Spare parts on Demand
– 3D Druck Metall im Kernkraftwerk Leibstadt

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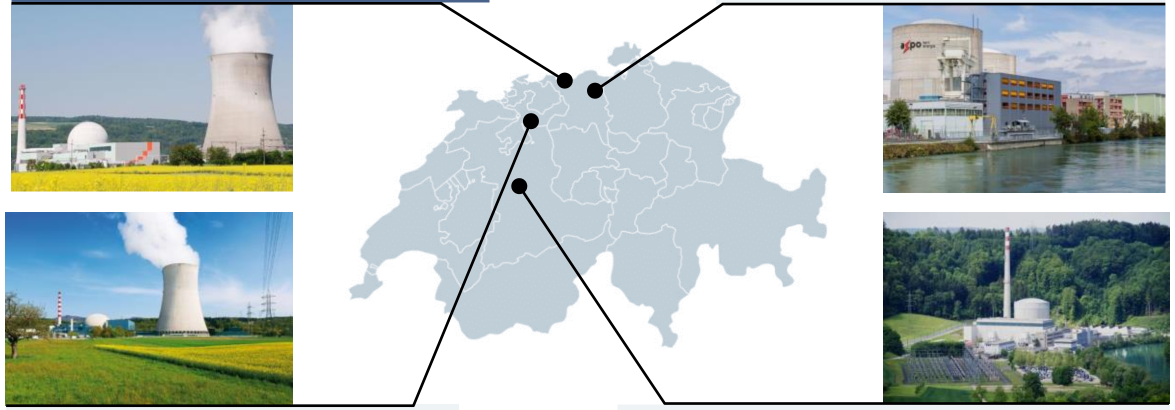
Nuclear power plant Leibstadt

Technical data and ownership structure

Leibstadt: KKL, 1285 MWe, 1984

Beznau: KKB I, 380 MWe, 1969
KKB II, 380 MWe, 1971



Gösgen: KKG, 1035 MWe, 1979

Mühleberg: KKM, 390 MWe, 1972-2019

KKL Leibstadt	
Boiling water reactor	GE, BWR6, Mark III
Thermal output	3’600 MW
Gross output / Net output	1’285 MWe / 1’233 MWe
Fuel elements	648

Swiss electricity mix			
Nuclear Power Plant 28.9 %	Storage Power Plant 35.1 %	Run-of-river power plants 26.4 %	Others 9.6 %

Partners

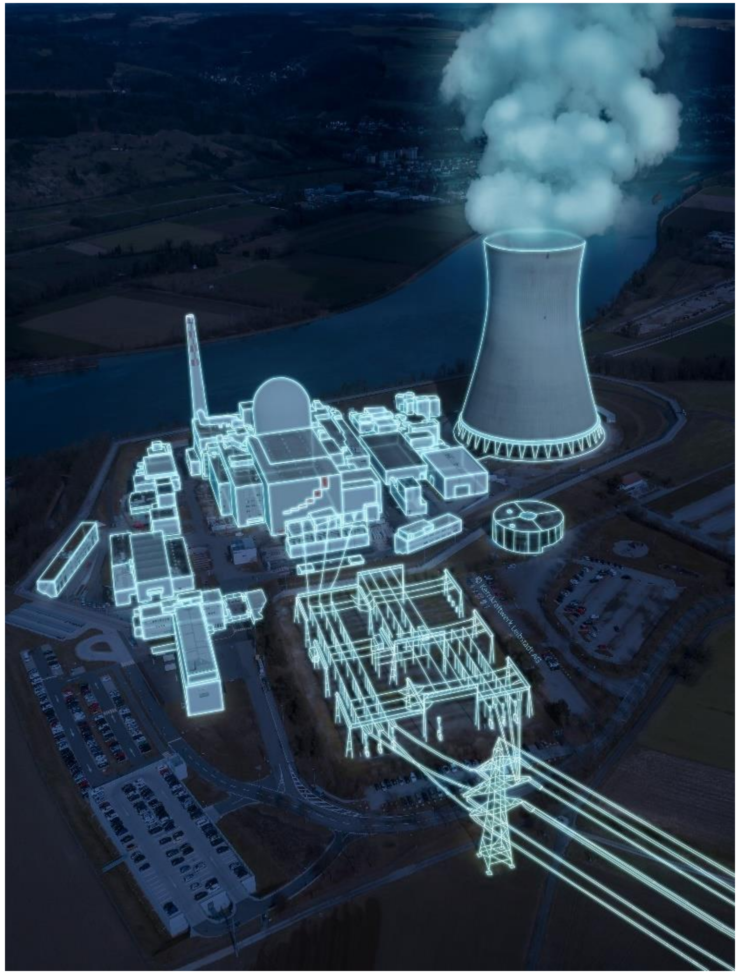
axpo

CKW.

AEW

ALPIQ

BKW



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Why is maintenance important?

What 8000h of operation really mean

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Challenges in nuclear maintenance

From aging components to lead time challenges

Aging SSCs (Structures, Systems, Components): Nuclear plants often operate beyond their initial design life, leading to increased wear and tear on components, especially in harsh environmental conditions.

High-Stakes Failures: The potential consequences of inadequate maintenance are severe, given the critical nature of nuclear plant operations.

Regulatory Compliance: Maintenance activities are governed by strict regulations requiring thorough documentation and adherence to safety standards.

Lead Time Challenges: Procuring specialized parts and components for nuclear maintenance often involves long lead times.

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Challenges in nuclear maintenance

From radiation exposure to cost pressure

Radiation Exposure: Maintenance tasks can expose workers to harmful radiation, necessitating strict safety measures.

Worker Safety: Ensuring the health and safety of workers is a critical priority in nuclear maintenance due to the hazardous environment.

Accessibility Issues: Many critical components are located in hard-to-reach areas within the plant, making maintenance physically challenging.

Cost Pressures: Nuclear maintenance involves high costs, particularly for specialized procedures and equipment.

A note on “Innovation per se” – short attempt on characterization

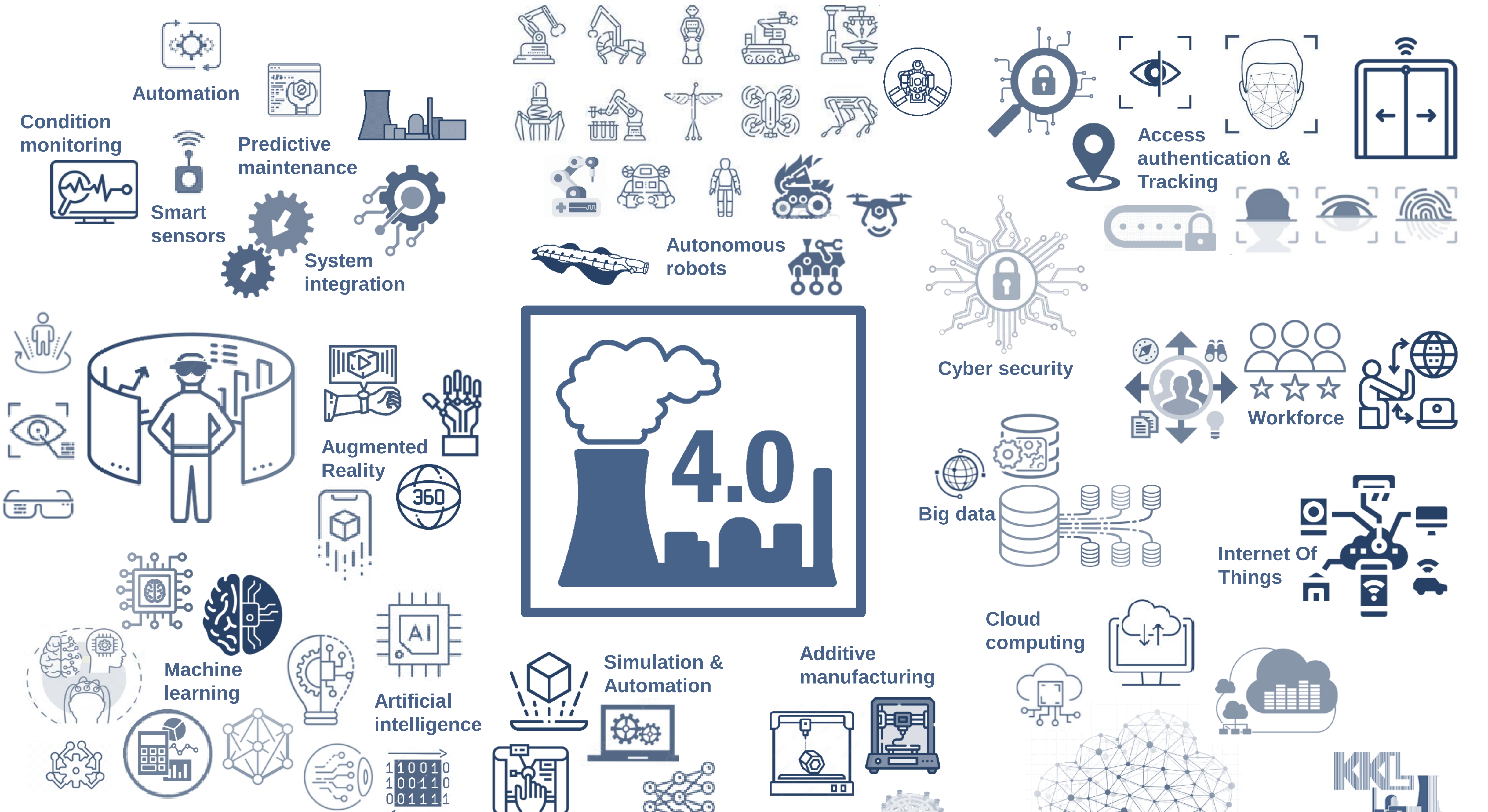
Emerging vs. Innovative vs. Critical vs. Disruptive Technologies

Emerging

Innovative

Disruptive

Critical



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Slide on technological evolution

Artificial Intelligence (AI)

- **Company/Component**: Deep Learning Techniques
- **Period**: 2012-2022
- **Emergence**: In 2012, deep learning began to significantly improve AI performance, particularly in image recognition and natural language processing.
- **Evolution**: Over the next decade, AI integrated into various industries, powering applications like virtual assistants, autonomous vehicles, and real-time analytics.
- **Relevance to Nuclear Technology**: AI's ability to analyze vast amounts of data, predict equipment failures, and optimize operational efficiency is highly relevant to nuclear technology, where safety, predictive maintenance, and decision-making are critical.

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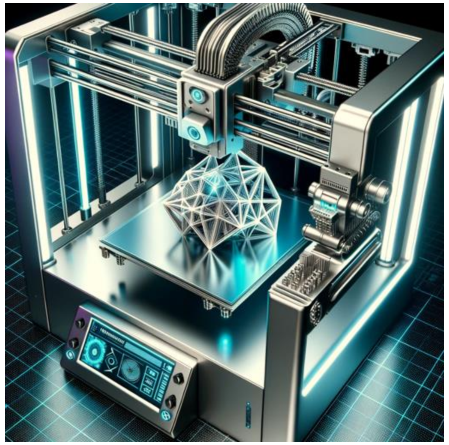
Slide on technological evolution

3D Printing

- **Company/Component**: MakerBot
- **Period**: 2010-2020
- **Emergence**: MakerBot introduced affordable desktop 3D printers in 2010, making 3D printing accessible to consumers and small businesses.
- **Evolution**: The technology evolved to support complex manufacturing, medical applications, and large-scale production, integrating into mainstream industry.
- **Relevance to Nuclear Technology**: 3D printing is increasingly important in nuclear technology for producing specialized components, prototyping, and potentially reducing lead times for critical parts, thus supporting maintenance and operational continuity.



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Slide on technological evolution

Robotics and Drones

- **Company/Component**: Various robotics and drone technologies
- **Period**: 2010-2020
- **Emergence**: Robotics and drones emerged as powerful tools for inspection, surveillance, and maintenance in various industries around 2010, particularly in hazardous or hard-to-reach environments.
- **Evolution**: Over the next decade, these technologies advanced rapidly, becoming more autonomous, capable of complex tasks, and widely adopted across industries, including nuclear, for safety and efficiency improvements.
- **Relevance to Nuclear Technology**: Robotics and drones are crucial in nuclear technology for performing inspections, maintenance, and repairs in hazardous environments, reducing human exposure to radiation and improving operational safety.

