



POLITECNICO
MILANO 1863

DEPARTMENT OF AEROSPACE
SCIENCE AND TECHNOLOGY

Additive Manufacturing technologies, applications and future perspectives

18.02.2026 | Antonio Mattia Grande

Introduction

3D Printing

Rapid Prototyping
Rapid Manufacturing

Additive Manufacturing (AM)
Additive Layer Manufacturing (ALM)

Laser Beam Melting (LBM)
Selective Laser Melting (SLM)
Selective Laser Sintering (SLS)
Direct Metal Laser Sintering (DMLS)
Electron Beam melting (EBM)
Powder bed fusion

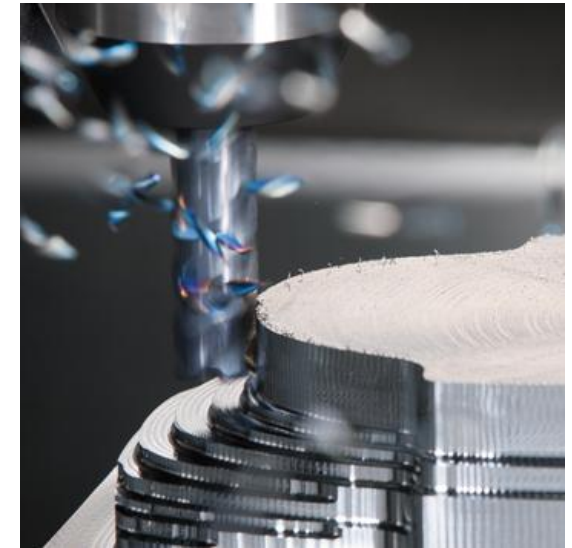
FreeForm Fabrication (FFF)
Solid Freeform Fabrication (SFF)

Laser Metal Deposition (LMD)
Laser Cladding
Direct Energy Deposition (DED)
Direct Metal Deposition (DMD)
Powdered fusion

Introduction

Manufacturing technologies:

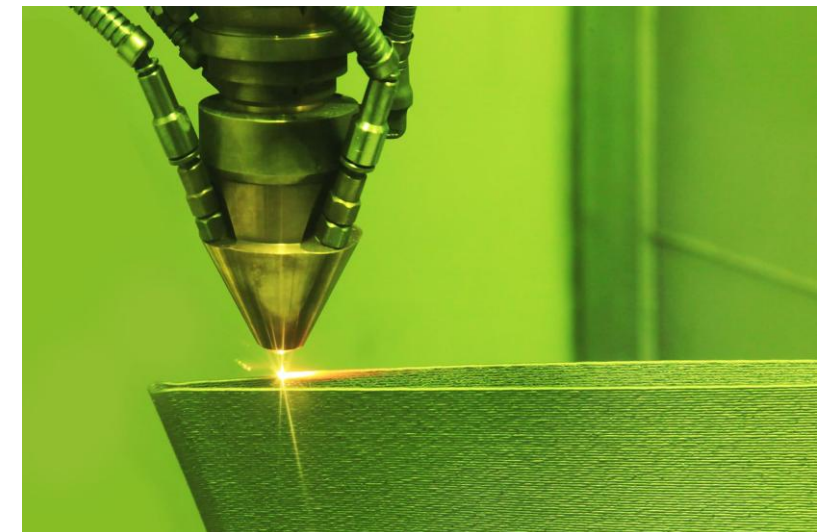
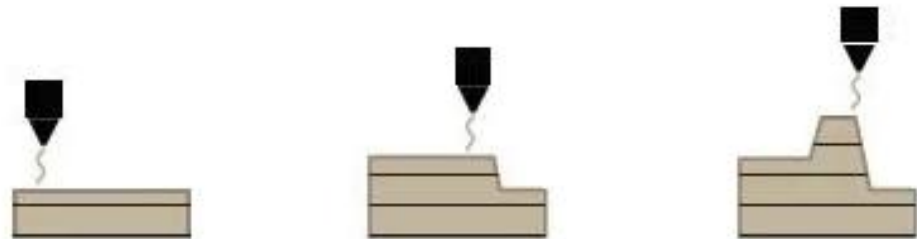
I. Shaping



