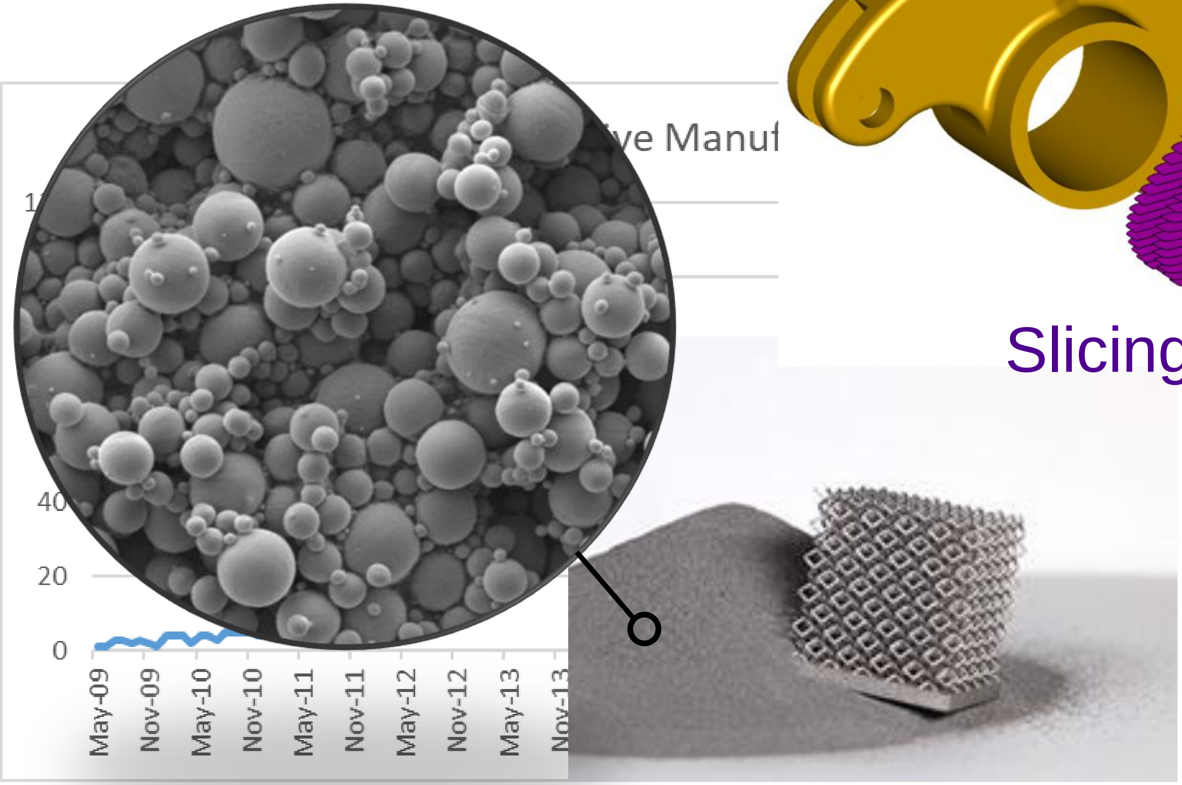
Content

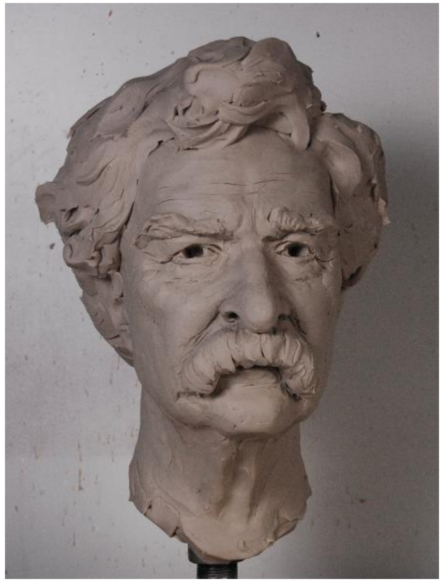
- Introduction
  - Historical overview
  - What is additive manufacturing?
  - Additive manufacturing process chain
- Applications
- Additive manufacturing classification
  - Pros & Cons
  - Process and material selection
- Conclusion
- Q&A

Introduction

The essence of additive manufacturing?

“The process of joining materials to make objects from 3D model data, usually layer upon layer.”



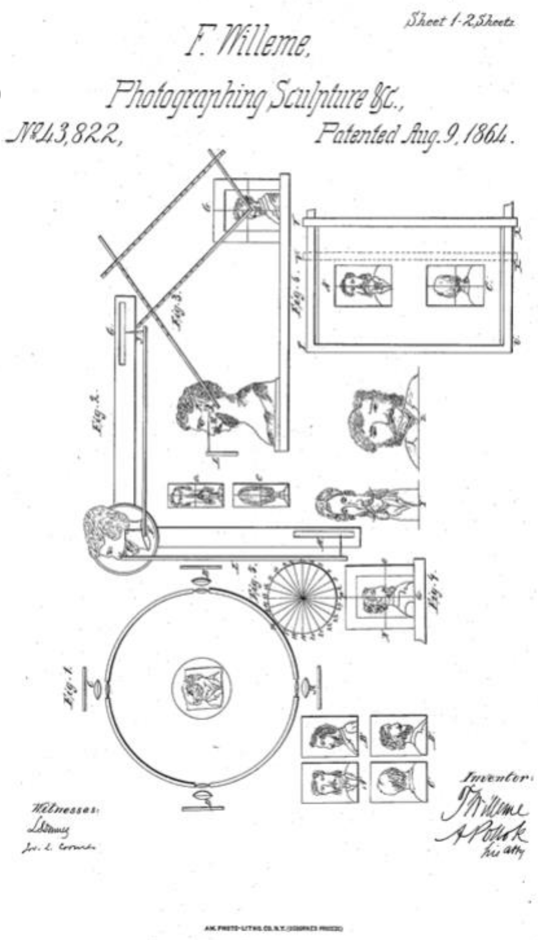


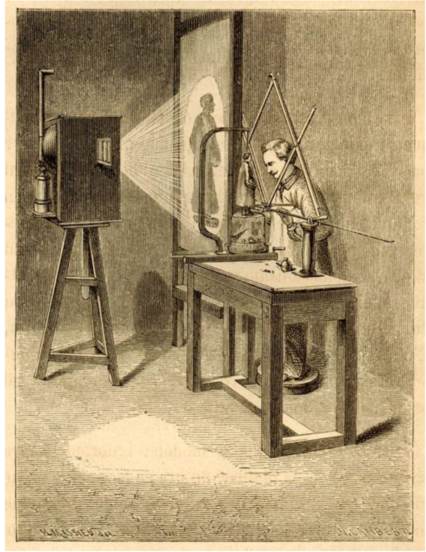
Introduction – Historical Overview

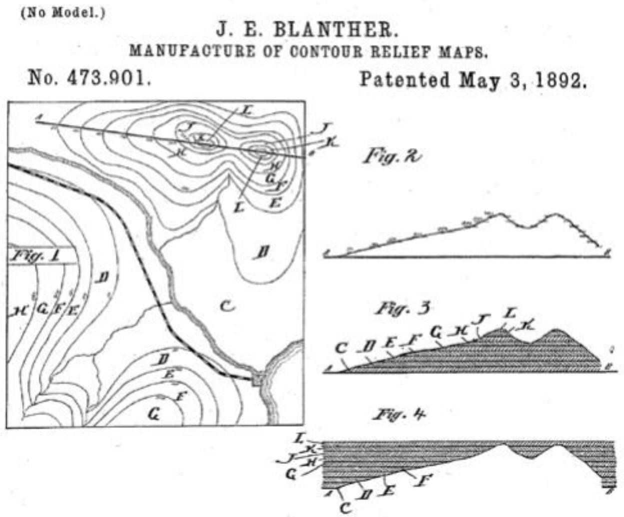
- 1859 : Photo-sculpture (Francois Willème)

- 1892 : 3D topographical maps (Joseph Blanther)

- 1980: Rapid prototyping (Hideo Kodama)
    - Polymers
    - Layer by layer

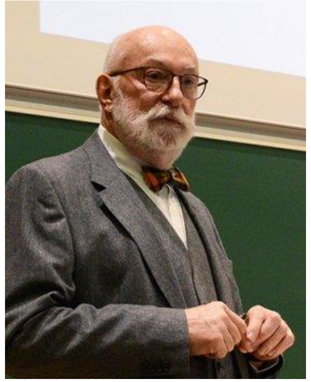
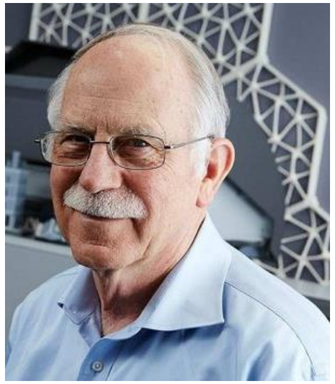
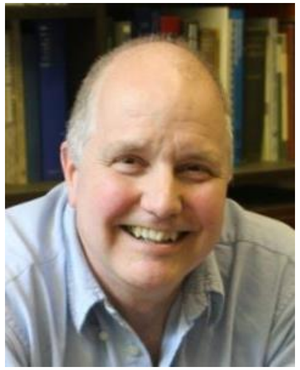






Introduction – Historical Overview

- 1984 : Stereolithography apparatus invention (Charles Hull & Jean Claude André)
- 1986 : First 3D printing company (3D Systems) (Charles Hull)
- 1988 : Selective laser sintering (Carl Deckard)
- 1989 : Fused deposition modeling (Stratasys Inc.) (Scott Crump)
- 1999 : Medical 3D bio-printing
- 2004 : RepRap open source project (Adrian Bowyer)
- 2011: Additive manufacturing industrialization

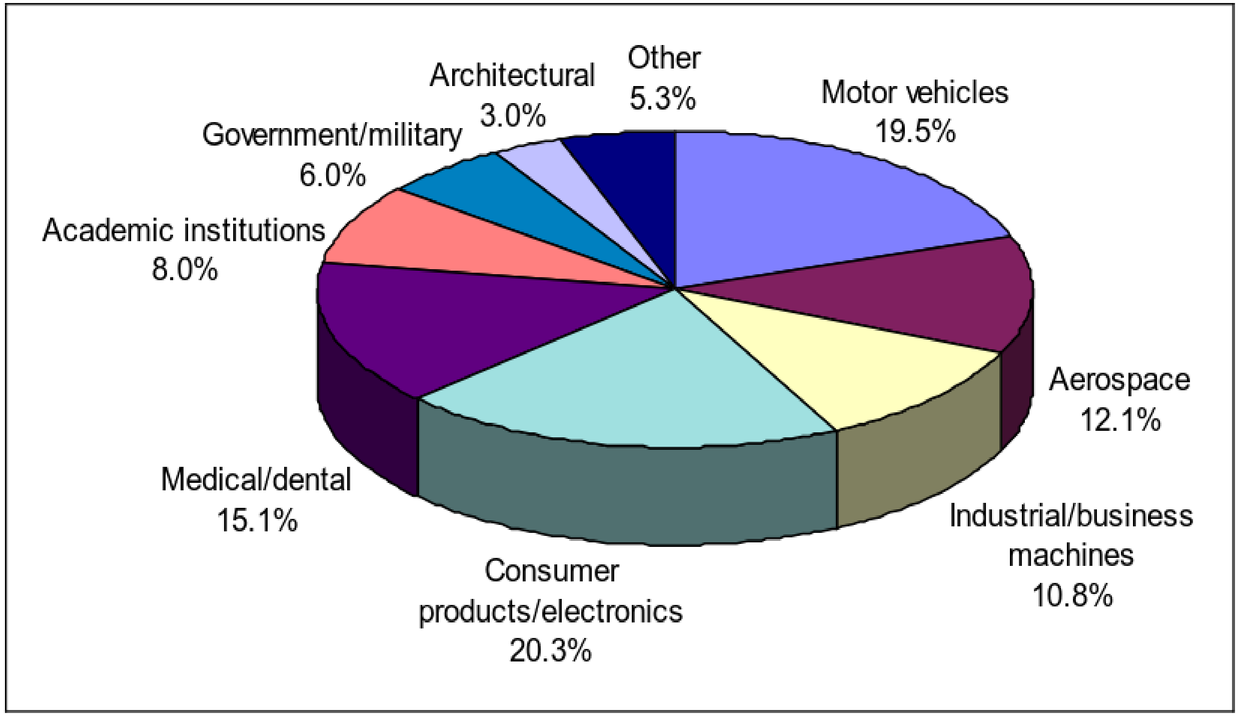
Brief overview on industrial AM eco-system