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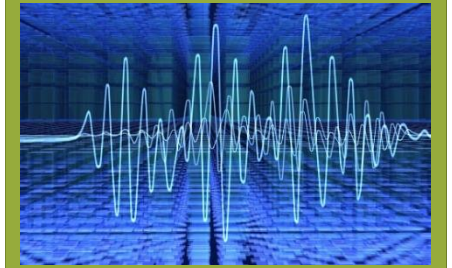
Value Streams in the Nuclear 4.0 programme

Clustering the broad range of topics into five connected bins

Analytics & Diagnosistics


Robotics & Automation



Digital Workforce



Modelling Digital Assets



Hardware & Processes



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Slide on technological evolution

3D Printing

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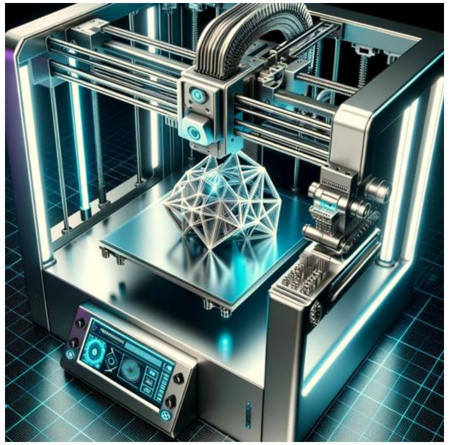
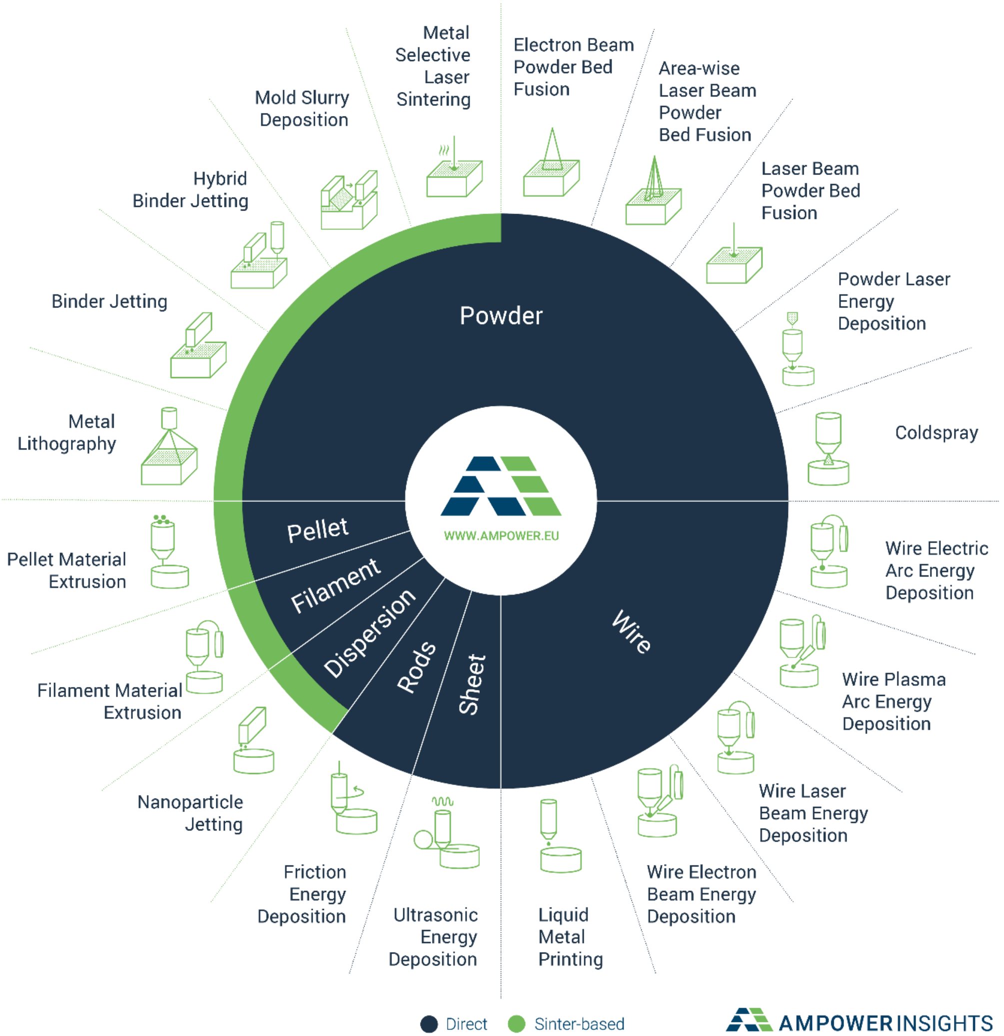
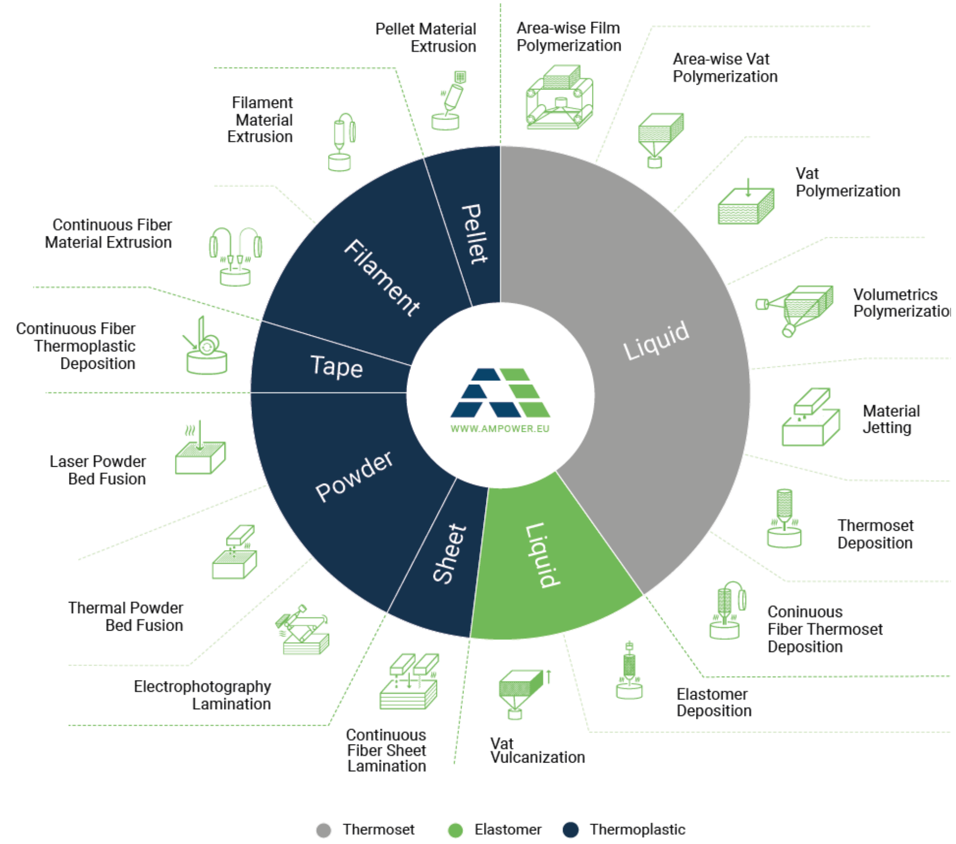


Additive Manufacturing

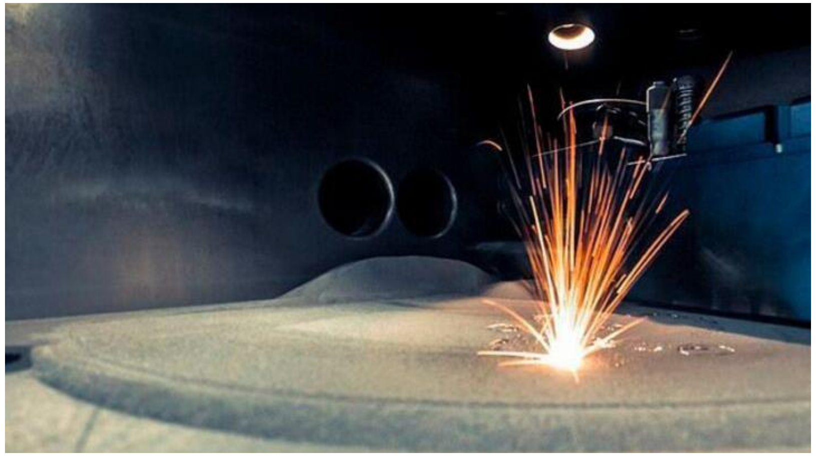
Technology landscape – metal and polymer

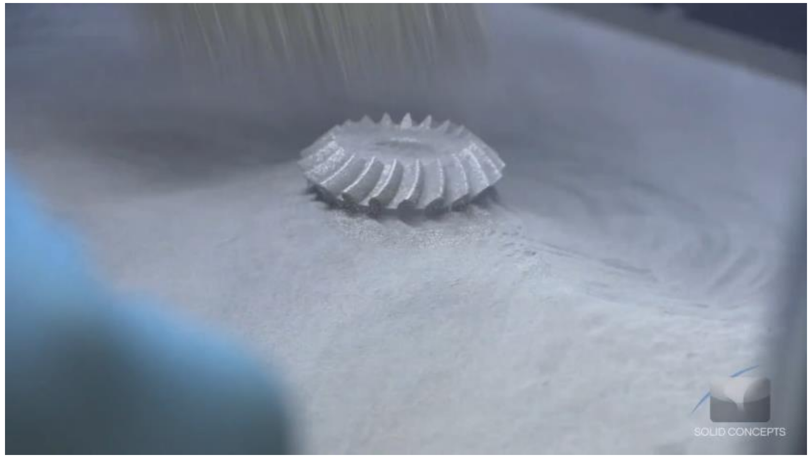




Additive Manufacturing

Powder bed fusion (PBF)

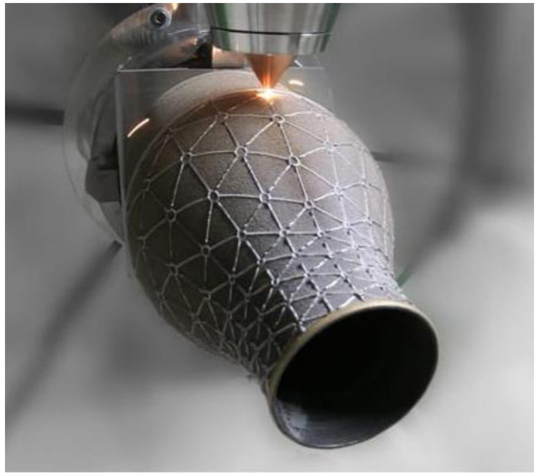


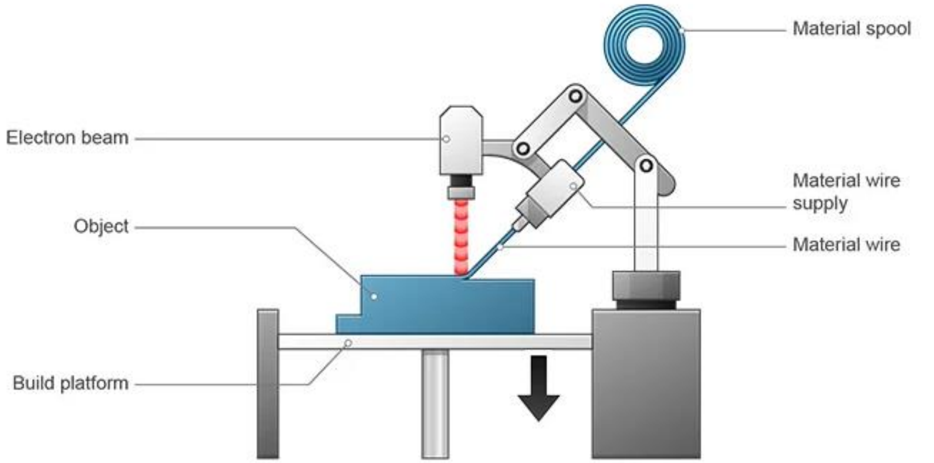


Additive Manufacturing

Directed Energy Deposition (DED)

- uses a directed energy source to deposit material directly onto a substrate
- it works by using a high-power laser or electron beam to melt and deposit metal powder onto a substrate.
- allows for a more efficient deposition process (parts with more intricate details and improved surface finish)
- more energy efficient compared to PBF
- can be used with subtractive manufacturing by CNC in one machine