II. Subtracting

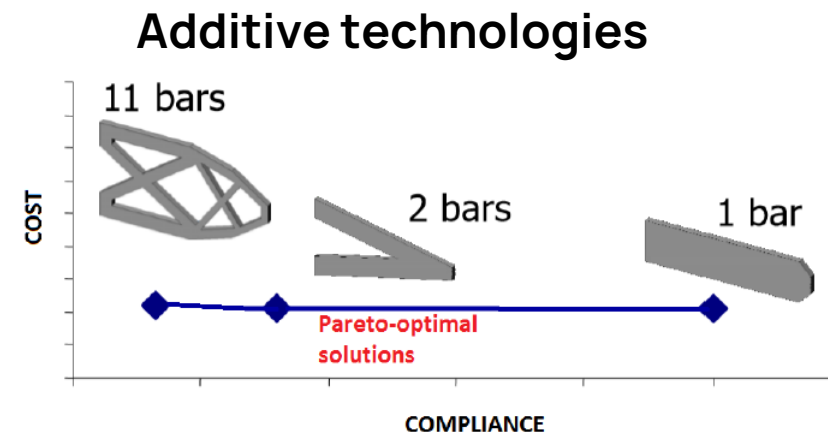
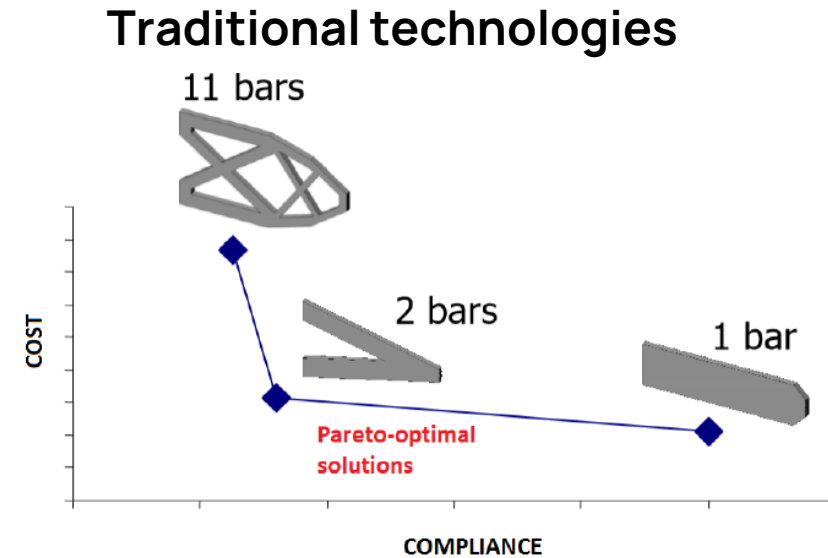
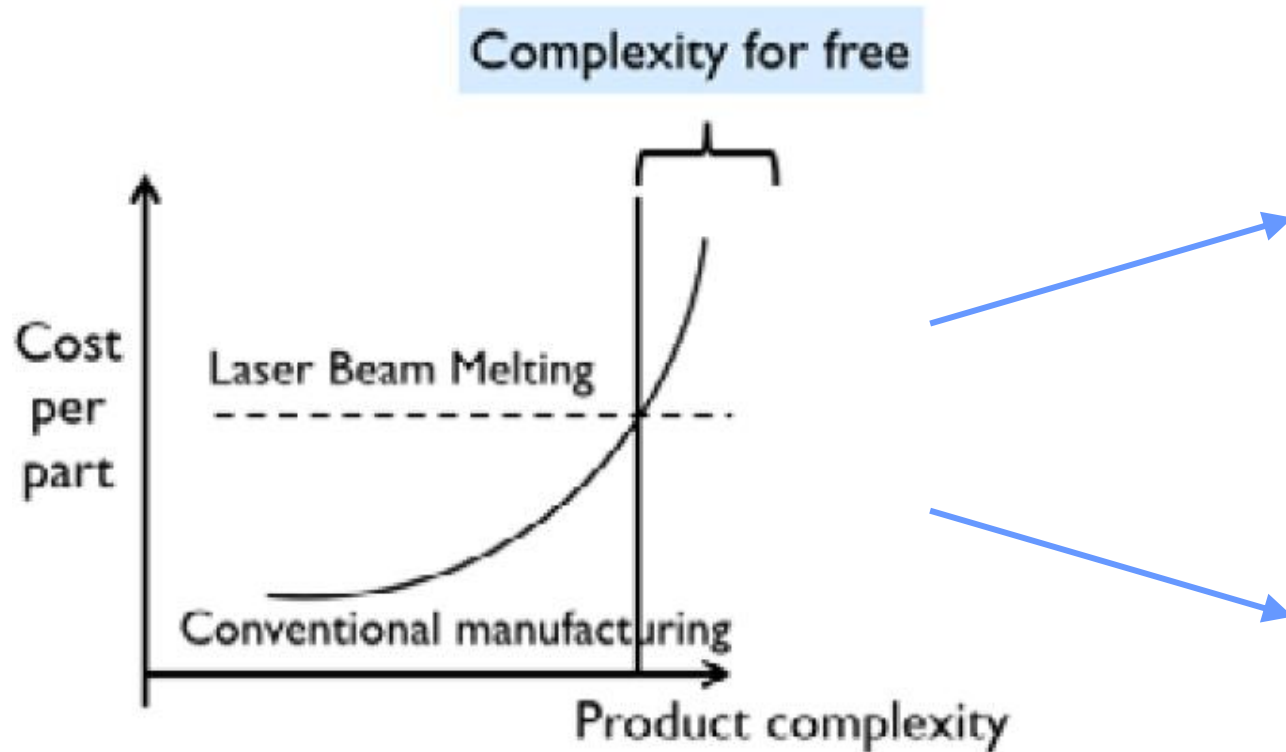