A fraction of a whole

https://amfg.ai/2019/02/27/additive-manufacturing-industry-landscape-2019/

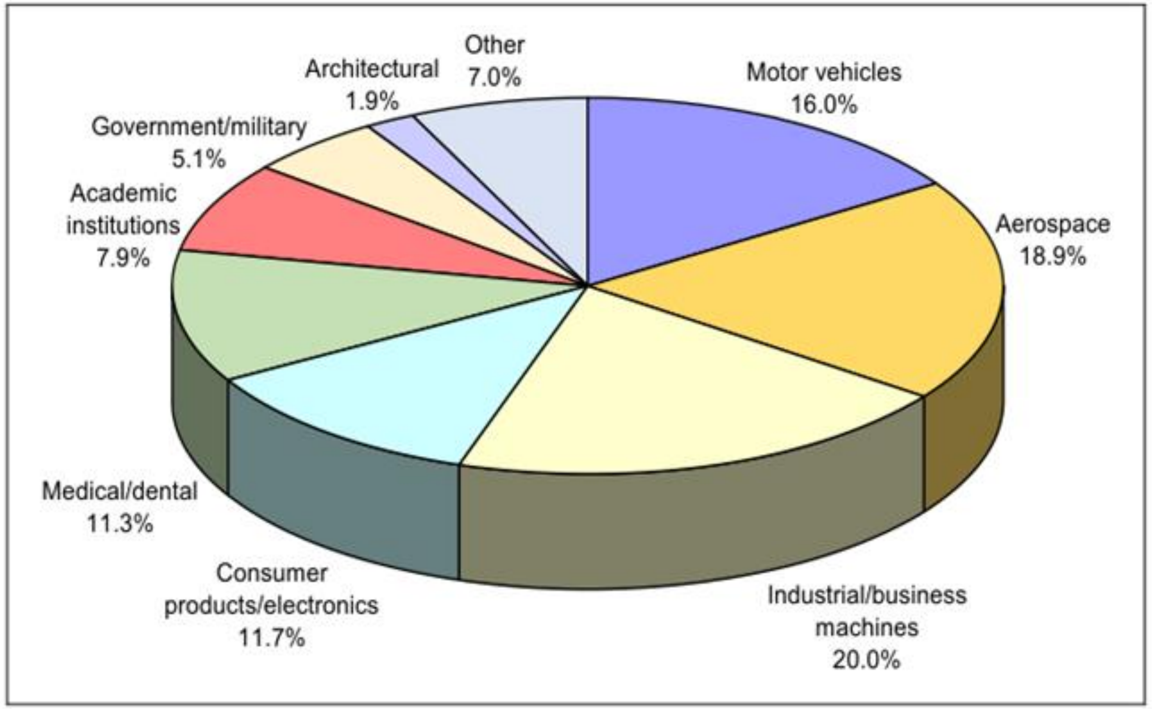
Additive Manufacturing Progress

2011 (Wohlers Report 2012)



Source: Wohlers Associates, Inc.

2017 (Wohlers Report 2018)



Source: Wohlers Associates, Inc.

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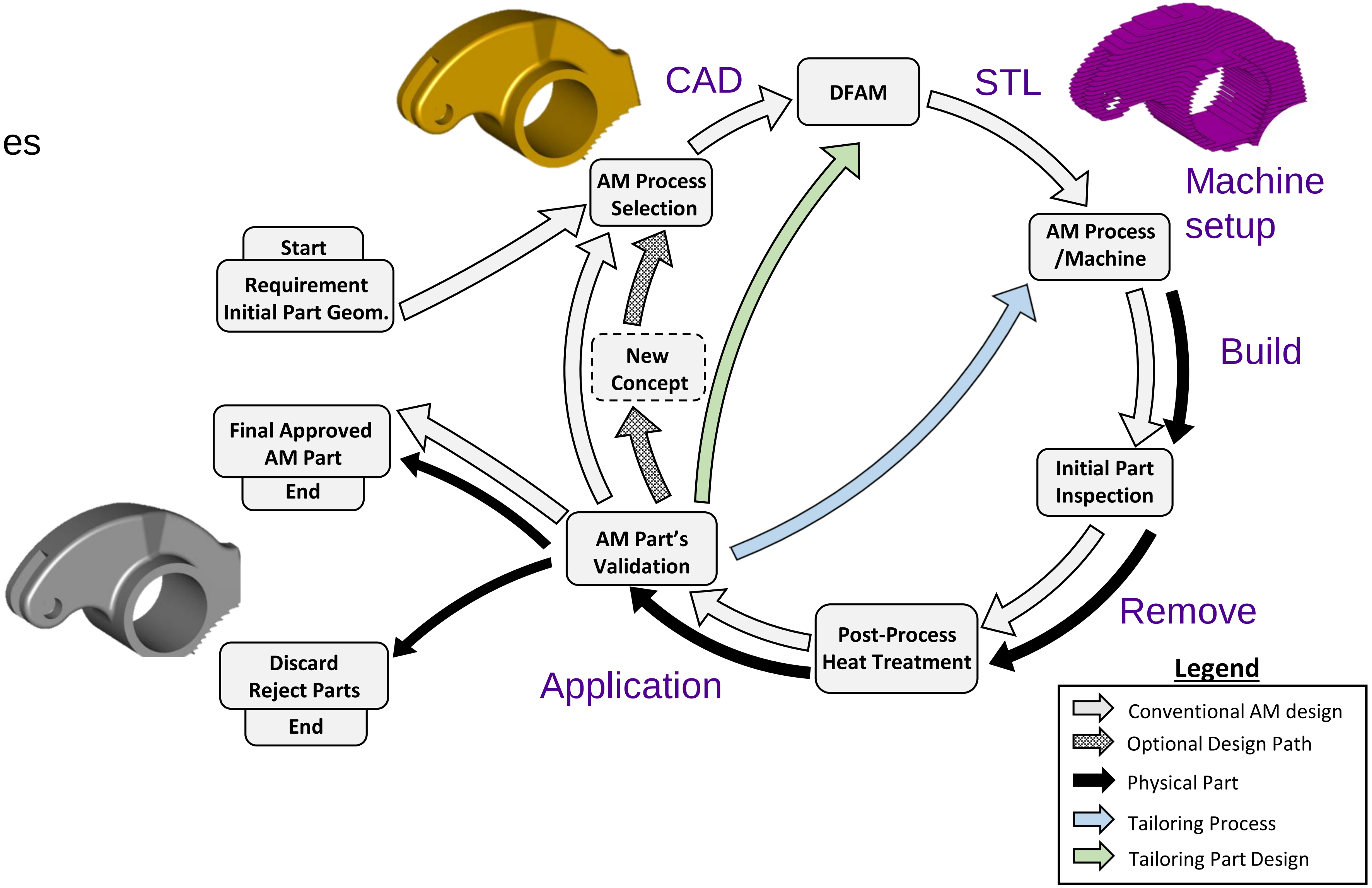
Communauté UNIVERSITÉ Grenoble Alpes

Introduction – Simplified AM Process Chain

- A complete value chain,

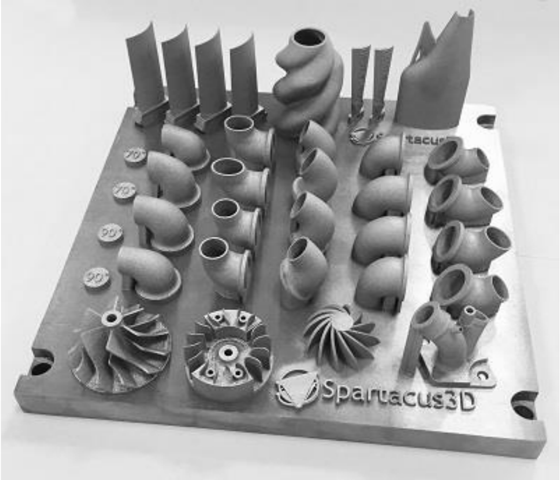
rather than just the technologies

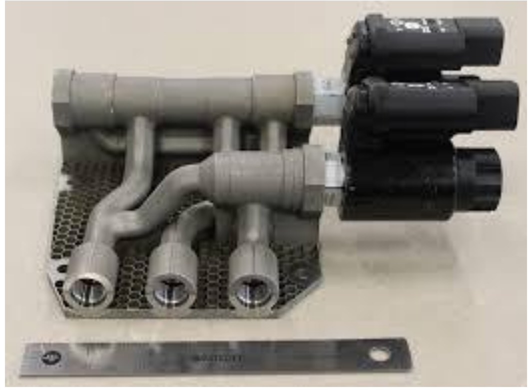


Introduction – Advantages of AM?

Additive manufacturing unique capabilities

- Shape complexity
- Variety in a build
- Mass customization
- Topology optimization
- Integrated assembly
- Material complexity
- Lead time reduction
- Etc.

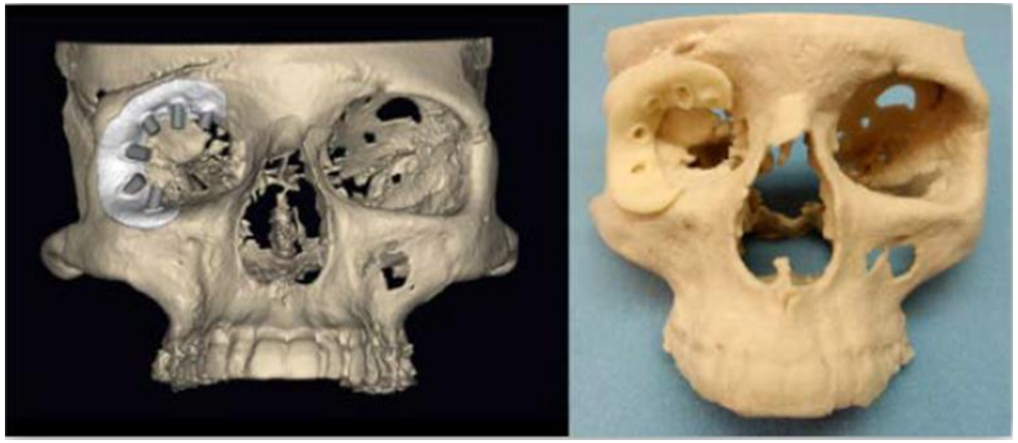


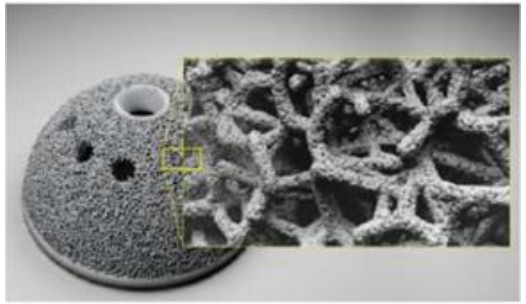


Introduction – Application Areas

Medical

- Anatomy learning
- Surgical implants
- Orthopedic devices
- Dentistry
- Etc.

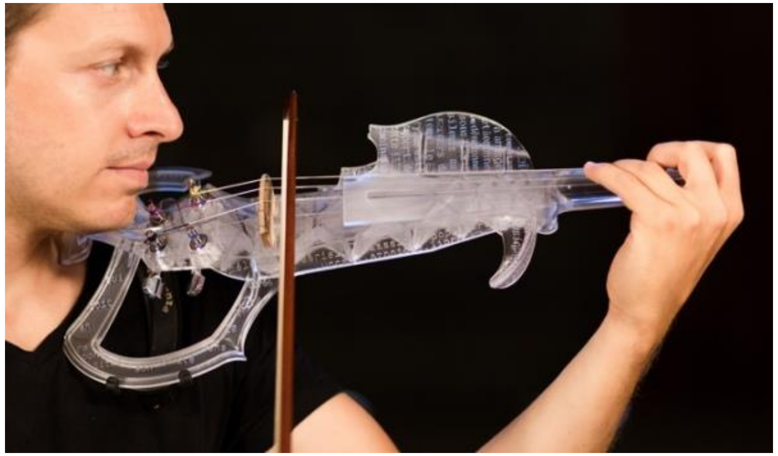




Introduction – Application Areas

Art & Design

- Contemporary art
- Jewelry
- Fashion
- Musical instruments
- Toys
- Food
- Etc.