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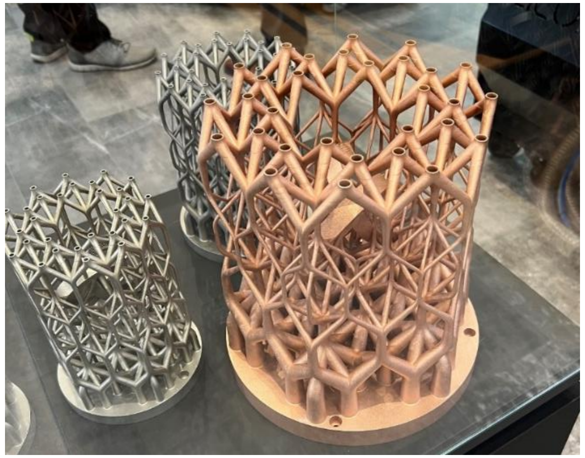
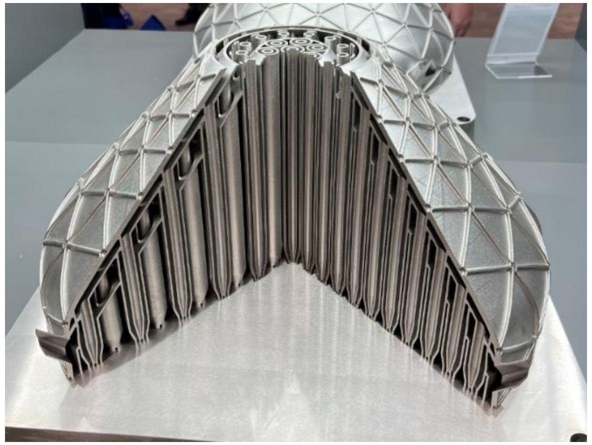
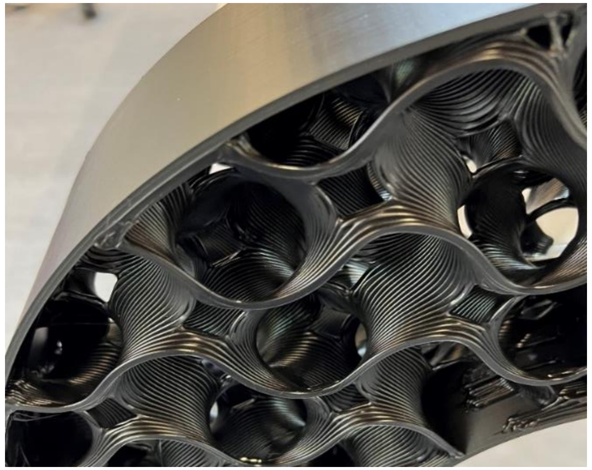
Additive Manufacturing

Impressions from Formnext November 2022

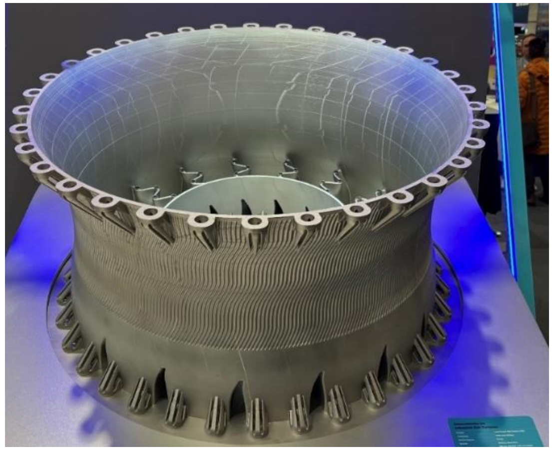
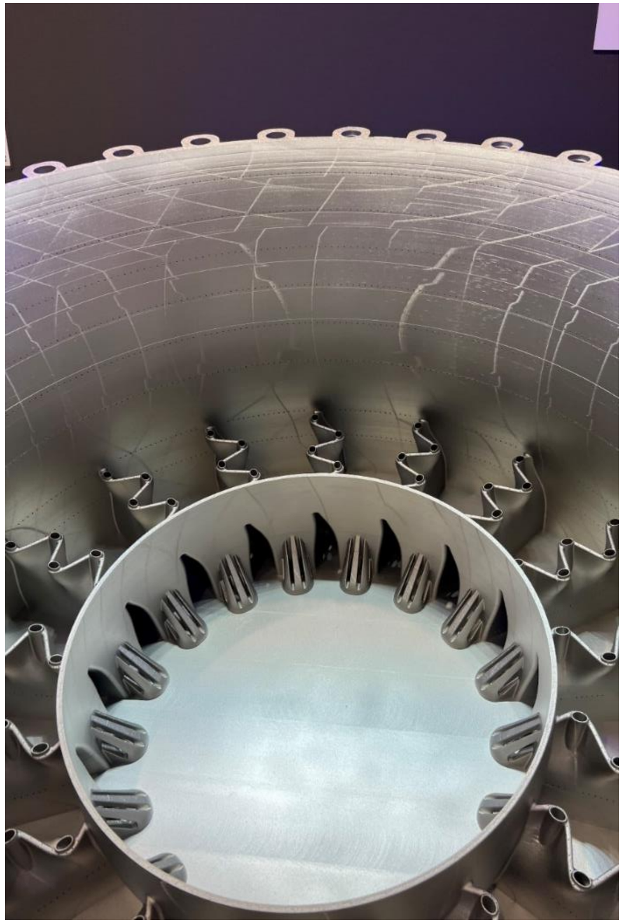




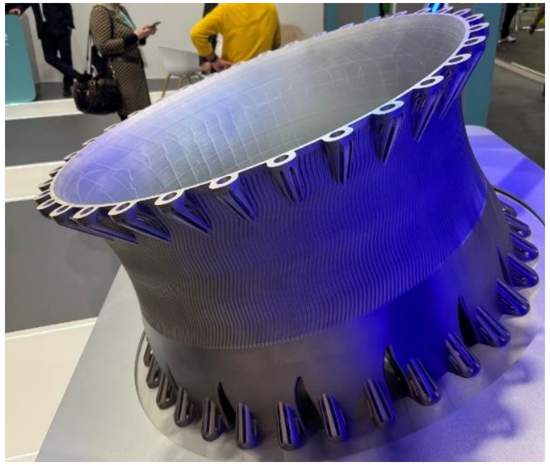


Additive Manufacturing

Impressions from Formnext November 2022



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Additive Manufacturing

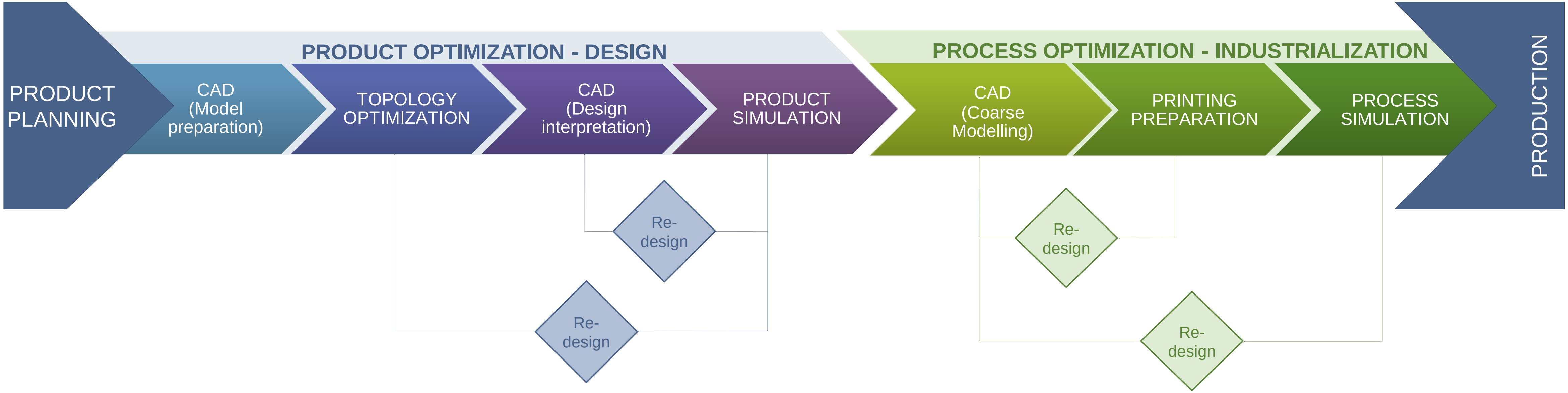
Impressions from Formnext November 2022

Kernkraftwerk Leibstadt

3D Printing at KKL Leibstadt

Software – Workflow

- Fusion 360 – Generatives Design - unlimited ideas to optimize designs by materials and manufacturing techniques
- Autodesk Inventor – Classic tool for preparation of CAD geometries for finite element analyses
- nTopology – a software suite built around the needs of designers of AM parts, heavily developped



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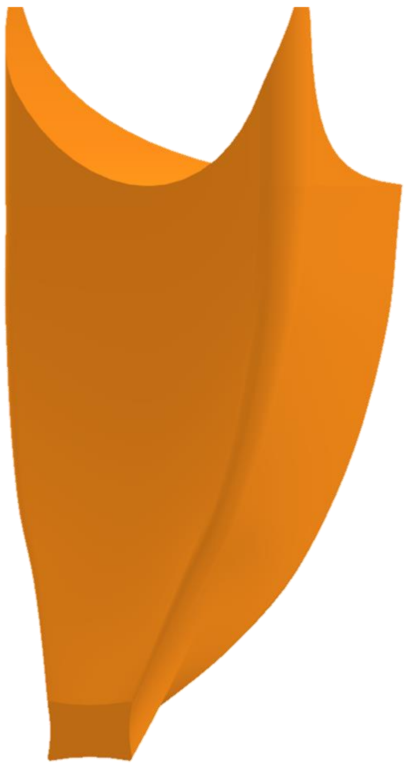
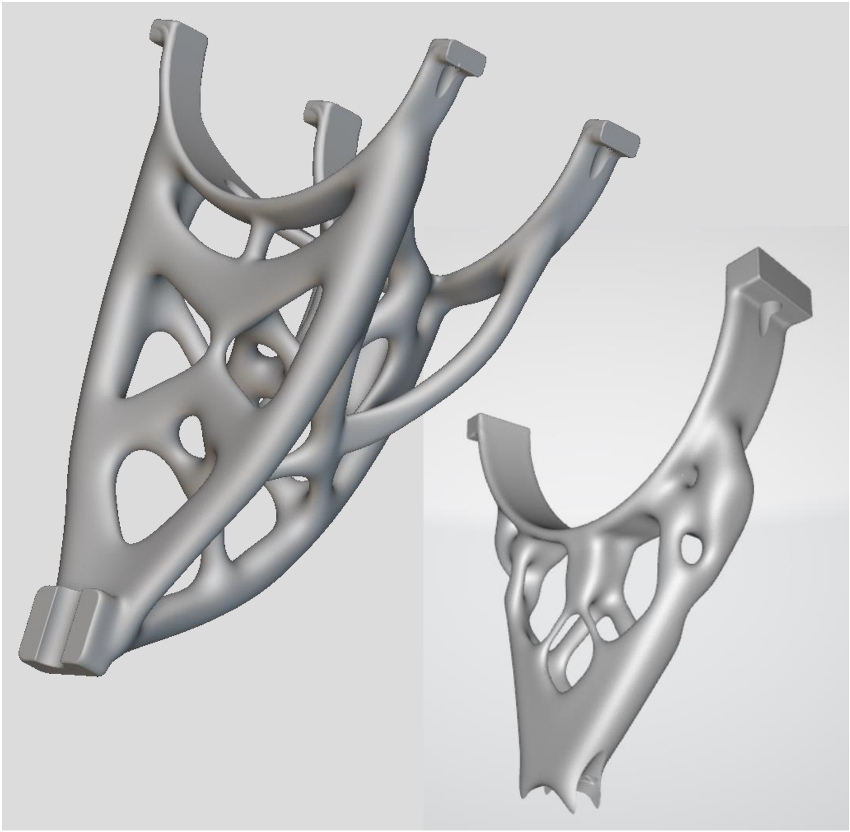
3D Printing at KKL Leibstadt

Topology optimization





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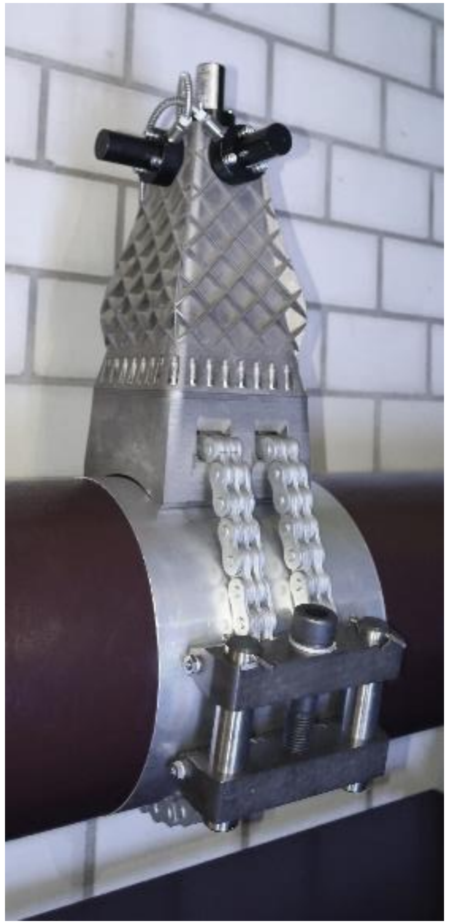
3D Printing at KKL Leibstadt