III. Additive



Introduction

Why do we do AM? Additive technologies enable part customization and increased design complexity at (almost) no cost compared to conventional manufacturing



Introduction

Why do we do AM? An example from the space sector

1. Design freedom
2. Material efficiency
3. Rapid prototyping
4. Part customization
5. On-demand production
6. Reduced lead times
7. Weight reduction
8. Part consolidation
9. Ability to repair and re-manufacture
10. Sustainability





AM technologies

Definition of additive technology

Additive Manufacturing → 3D Printing

“Additive Manufacturing is a process of joining materials to make object from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies”

ASTM Committee F42 on AM Technologies, 2012



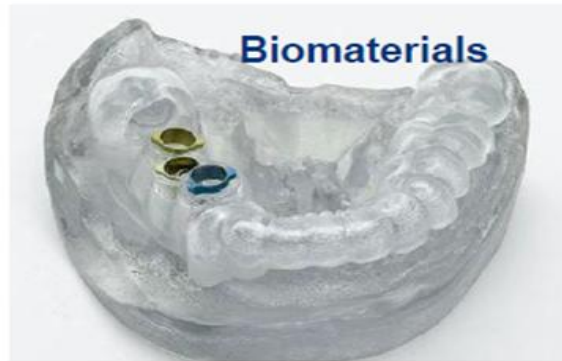
Definition of additive technology

The ASTM F42 standard identifies 7 categories:

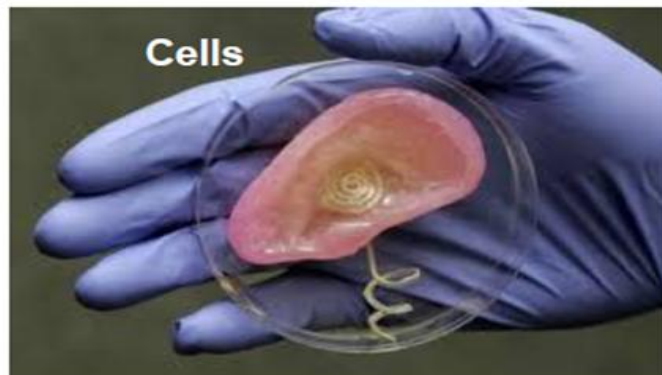
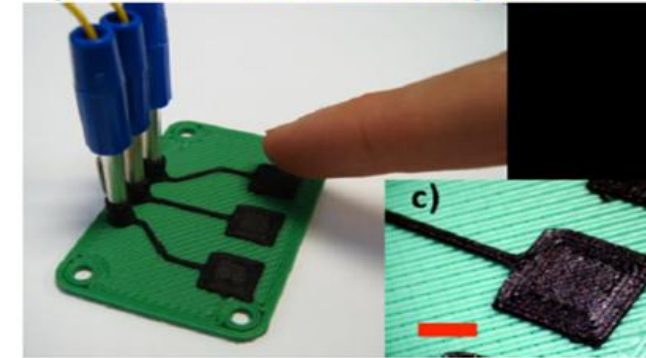
- 1) Binder Jetting (BJ)
- 2) Directed Energy Deposition (DED)
- 3) Material Extrusion (ME)
- 4) Material Jetting (MJ)
- 5) Powder Bed Fusion (PBF)
- 6) Sheet Lamination (SL)
- 7) Vat Photopolymerization (VPh)