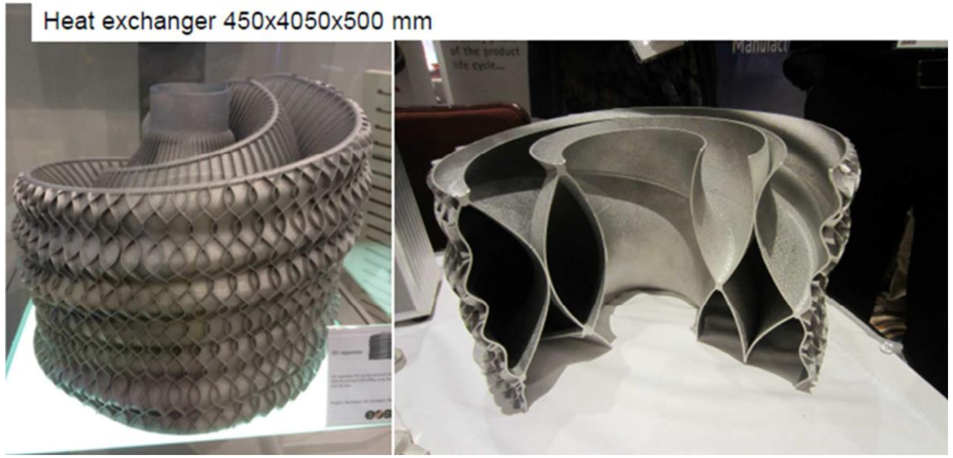


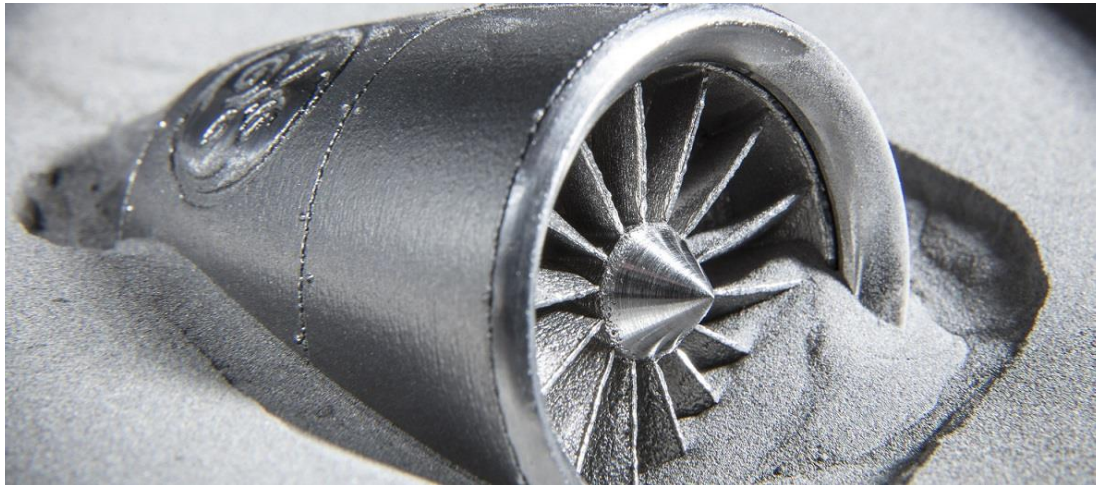


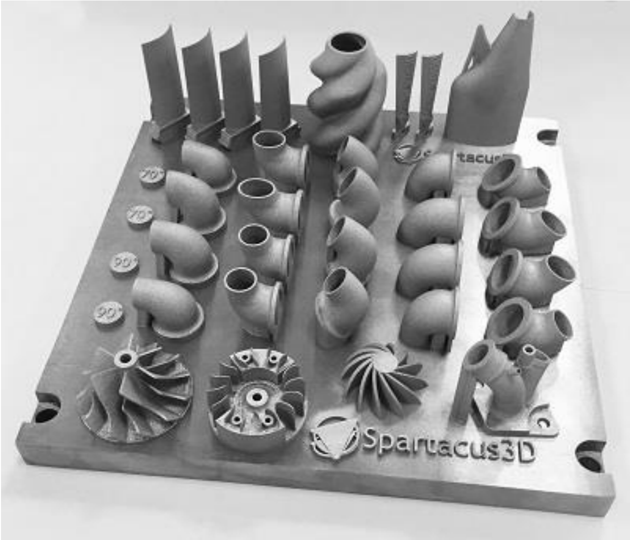
Introduction – Application Areas

Industry

- Aerospace
- Automotive
- Tooling
- Energy sector
- Etc.

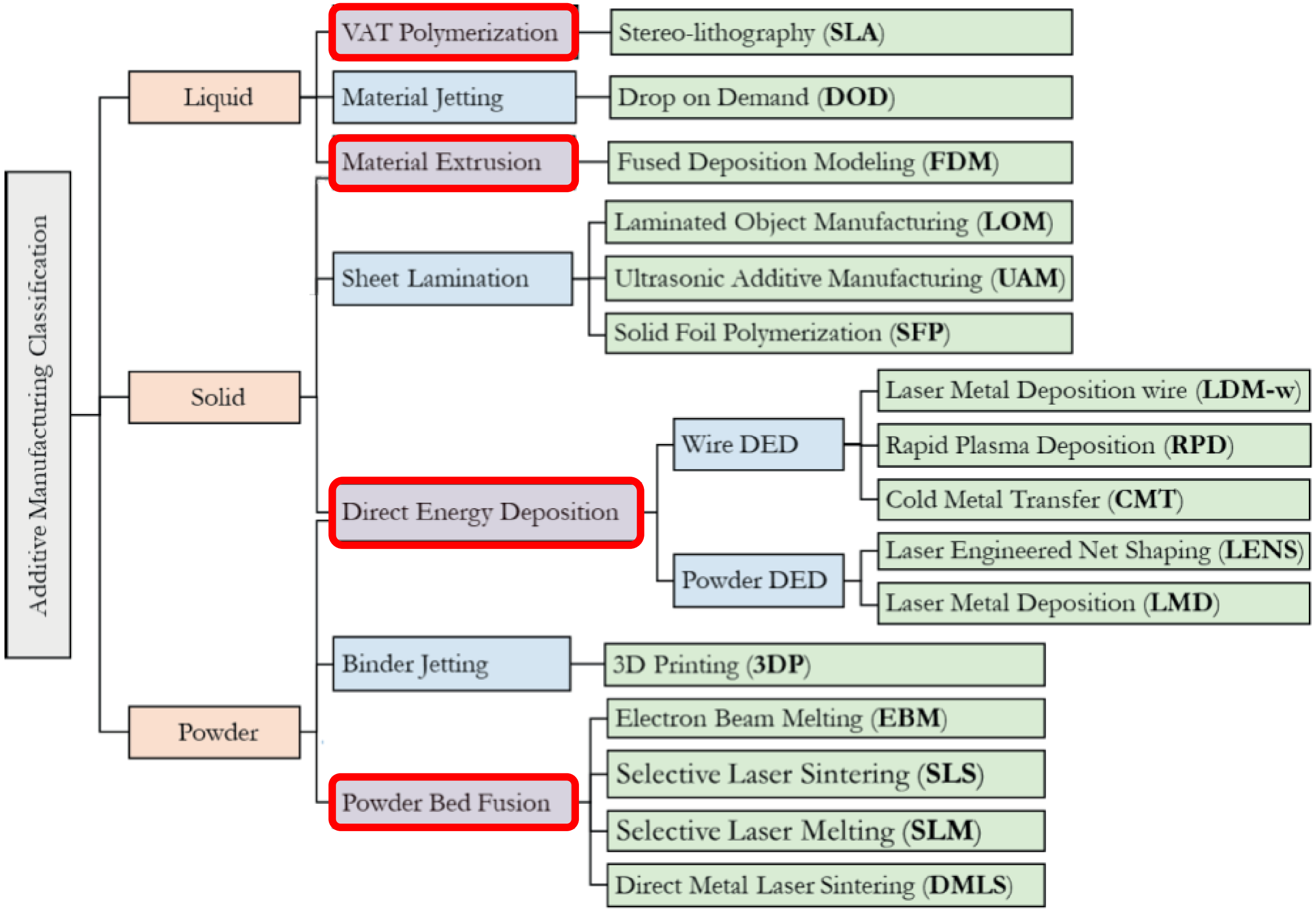






Additive Manufacturing Classification

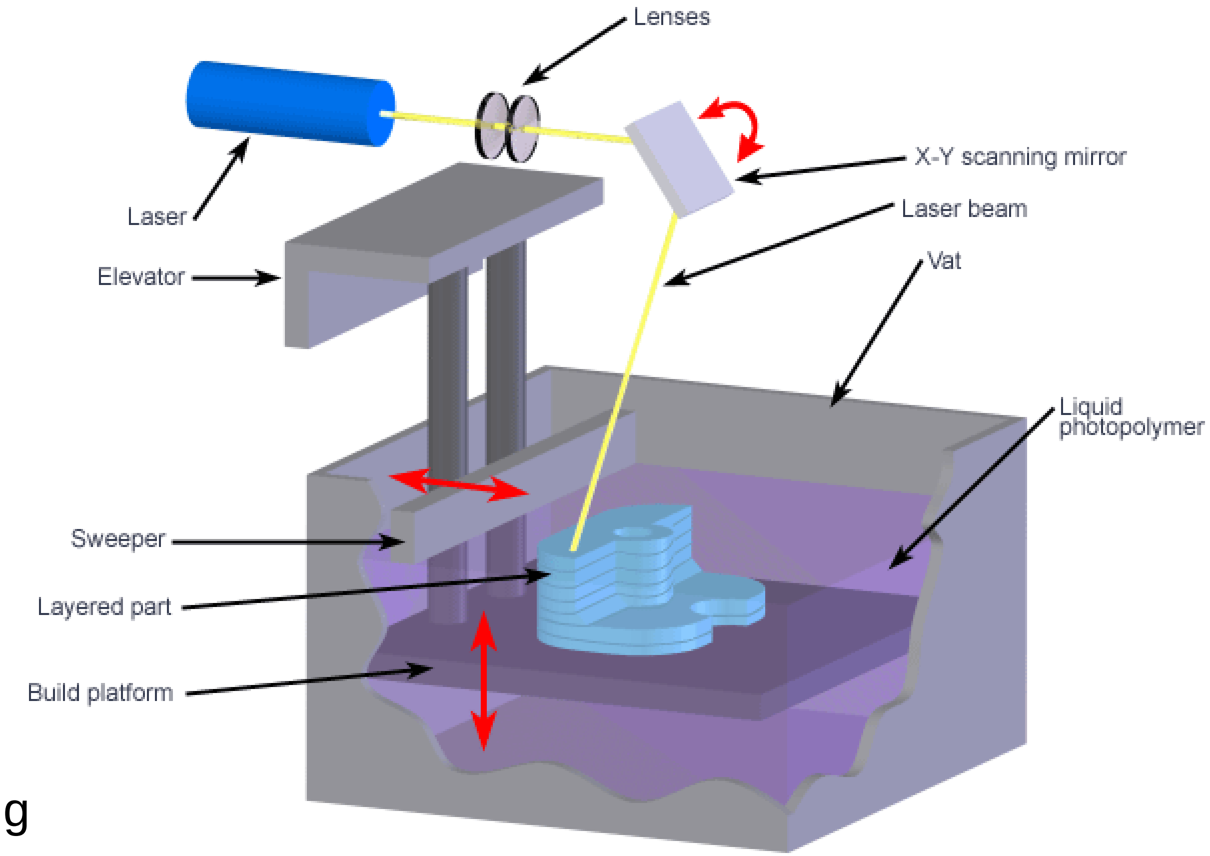
- Various AM processes
- Classification: ASTM F2792 Standards



Mokhtarian, 2019, Product-Process Integrated Meta-Modeling Using a Graph-Based Approach: Application to Additive Manufacturing. Tampere University Dissertations.
ASTM F2792 Standards

VAT Photopolymerisation

- **Stereolithography**
- **Source of Energy:** Ultraviolet (UV) light
- **Materials**
    - Liquid UV-curable photopolymer resin
    - Plastics or polymers
- **Advantages**
    - Relatively fast
    - High accuracy and surface finish
    - Large build area (e.g 1000 x 800 x 500 mm)
- **Disadvantages**
    - Limited application of photo-resins materials
    - Relatively expensive
    - Time-consuming material removal post processing



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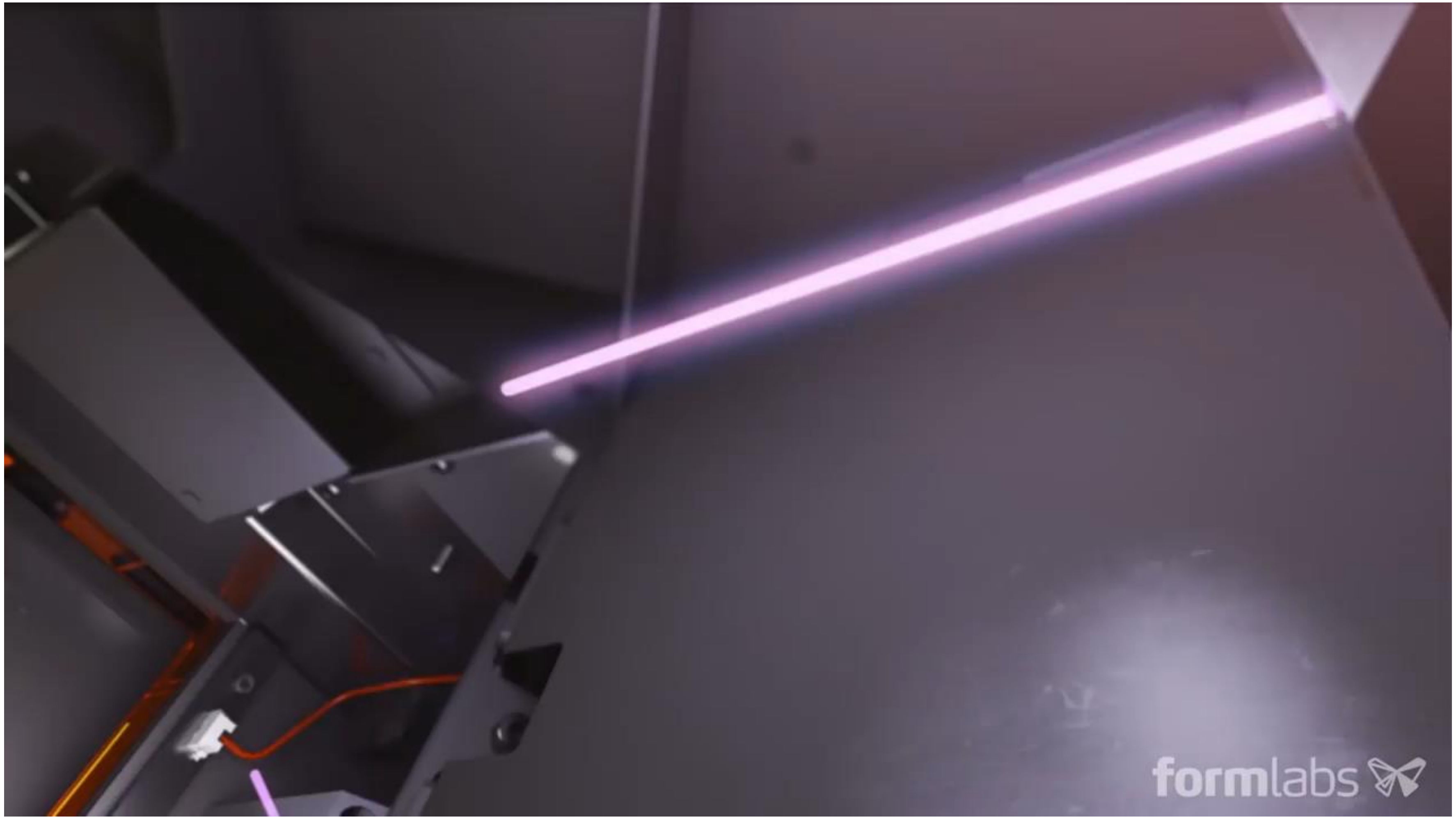
VAT Photopolymerisation