Examples of 3D printed parts



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3D Printing at KKL Leibstadt

Fun bracket prototype

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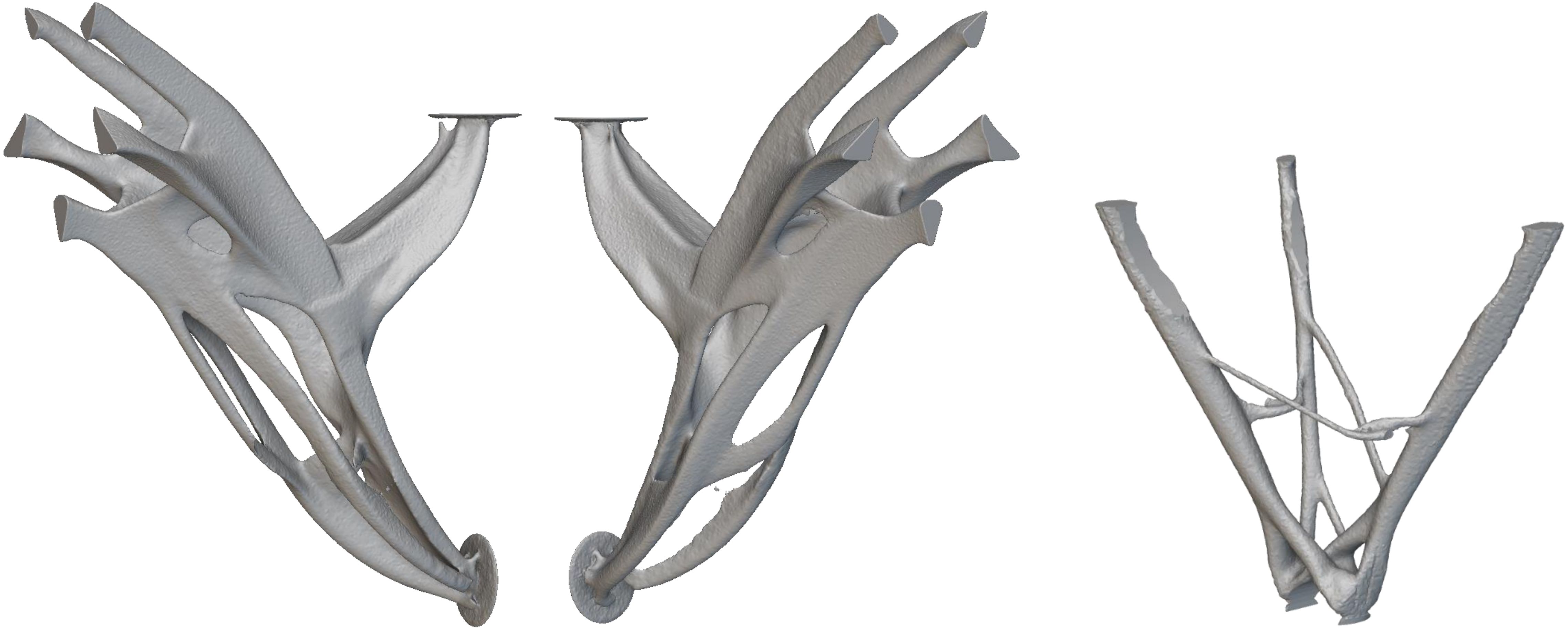
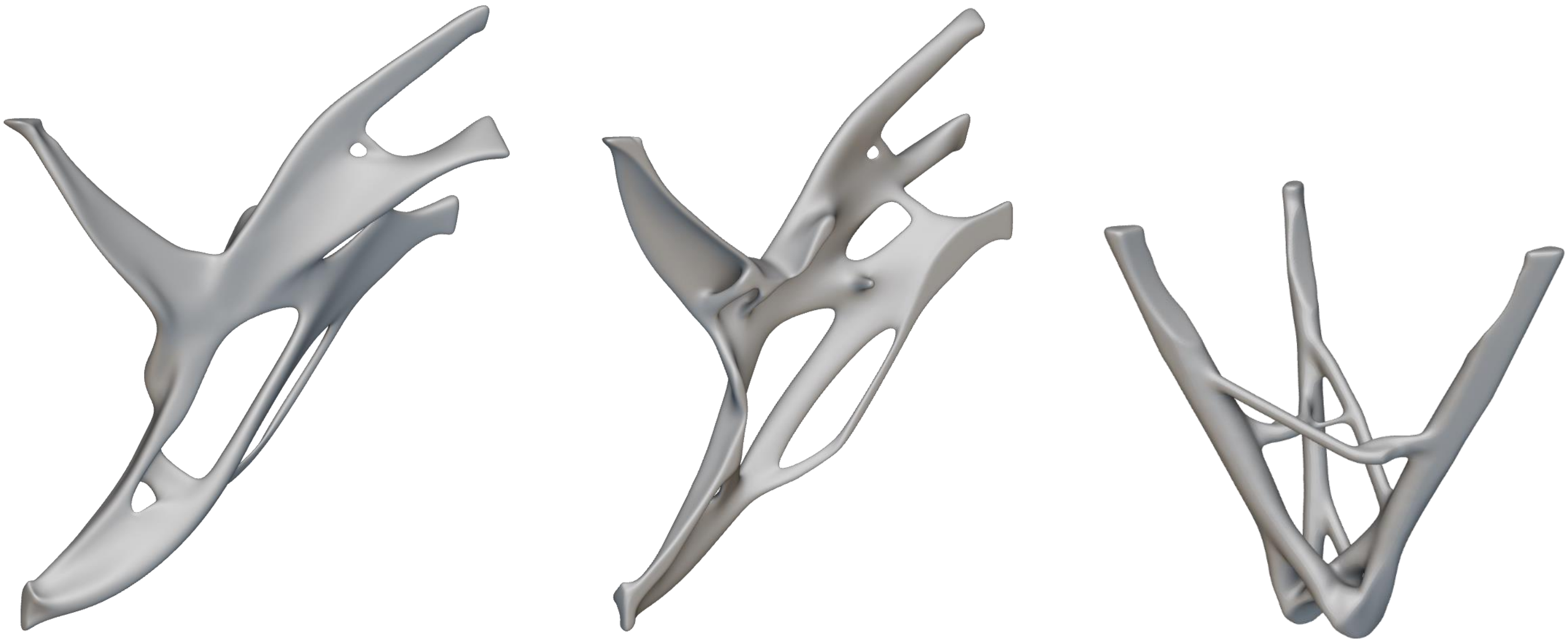
Topology optimization results

Raw output, not smoothed up or symmetrized

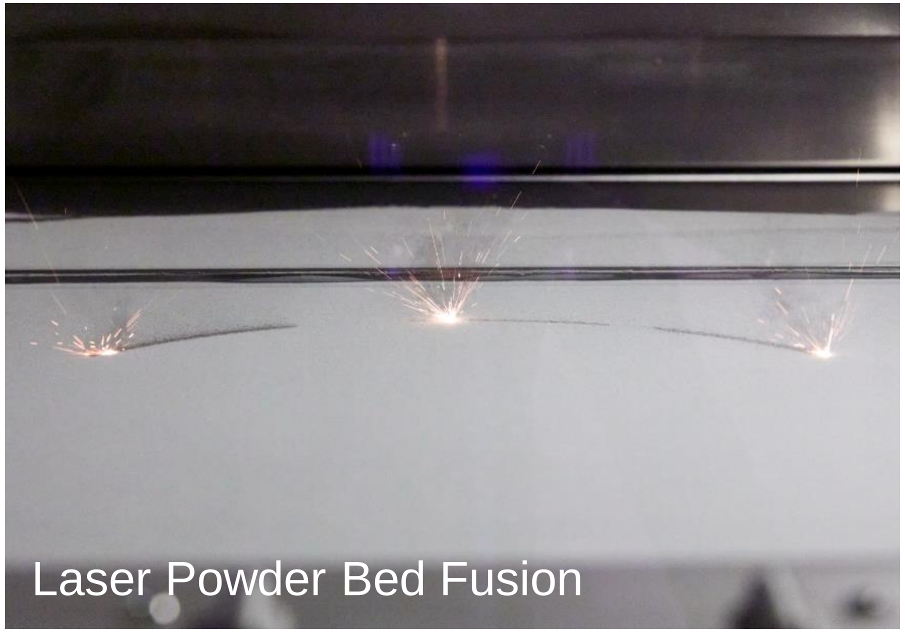


Smoothed and symmetrized topology optimization results

Appropriate level setting for robust and flexibel geometry design



AMotion Center: Additive Manufacturing - Powder bed technology



+GF+

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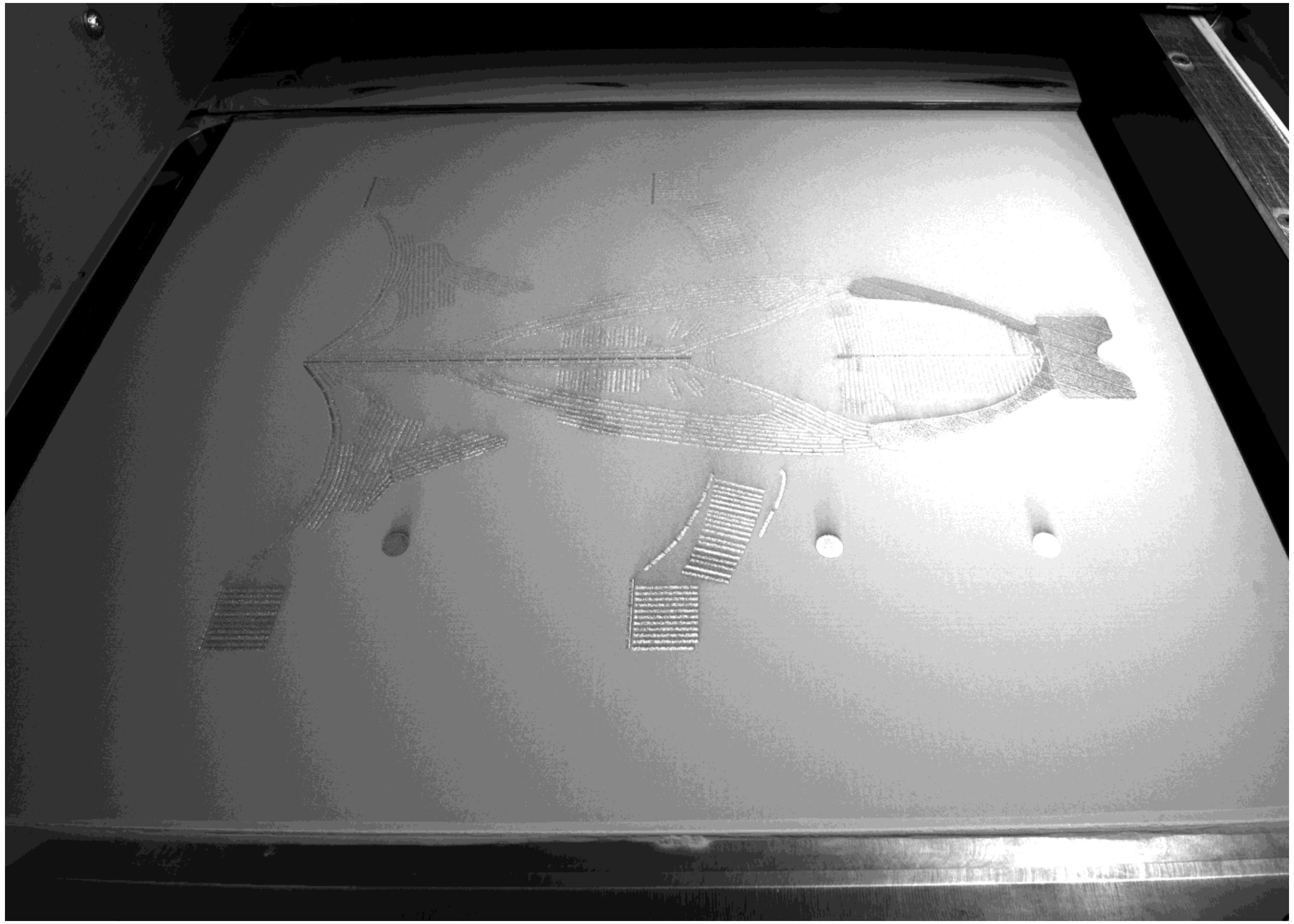
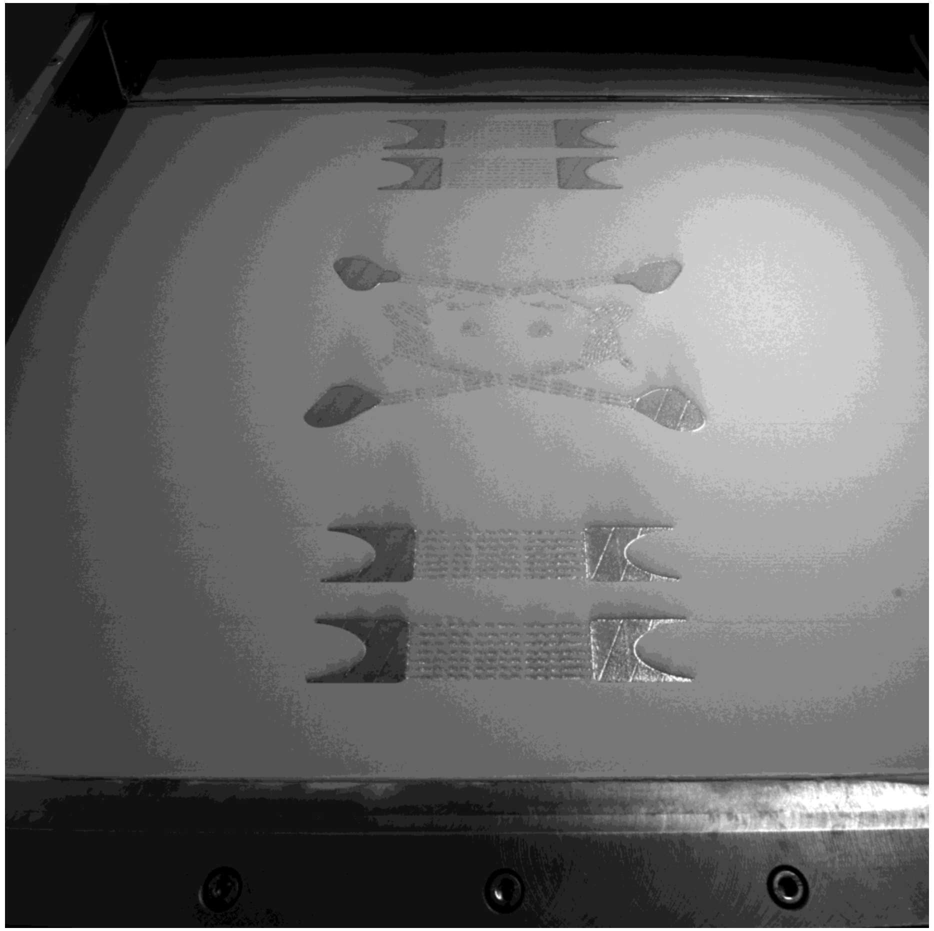
Manufacturing of new brackets