VAT Photopolymerisation

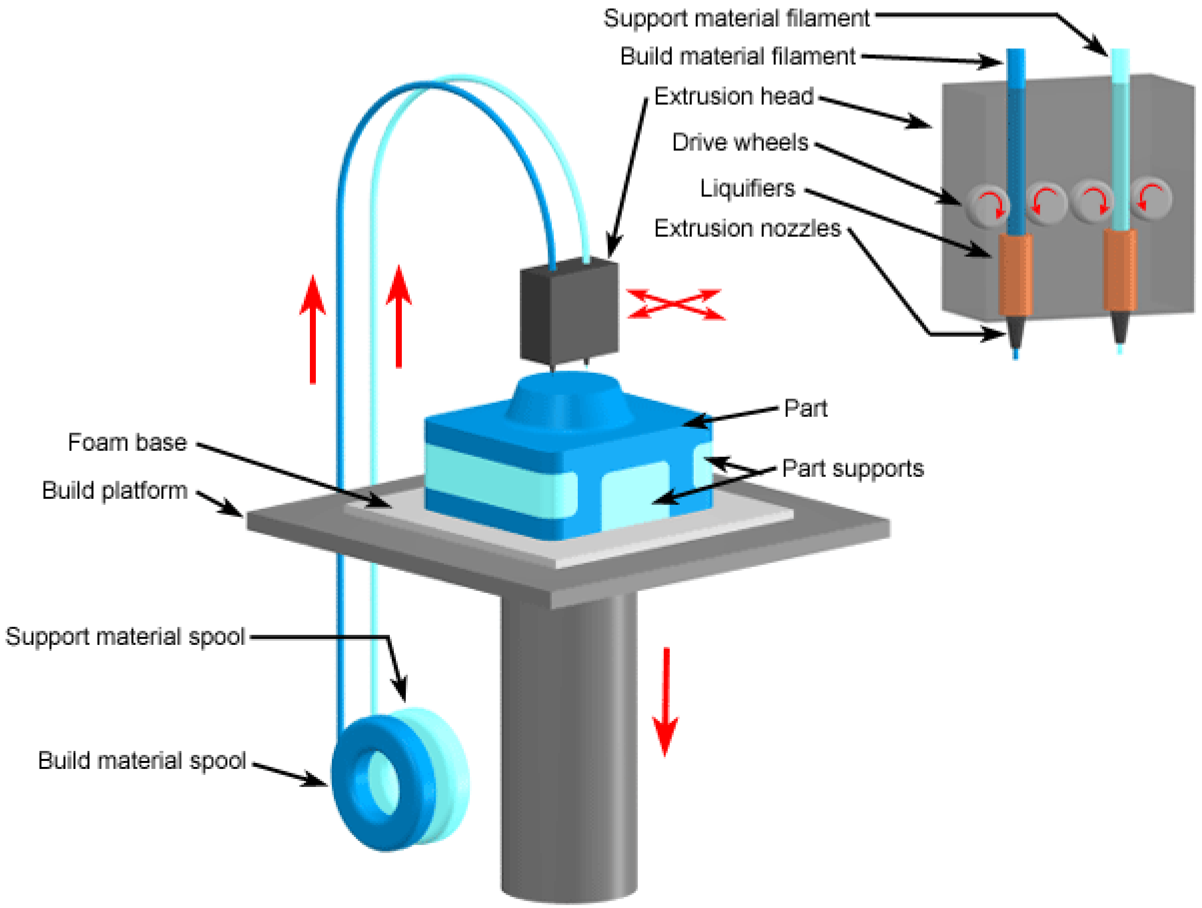
Technical Specifications

- **Layer thickness**
  - Standard SL: 0.1 mm to 0.15 mm (varies by material)
- **Minimum Wall thickness**
  - 1 mm to 3 mm (depending on part dimensions)
  - Minimum radial feature size: .030
- **Maximum build dimensions**
  - 2100 x 700 x 800 mm
- **Post-processing**
  - Stereolithography parts can be sandblasted, painted, varnished, covered and coated

https://www.materialise.com https://www.formlabs.com/ https://www.3dsystems.com/

Material Extrusion

- **Fused deposition modeling (FDM)**
- **Source of Energy:** Thermal Energy
- **Materials**
  - Solid polymer filament (Thermoplastics)
  - Polymers such as (ABS, Nylon, etc.)
- **Advantages**
  - Available inexpensive process
  - Material accessibility and low price
- **Disadvantages**
  - Low accuracy and speed
  - Nozzle radius limits the part quality
  - Rough surface finish



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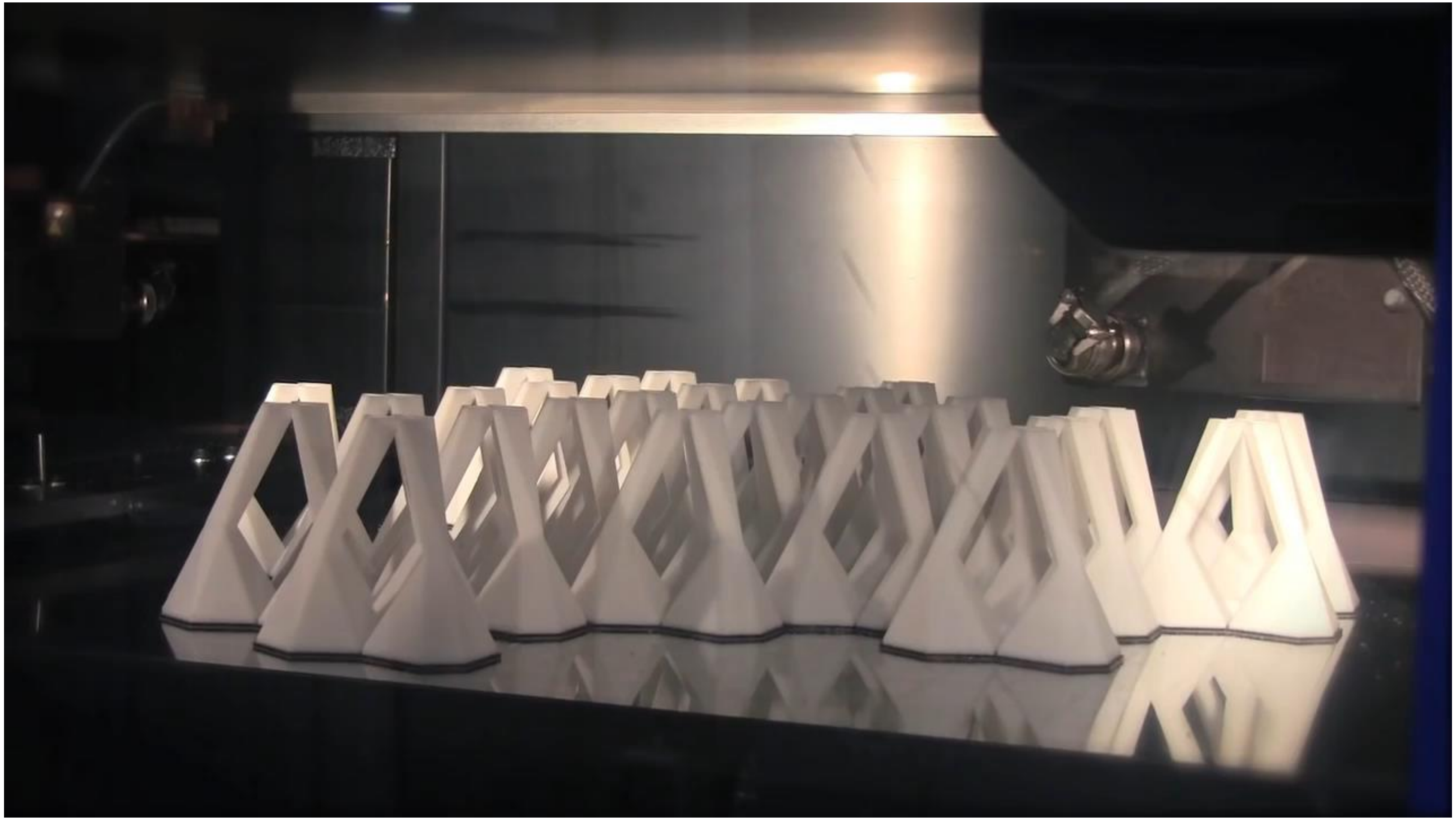
Material Extrusion



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Material Extrusion

Technical Specifications

- **Layer thickness**
  - 0.18 – 0.33 mm (depend on extruder diameter)
- **Dimensional Accuracy**
  - ±0.15% (with a lower limit on ± 0.2 mm)
  - Minimum wall thickness is 1 mm.
  - Minimum hole diameter is 0.5 mm.
- **Maximum build dimensions**
  - 914 x 610 x 914 mm
- **Post-processing**
  - Removing support structures.
  - material transmissivity can be done

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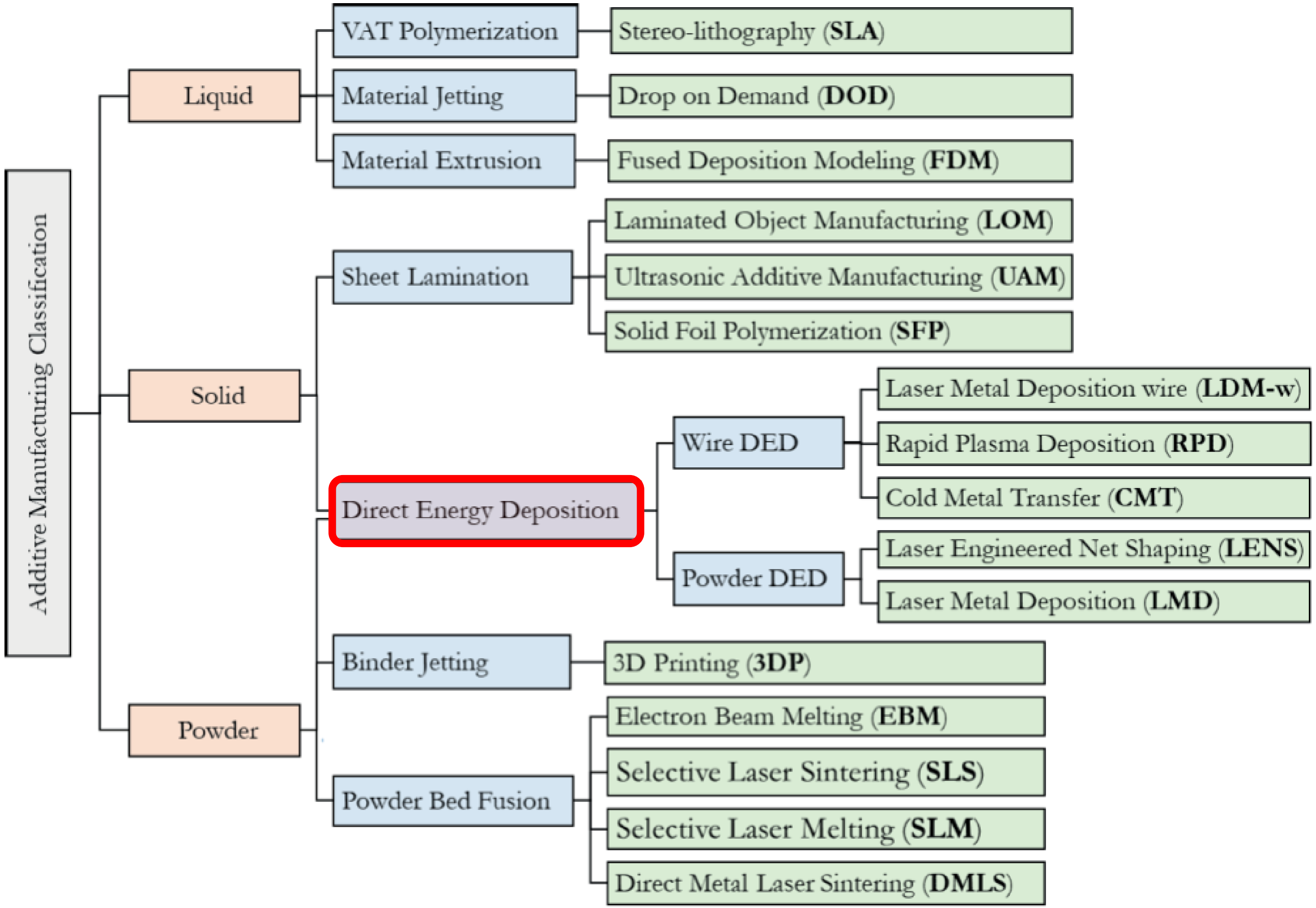
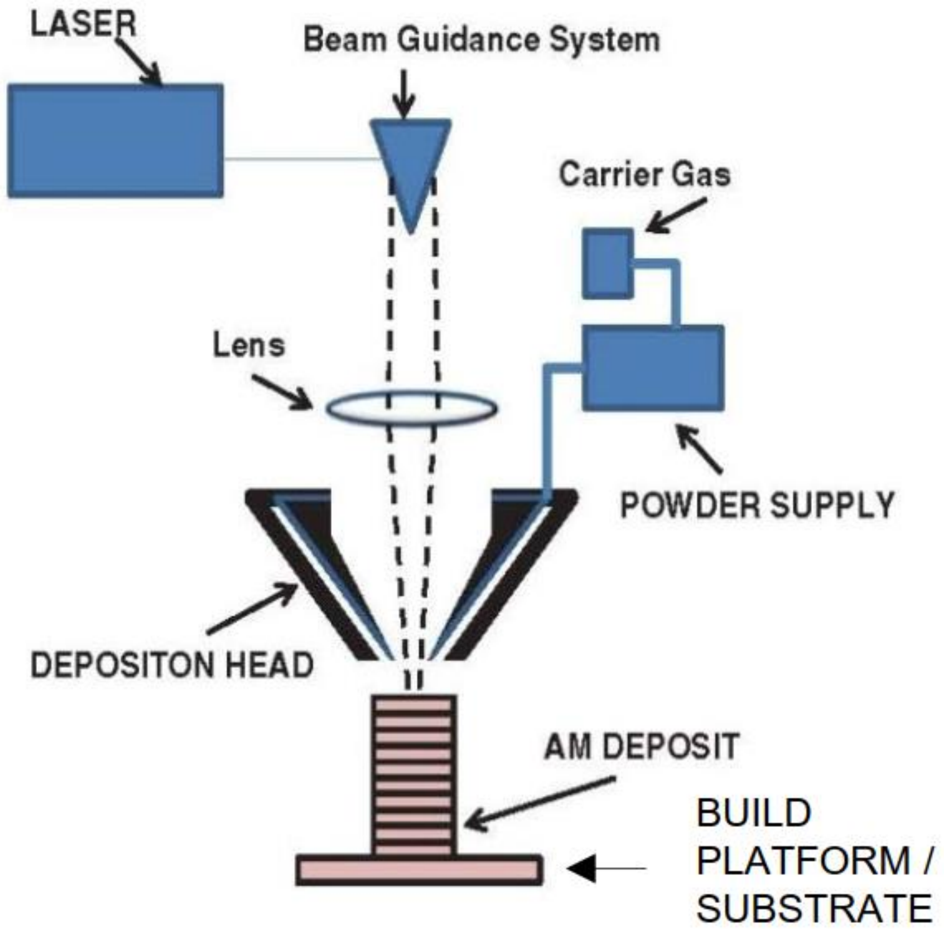
Direct Energy Deposition