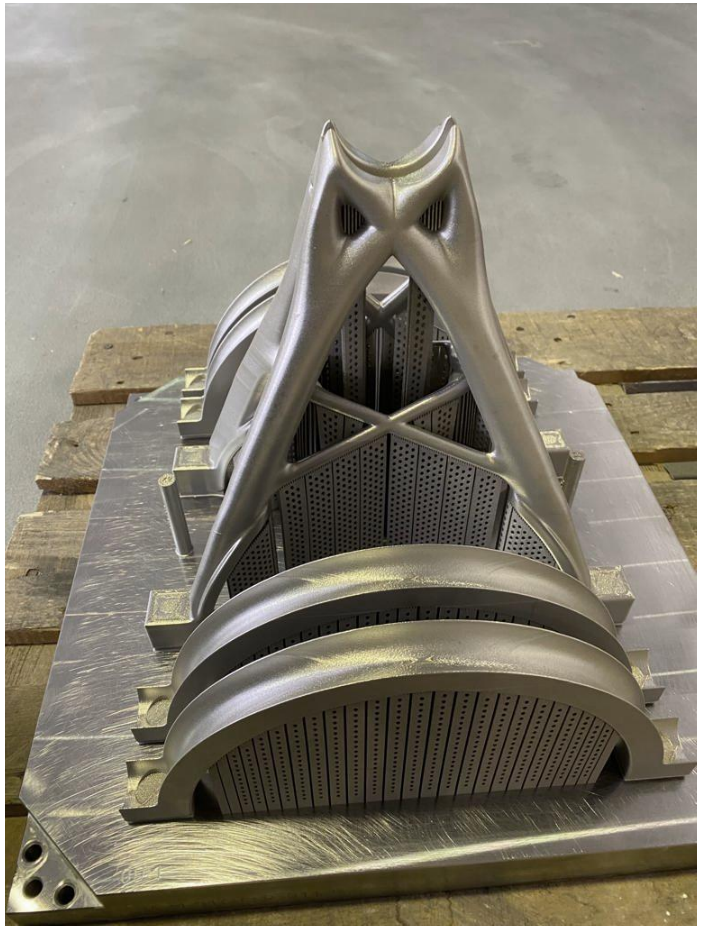
+GF+ using multiple DMP 500 for production of Inconel 718 parts





Manufacturing of new brackets

Finished prints on based plate and with support structures

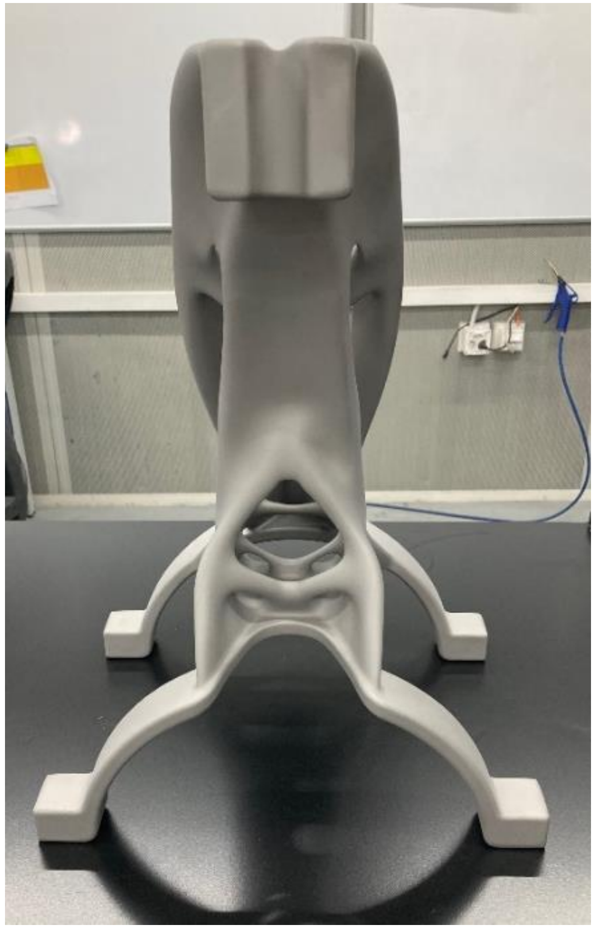
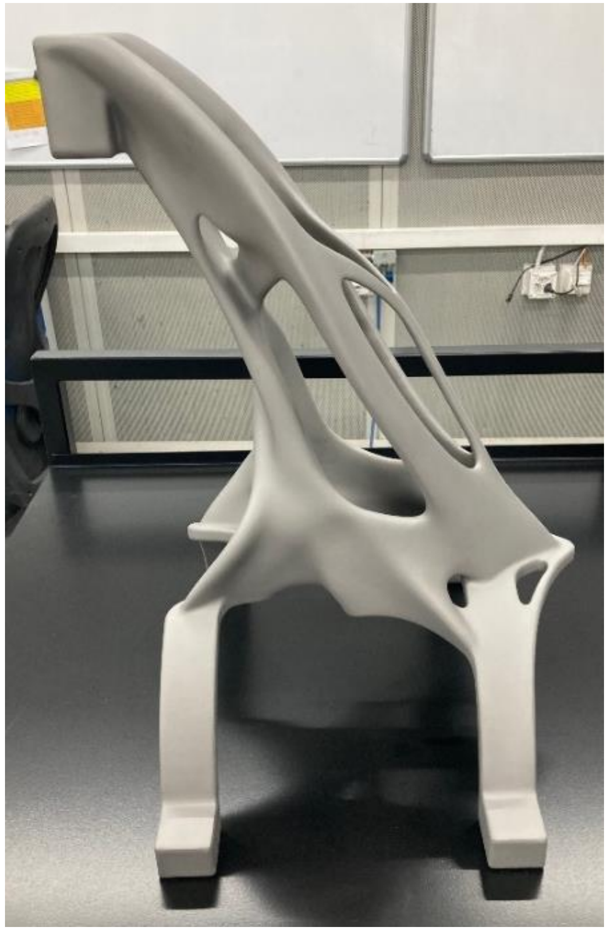


Manufacturing of new brackets

Roughly removed support structures

Manufacturing of new brackets

Support structures removed, grinded and blasted


Finally, finished parts arrive on site at KKL for finishing operations

The proud designers received their «precious»

Finished brackets after machining of functional surfaces

Excess material added in critical areas accounting for potential distortion

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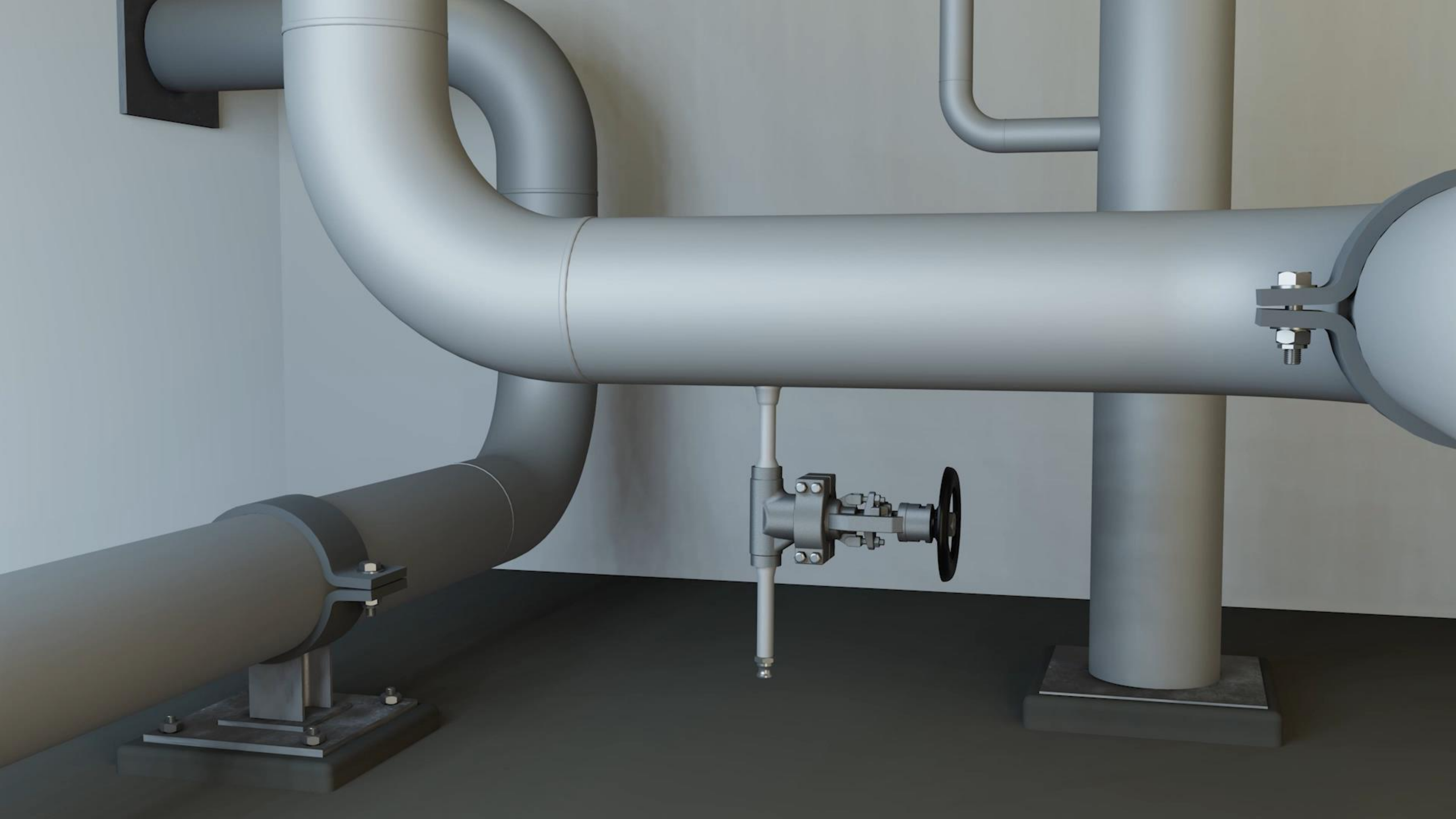
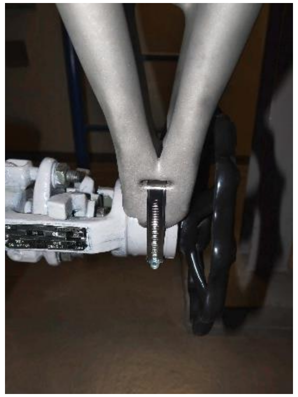