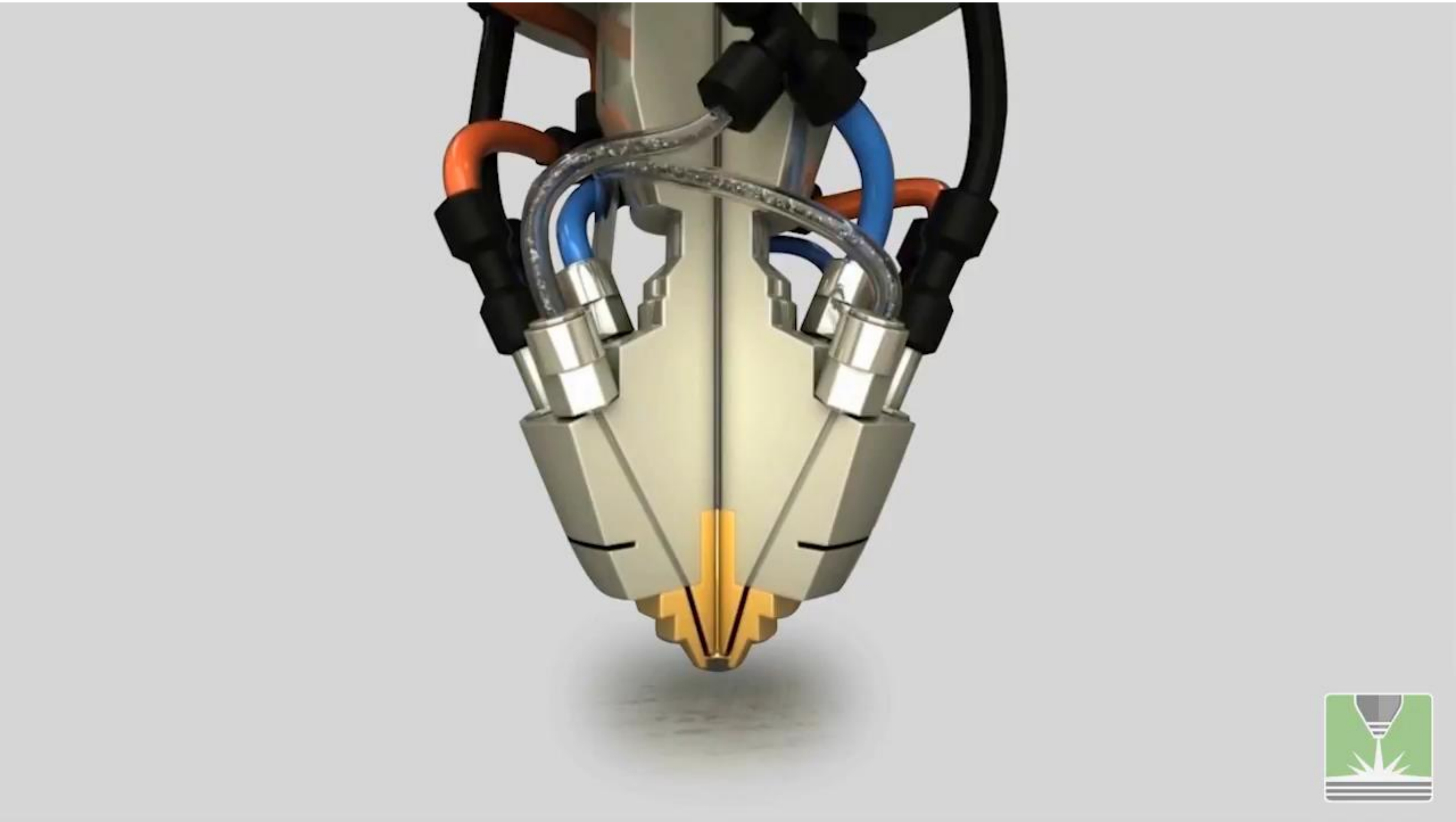


Direct Energy Deposition – Powder DED

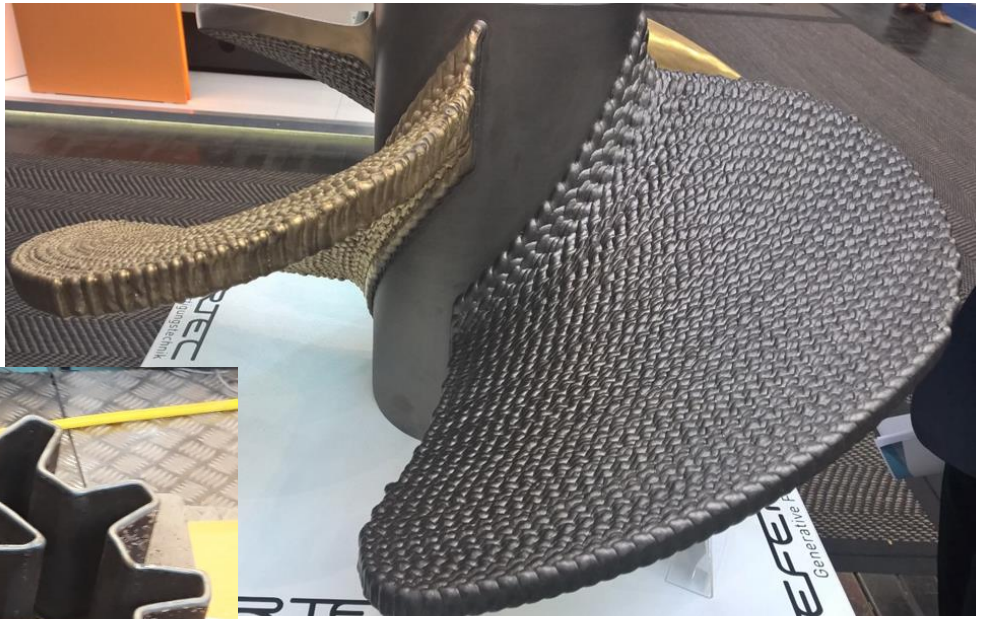
- **Source of Energy:** Laser beam
- **Materials**
  - Metal powder and ceramics
  - Cobalt Chrome, Titanium, etc.
  - Shielding gas
- **Advantages**
  - Not limited by direction or axis
  - Effective for repair and adding feature
  - Ability to control the grain structure
  - High build rate
- **Disadvantages**
  - Near to net-shape final geometry
  - Relatively limited material use
  - High energy input
  - Time consuming pre-processing & post-processing

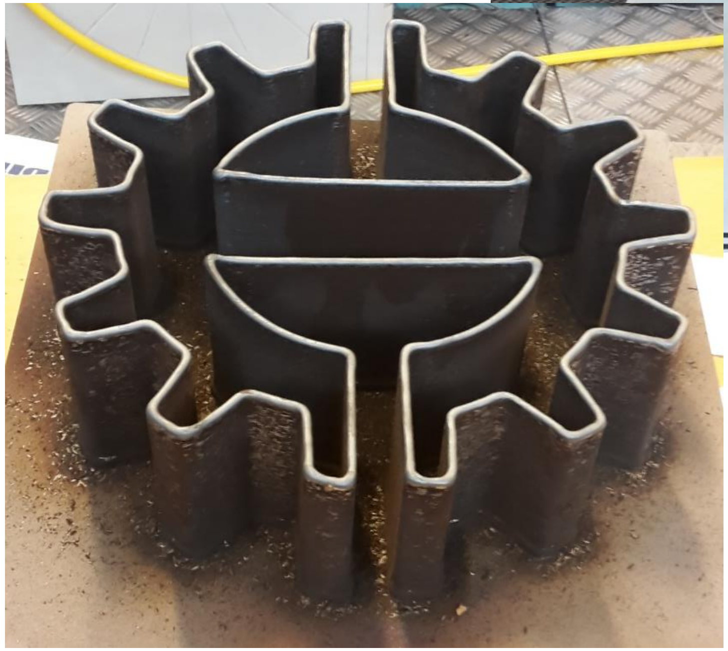


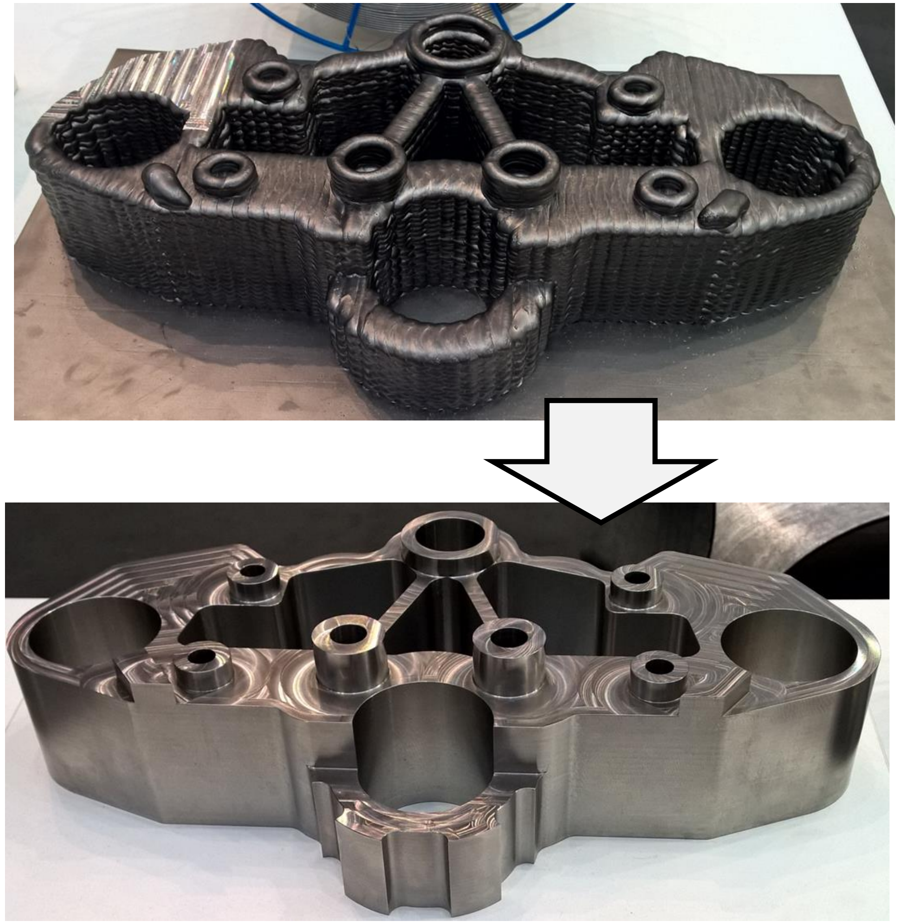
Direct Energy Deposition – Powder DED



Direct Energy Deposition – Parts

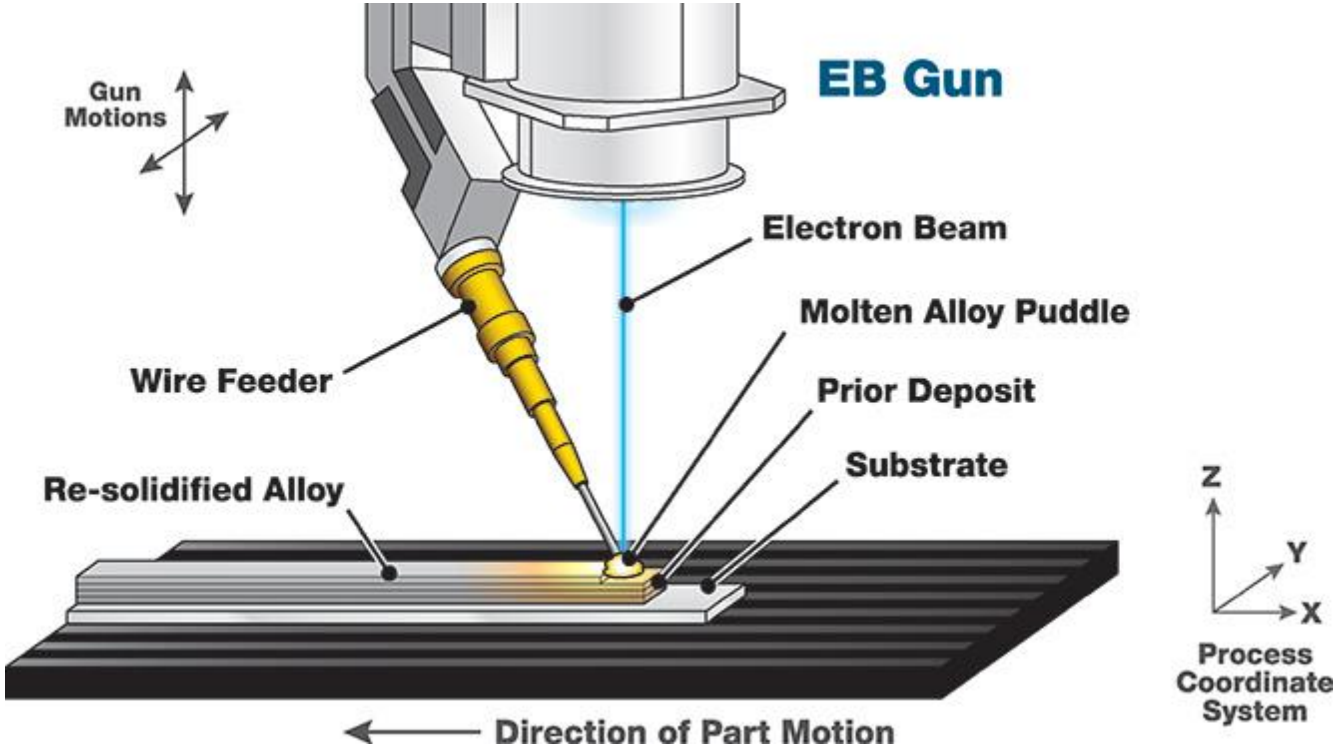






Direct Energy Deposition – Wire DED

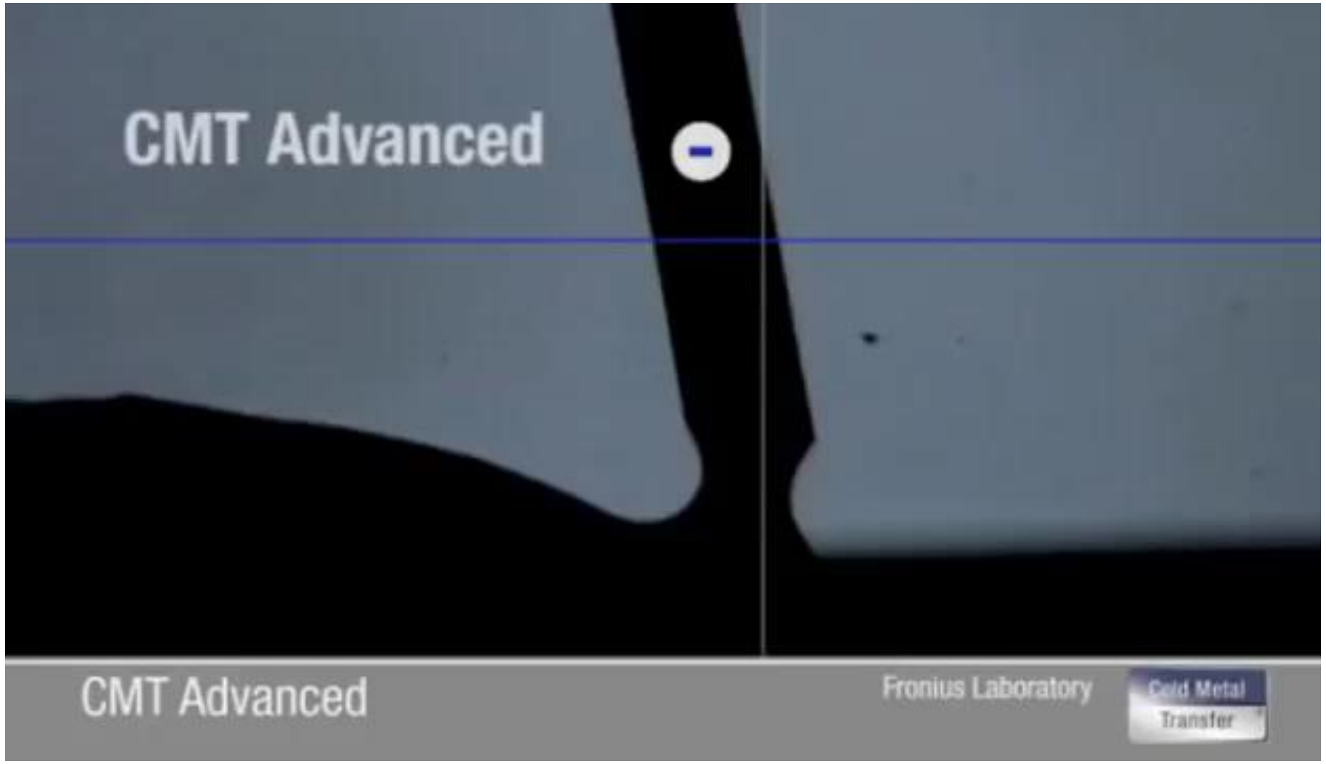
- **Wire Arc Additive Manufacturing (WAAM)**
- **Source of Energy:** Laser beam or electron beam or arc
- **Materials**
  - Metal wire
  - Stainless steel, Ni base alloy, etc.
  - Shielding gas
- **Advantages**
  - Not limited by direction or axis
  - Effective for repair and adding feature
  - Material efficiency
  - High build rate
- **Disadvantages**
  - Near to net-shape final geometry
  - Limited material use
  - Rough surface finish



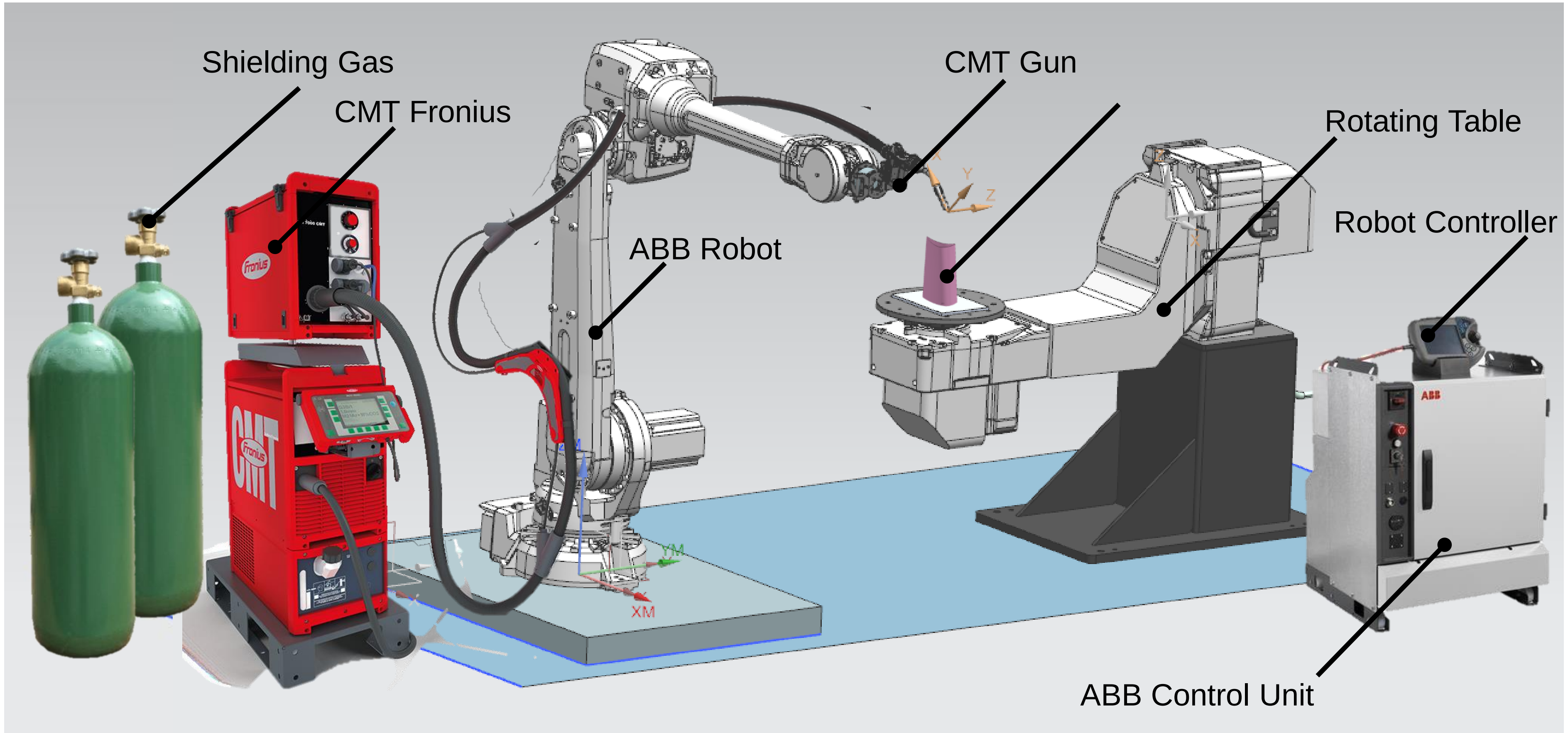
Direct Energy Deposition – Wire DED + CMT

Cold Metal Transfer Technology (CMT)

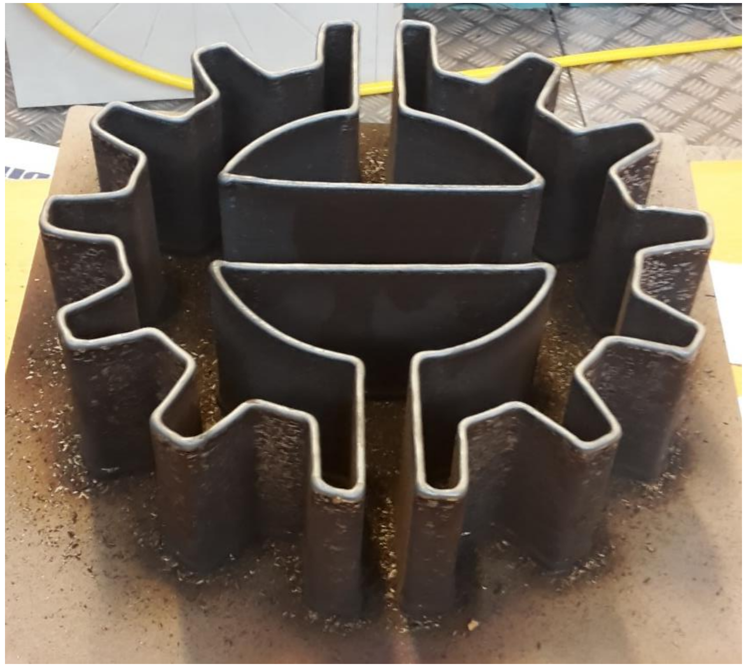
- **Additional Advantages**
  - Lower heat input
- **Disadvantage**
  - Accessibility to all parameters