PBF-manufactured small bore pipe anti-vibration bracket

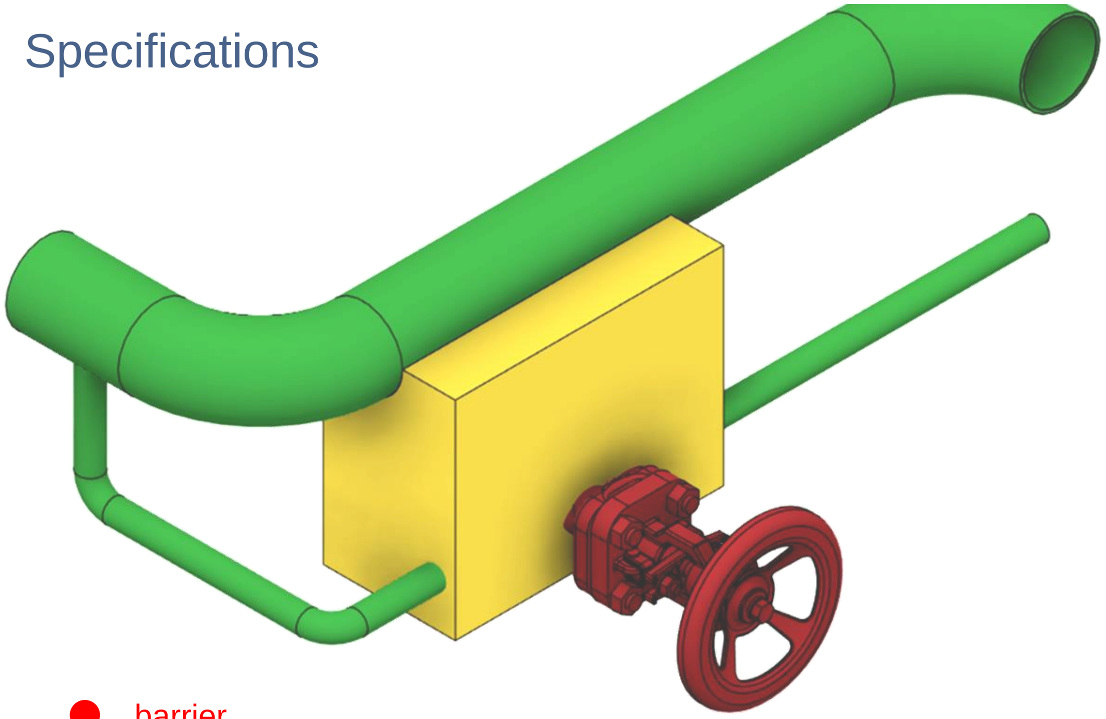
Ultra high fatigue and tensile strength IN 718 material – proudly installed end of November 2023



3D Printing at KKL Leibstadt

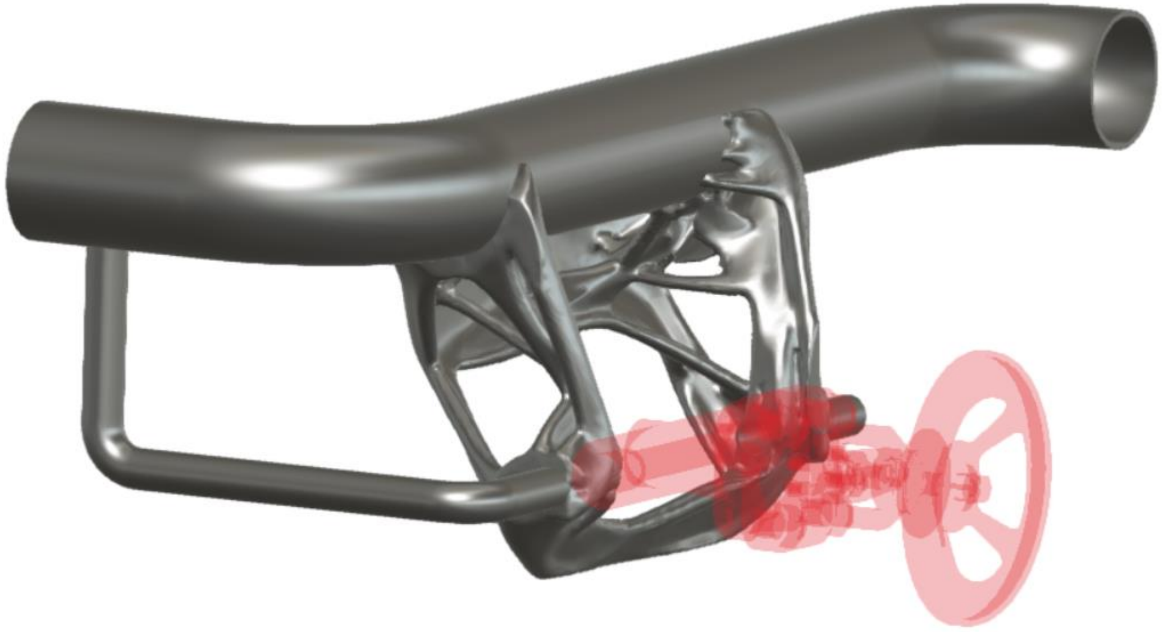
Generative Design – «AI» creating complex geometry

Specifications



- barrier
- available space
- existing parts

Created geometry – one of numerous



PBF-manufactured small bore pipe anti-vibration bracket (small main pipe)

Early design printed from 316L – to be installed in January 2024

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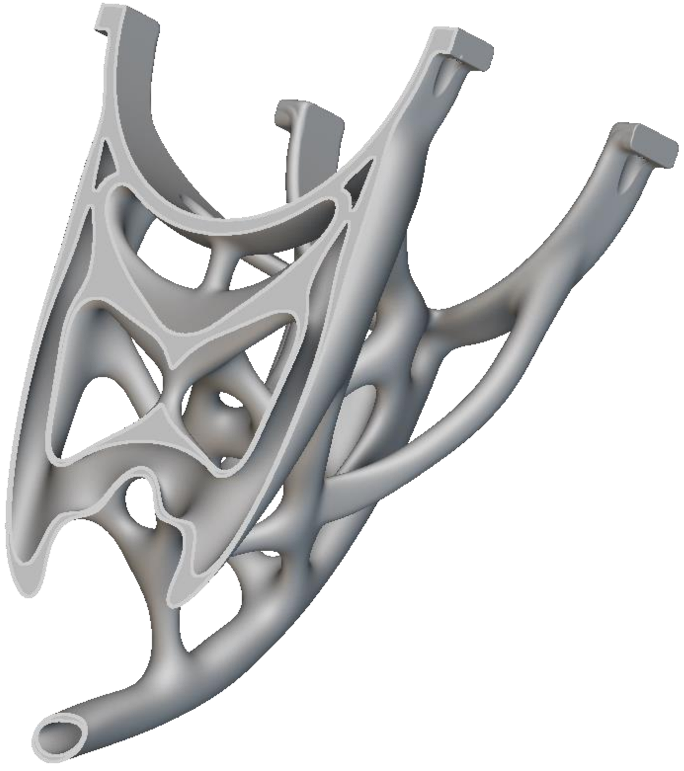
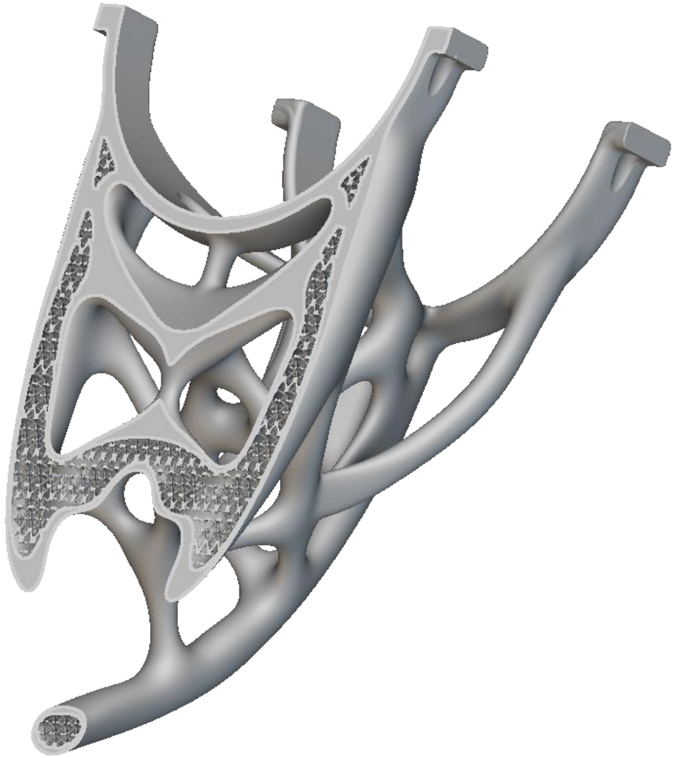
PBF-manufactured small bore pipe anti-vibration bracket (small main pipe)

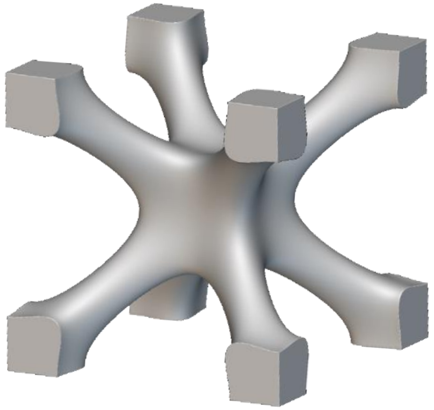
Latest design printed from 316L – to be installed in January 2024

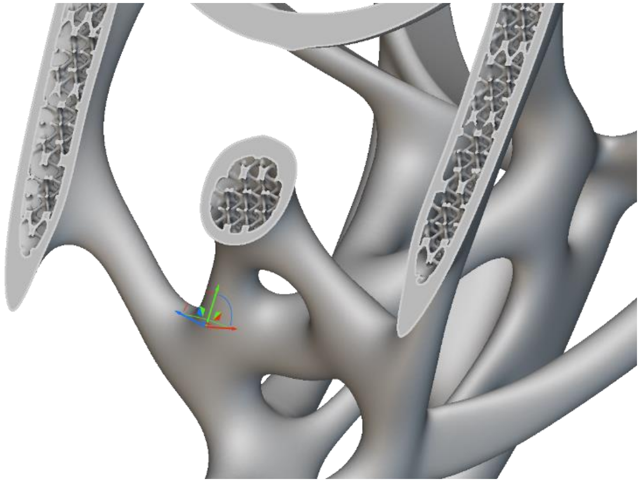
Farther Outlook

Manufacturing needs to catch up now!





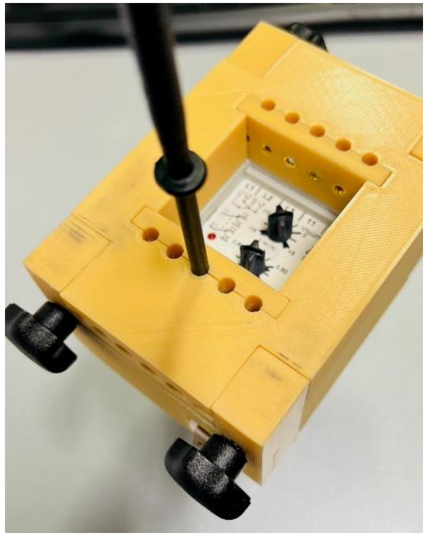


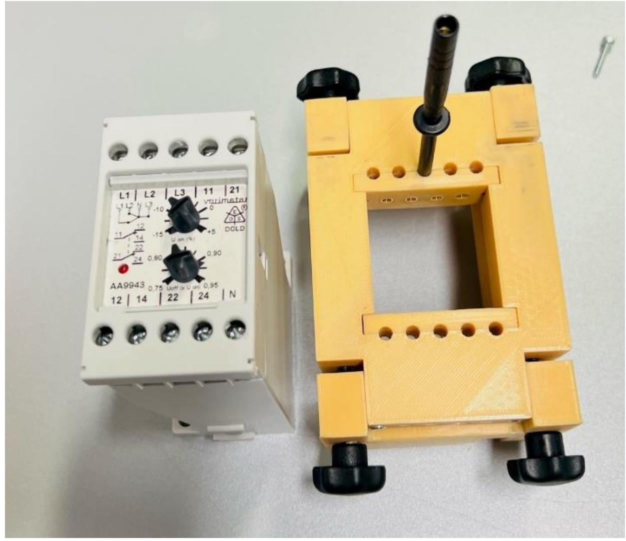


- Variable wall thickness and internal lattice structure

3D Printing at KKL Leibstadt

Examples of 3D printed parts

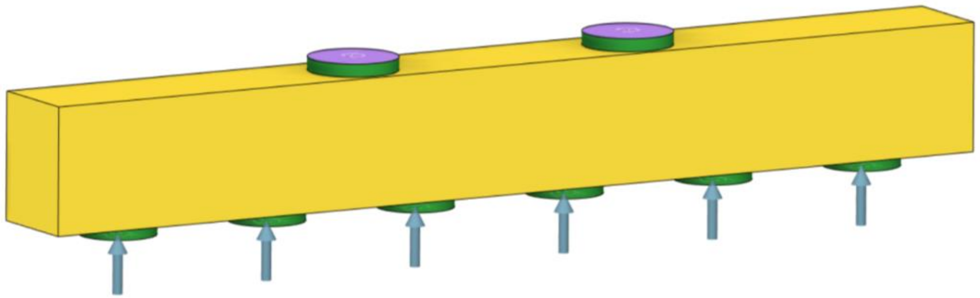




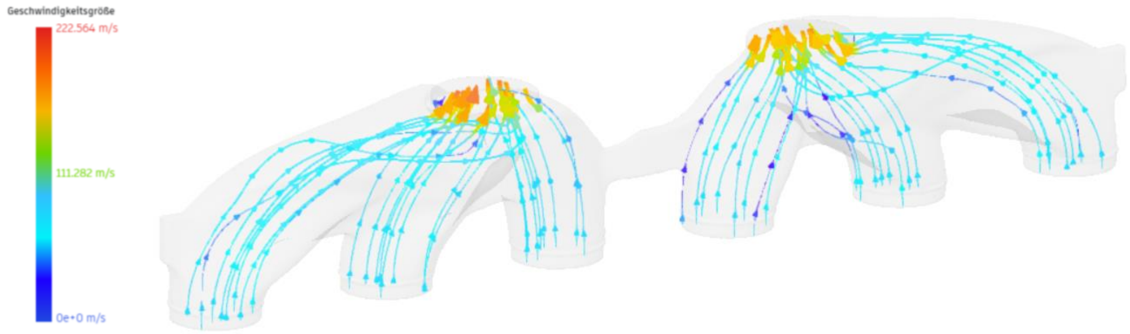
- In Department E, more than 400 undervoltage relays have to be tested last year. These have a test voltage of 400 V, so they must be contact protected.
- Because this plastic (PLA) is electrically insulating and a printer is just perfect for this application, it was made on a home printer of one of our employees.
- If we had milled the parts on a CNC machine, one person might have spent 40 hours on it, the printer took just under 20 hours.

3D Printing at KKL Leibstadt

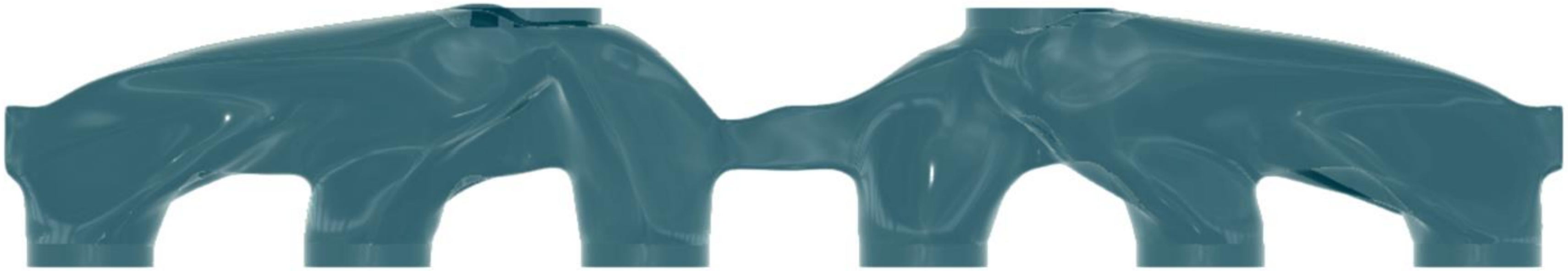
«AI» generated flow optimized 3D printed parts



- available space
- existing parts
- flow constraint

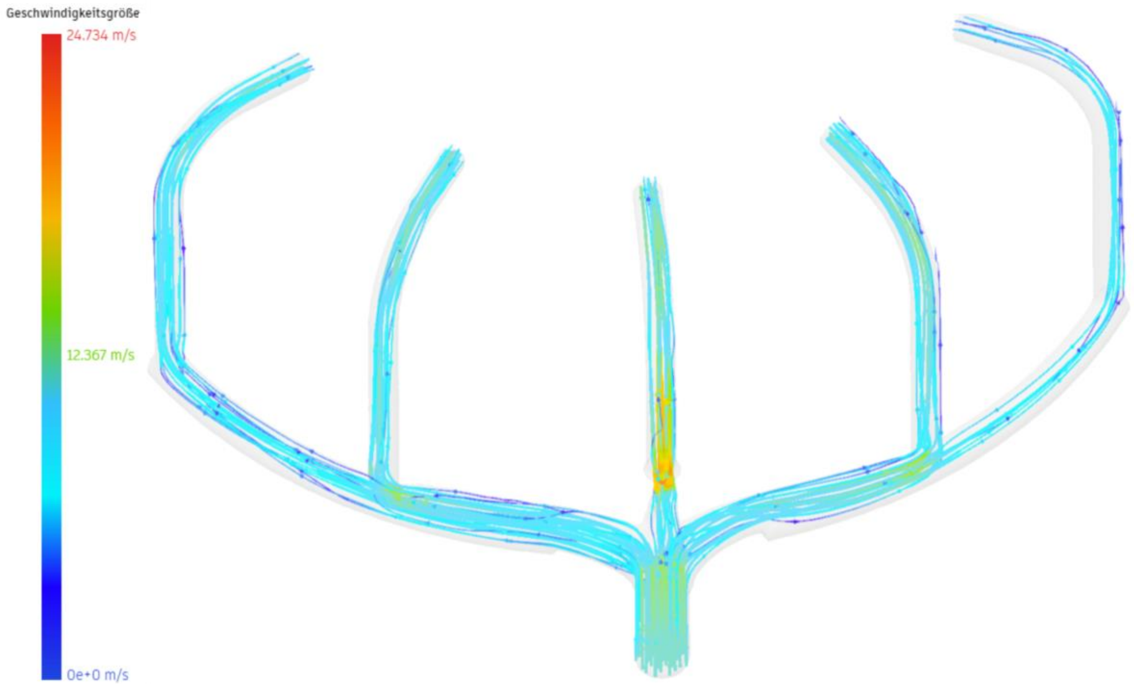


- flow optimized inner structure

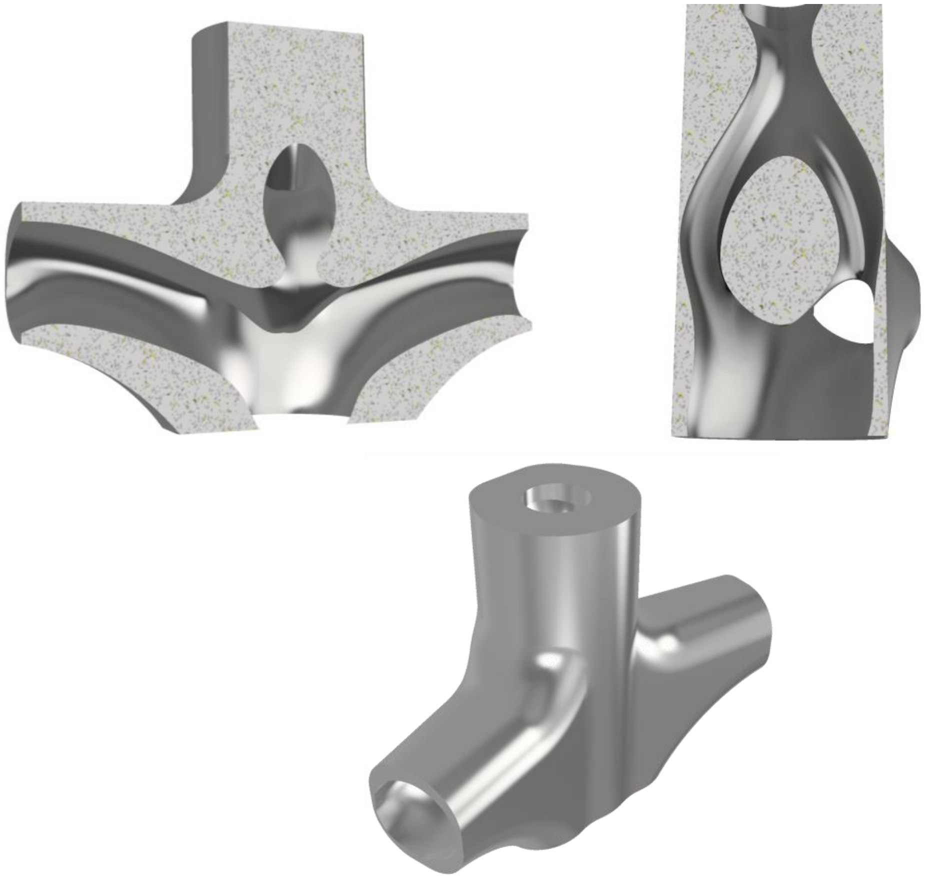


3D Printing at KKL Leibstadt

«AI» generated flow optimized 3D printed parts



- flow optimized recirc cross

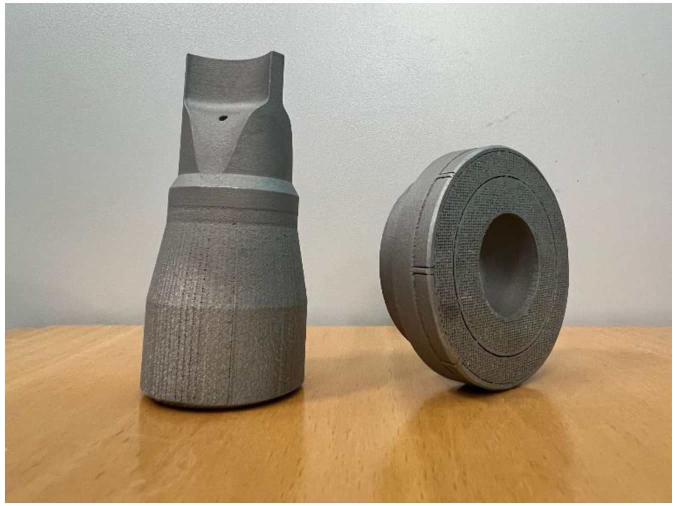


- less pressure drop
- equal flow rates per runner
- less prone to pressure surge

Reverse Engineering, Re-engineering and optimization of spare parts

The art of understanding design beyond documentation and traditional limits



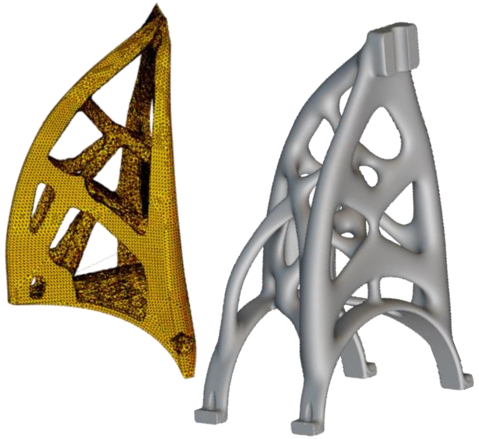
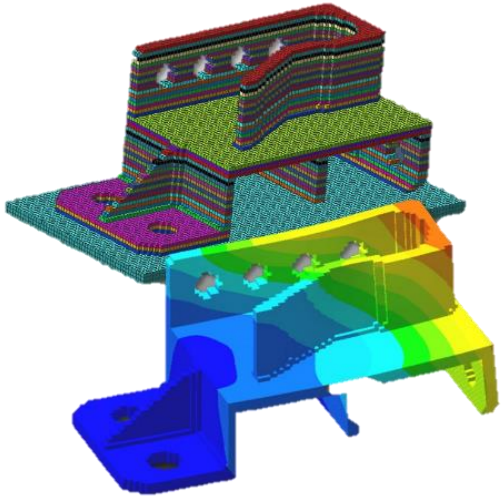
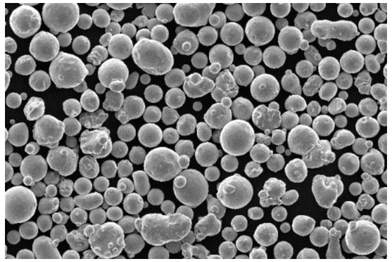