WAAM+ CMT at Tampere University



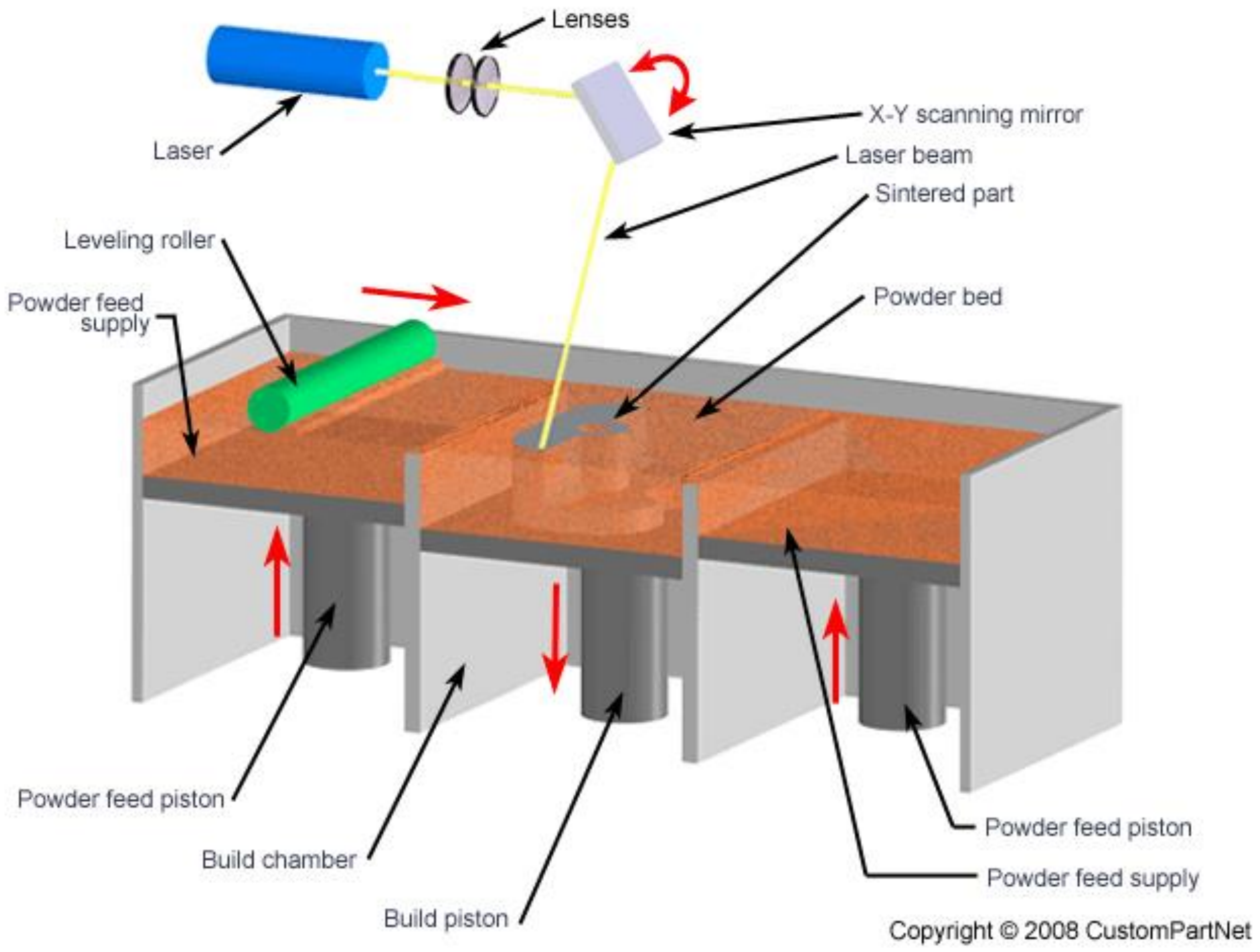
WAAM+ CMT at Tampere University



Powder Bed Fusion- Selective Laser Sintering

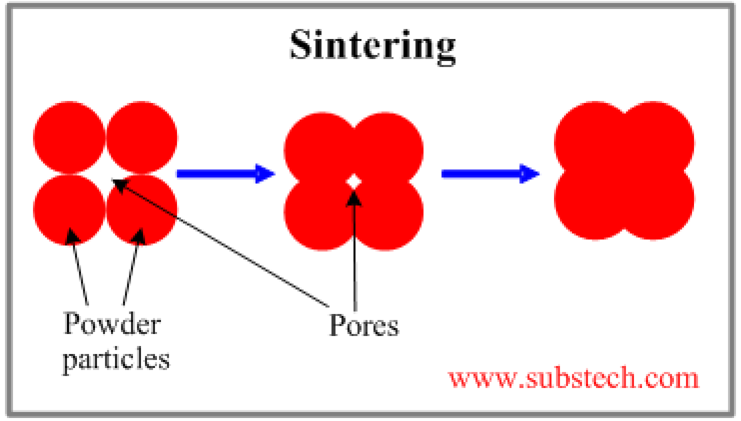
- **Source of Energy:** Laser beam
- **Materials**
  - Powder based materials
  - Stainless steel, titanium, Aluminum, etc.

- **Advantages**
  - Range of available materials
  - Powder recycling
  - Comparatively low cost
  - Relatively good resolution
- **Disadvantages**
  - High power usage
  - Size limitation
  - Relatively low
  - Thermal distortions

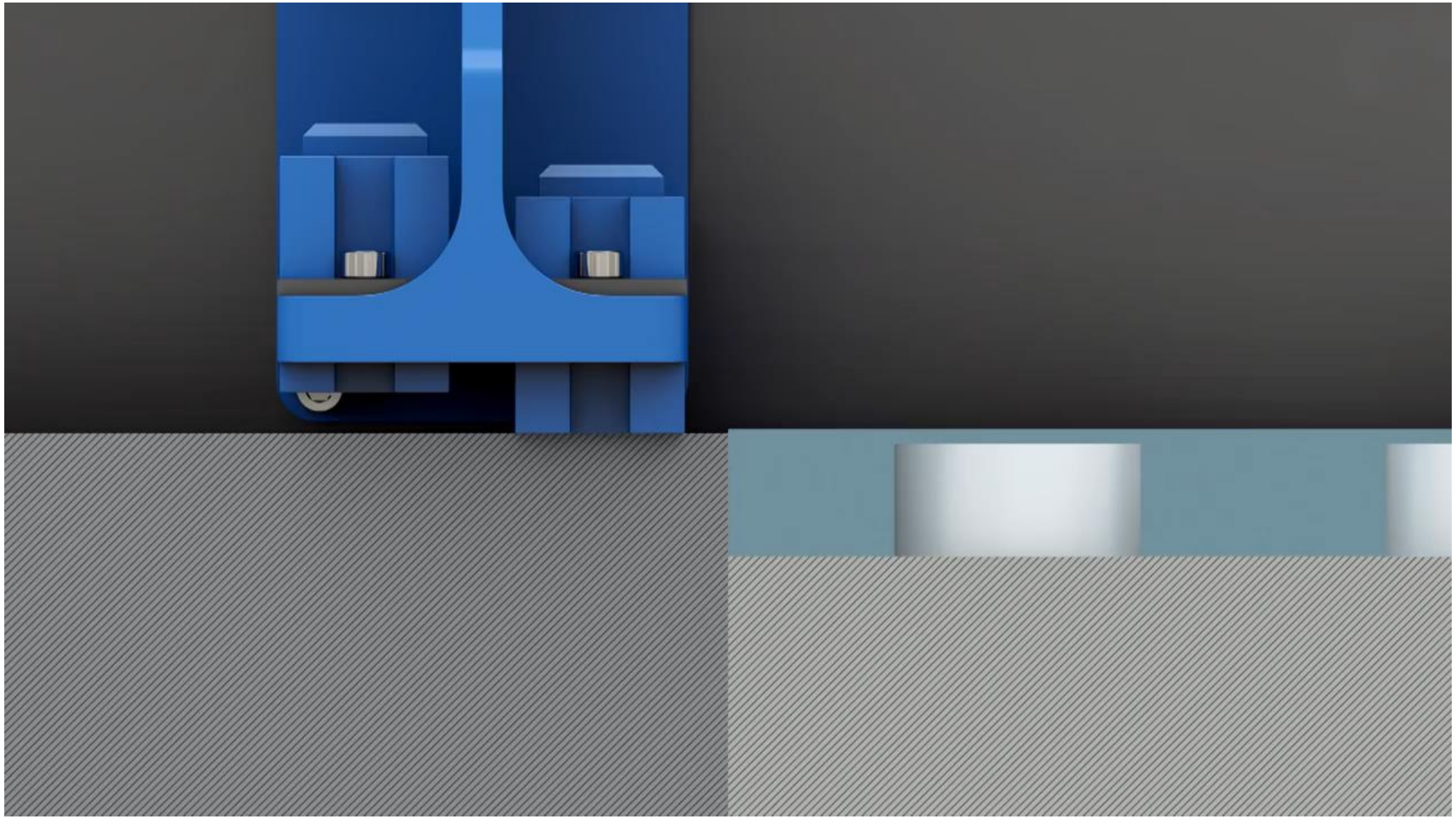


https://www.custompartnet.com/wu/images/rapid-prototyping/sls.png

Powder Bed Fusion- Selective Laser Sintering



Sintering is the process of compacting and forming a solid mass of material by heat or pressure without melting it to the point of liquefaction.



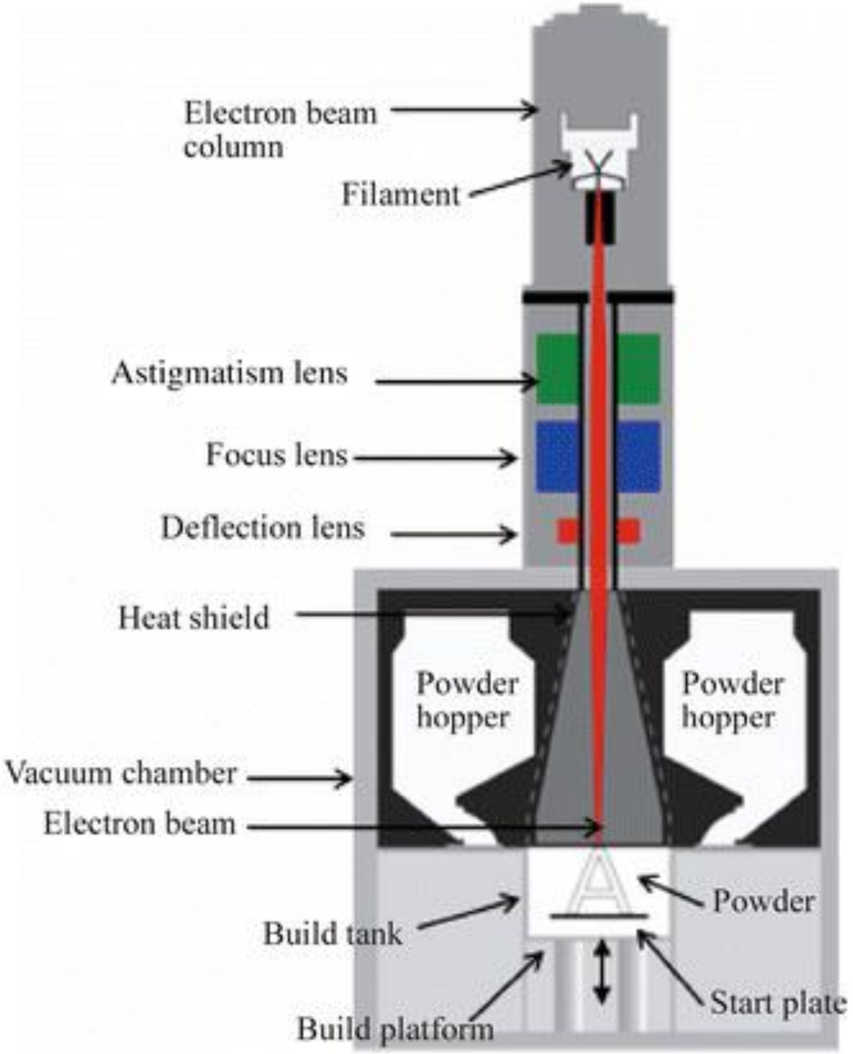
Powder Bed Fusion- Selective Laser Sintering

Technical Specifications

- **Layer thickness**
  - 0.08 – 0.15 mm
- **Dimensional Accuracy**
  - Average accuracy is 0.1mm
  - Minimum hole diameter is 2 mm.
- **Maximum build dimensions**
  - 550 x 550 x 750 mm
- **Post-processing**
  - Removing support structures.
  - Shot peening.
  - Etc.