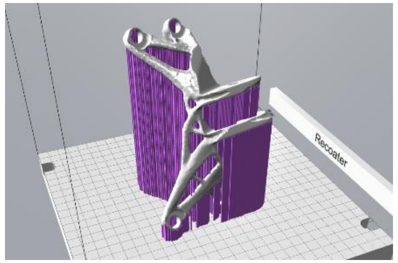
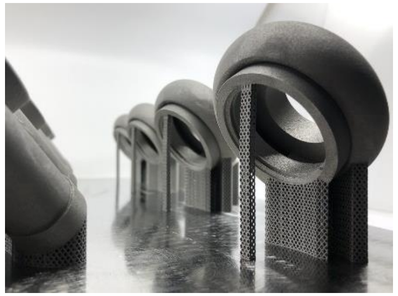


Life Cycle Management

From norms and standards to Pre-Processing

Norms and Standards → Design → Simulation → Material Selection → Pre-Processing →

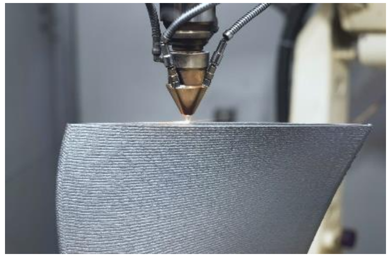
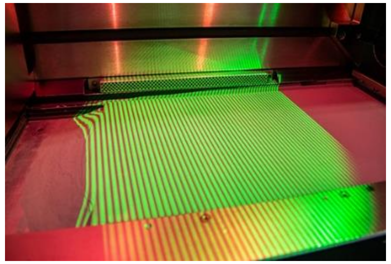





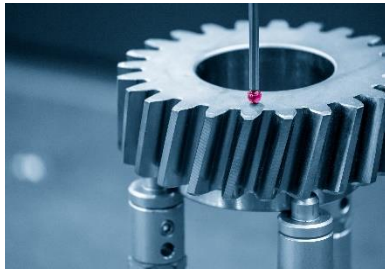
Life Cycle Management

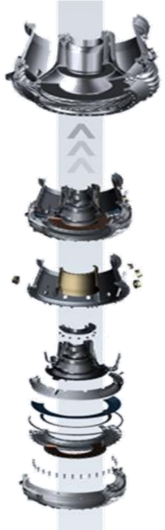
From manufacturing to installation

Manufac-turing → Post-Processing → Inspection → Qualifica-tion → Installation →



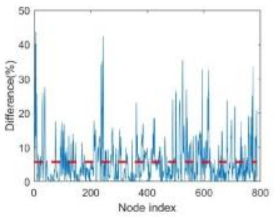


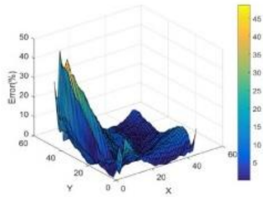



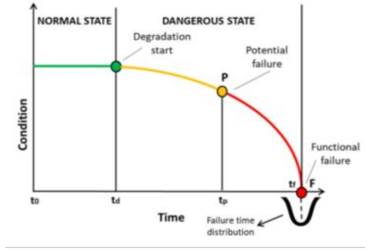
Life Cycle Management

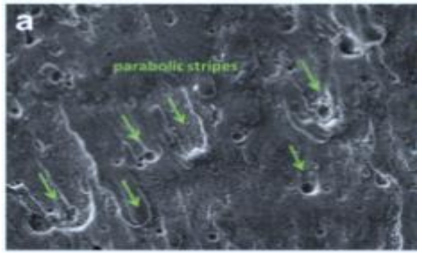
From operation to end-of-life

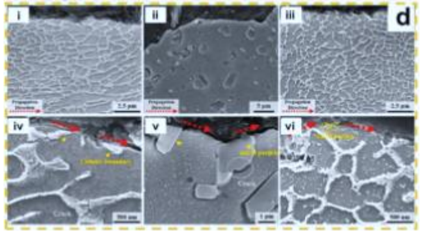
Operation → Mainte-nance → Ageing Manage-ment → End-of-Life





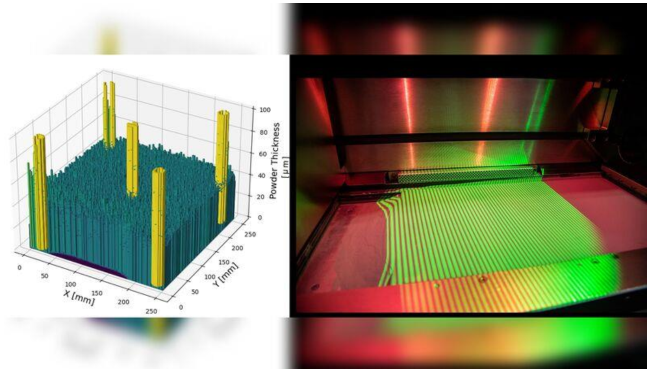




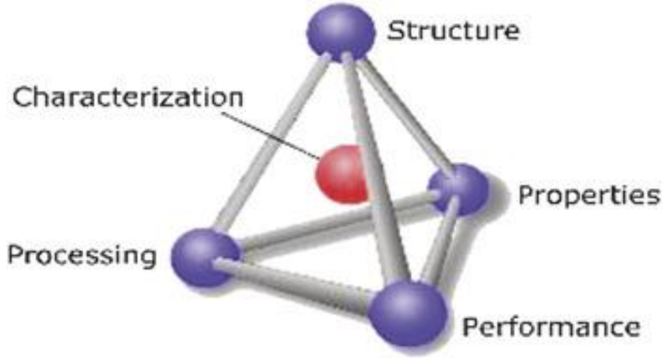


Next steps and challenges

Develop general nuclear specification for procurement of LPBF parts



In-situ monitoring



Material characterization

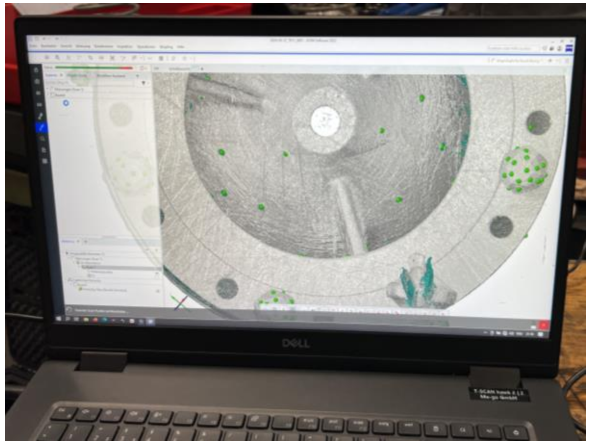
Quality control

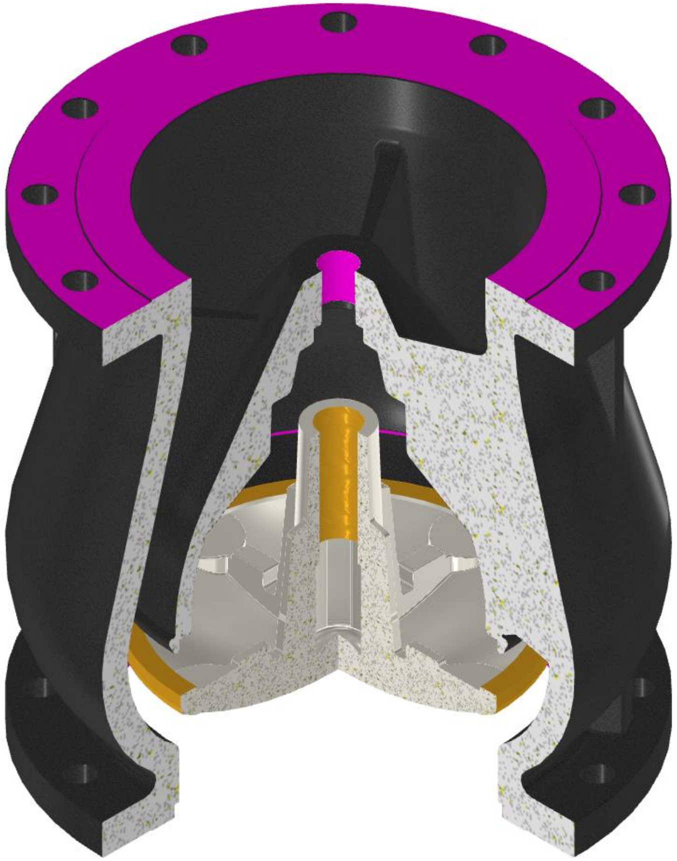
Surface finishing

Code compliance

Next steps and challenges

Proof of concept examples with regulator





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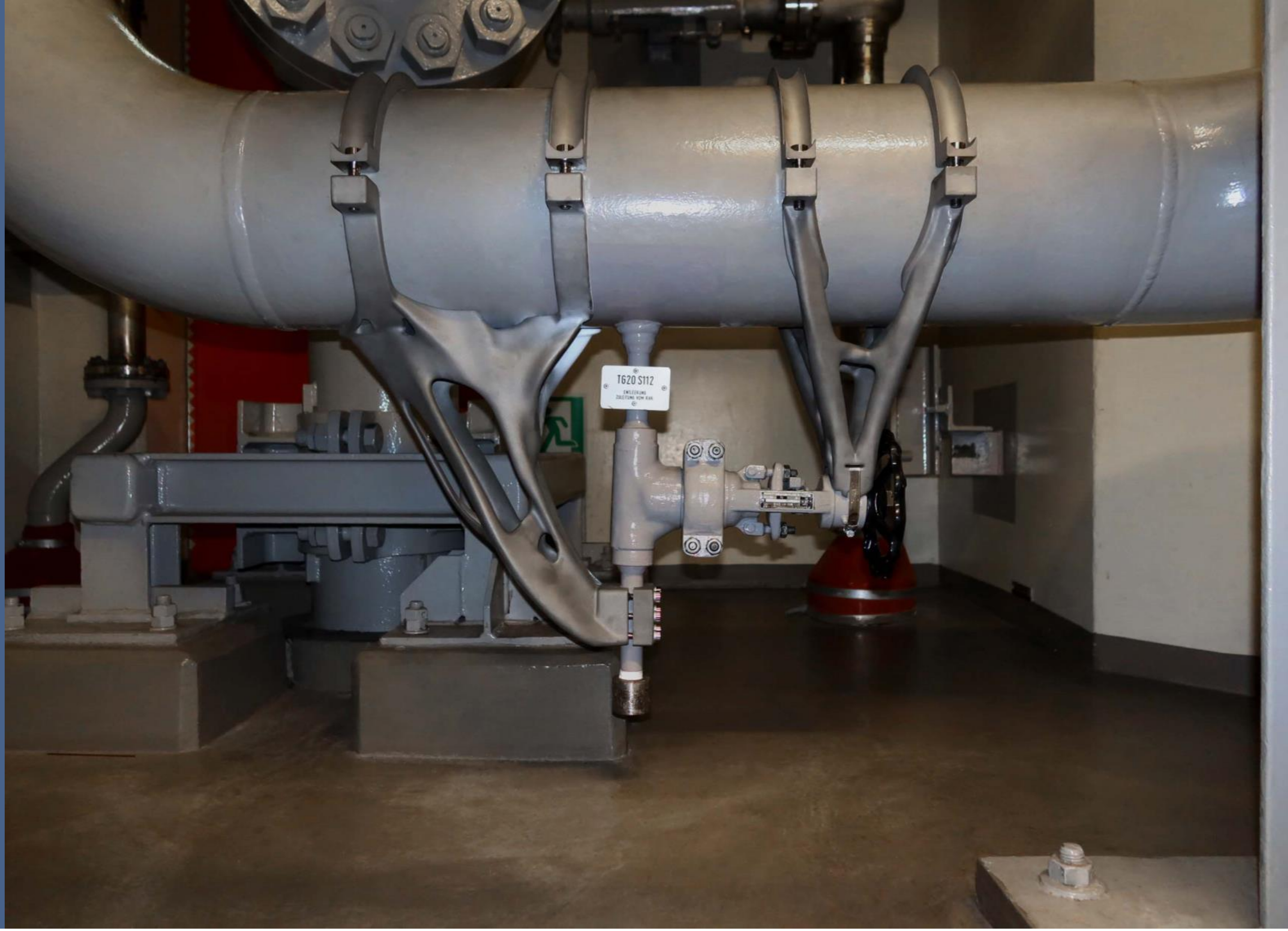
Thank you for your attention!

Benjamin Regener, M



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