Powder Bed Fusion- Electron Beam Melting

- **Source of Energy:** Electron beam
- **Materials**
  - Stainless steel, titanium, Cobalt-Chrome, Inconel 718.
  - Vacuum chamber is required.
- **Advantages**
  - Relatively high build rate
  - Powder recycling
  - Higher energy efficiency
- **Disadvantages**
  - Availability of material
  - Conductive material
  - Low speed and expensive
  - Lower resolution than laser melting



http://www.arcam.com/technology/electron-beam-melting/hardware
http://www.ge.com

Hybrid Manufacturing

- **Advantages**
  - Relatively high build rate
  - High geometrical flexibility
  - Multi-material parts
  - Add feature & repair
  - Milling of internal channel
- **Disadvantages**
  - Machining before heat treatment
  - Remaining residual stress
  - Wastage of the machining coolant fluid

DMG Mori Lasertec 65 Hybrid 3D Printer

Hybrid Manufacturing

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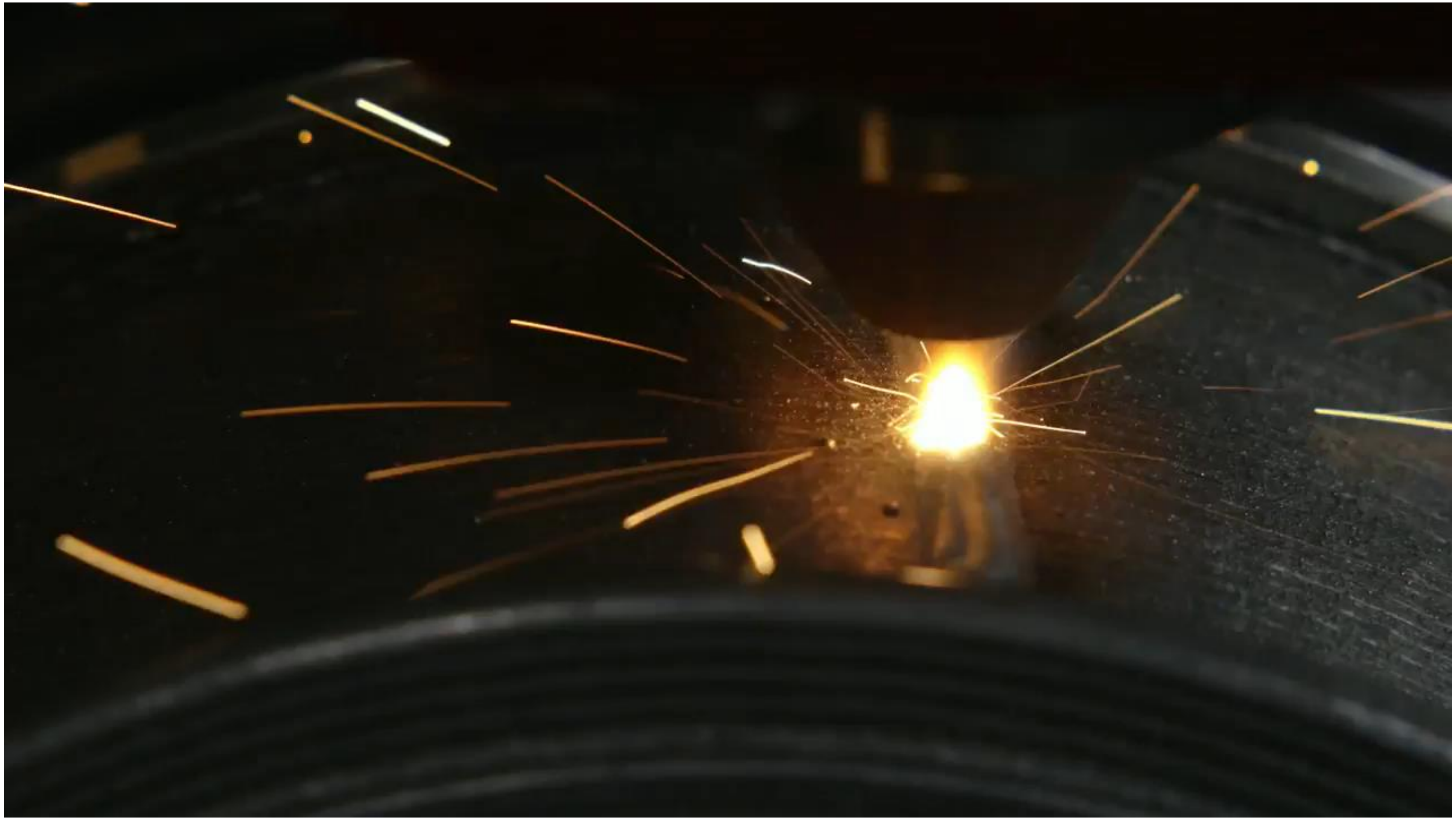
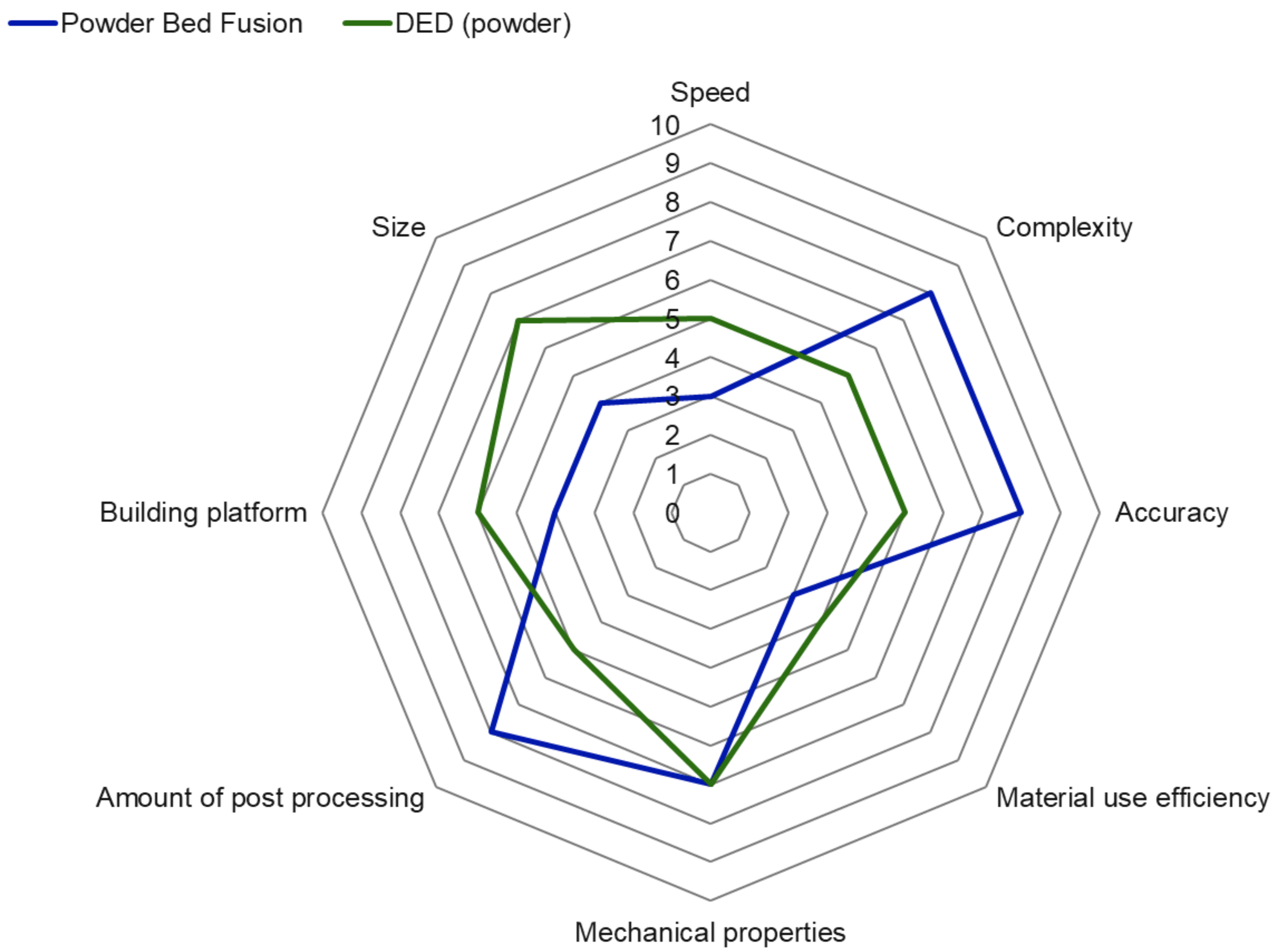


AM Process Selection

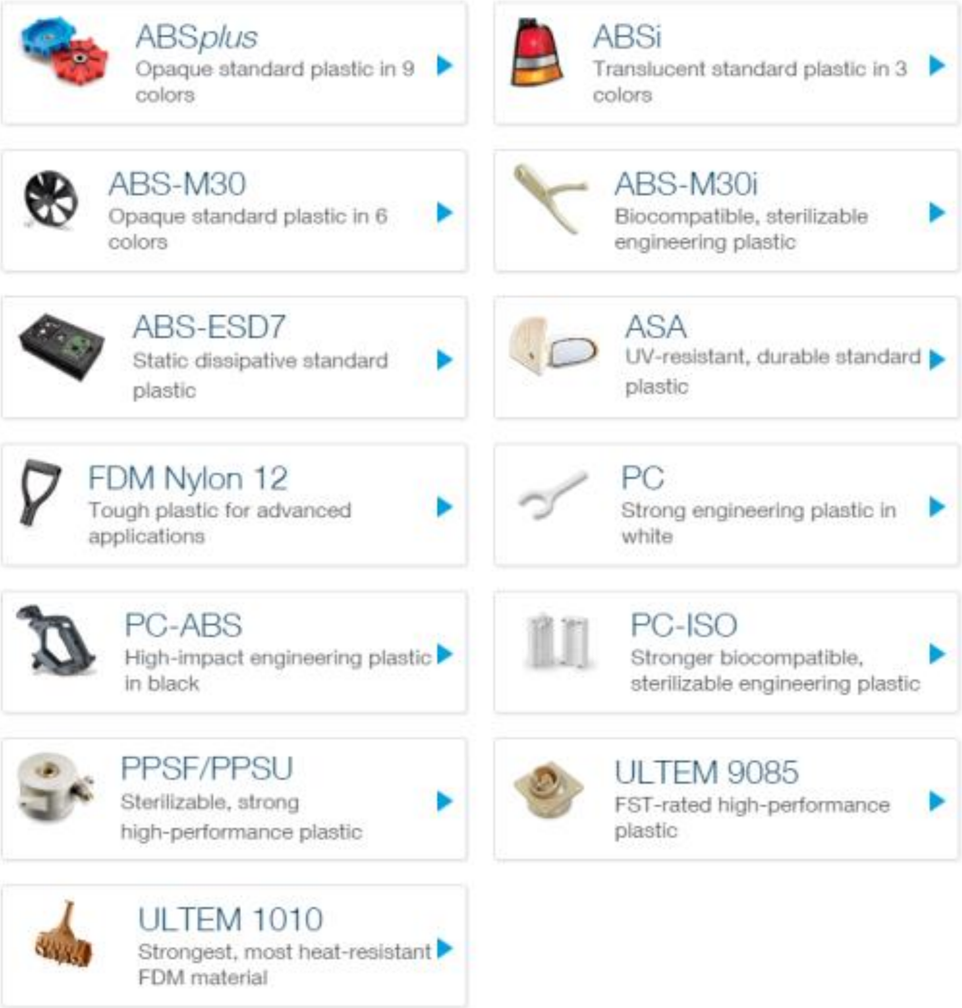
- Technology principle

- Comparison & Trade off
  - Capabilities and limitations
  - Part Size
  - Part Accuracy
  - Complexity
  - Required Material
  - Cost Consideration
  - Available Technologies
  - Etc.

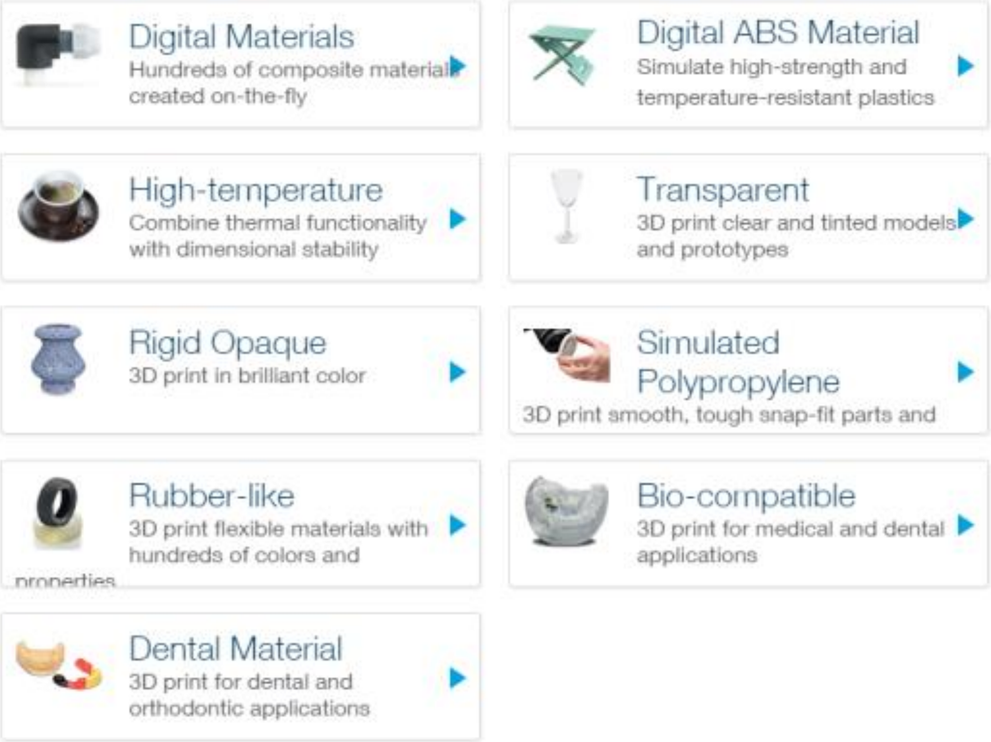


AM Materials (Polymers)

Thermoplastics (FDM)



Photopolymers (Polyjet)



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AM Materials (Metals)

Non-Reactive Metal Alloy

316L Stainless Steel

Maraging Hot-Work Steel

Stainless Hot-Work Steel

17-4 PH Stainless Steel

Inconel 718

Inconel 625

Bronze Alloy

Biocompatible CoCrW Alloy

Reactive Metal Alloy

30Al/31Al Aluminum Alloy

Ti6Al4V Titanium Alloy

Commercially Pure Titanium

Biocompatible Ti6Al4V Alloy

Conclusion

Thank you for your attention

Hossein Mokhtarian

Questions?