Materials processable with AM



plastic and carbon composite

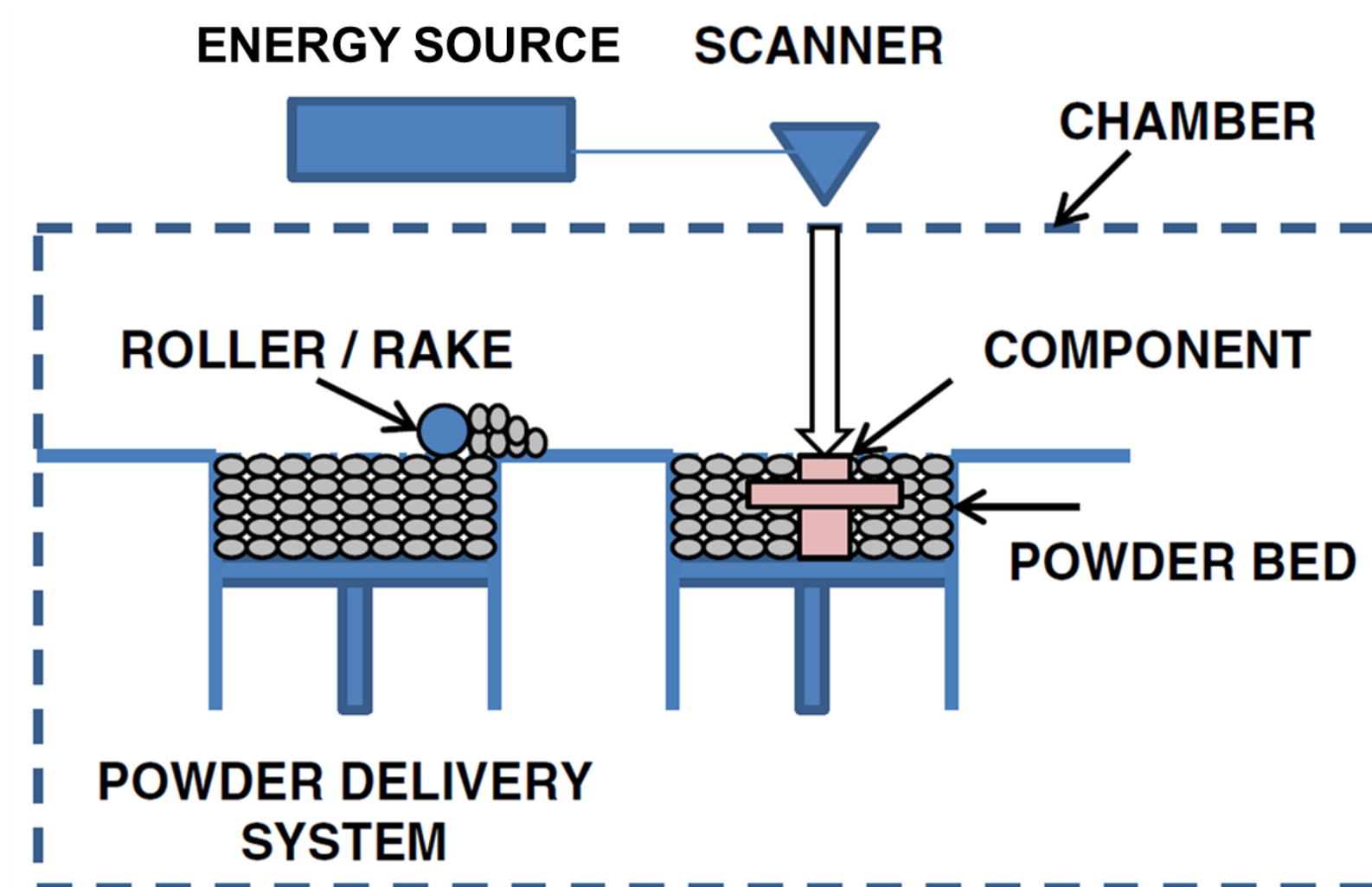


Chocolate



Powder Bed Fusion - PBF

Thermal energy to selectively melt regions of a powder bed



Powder Bed Fusion - PBF

Classification: based on **energy source** and **consolidation mechanism**:

- Selective Laser Sintering (SLS): **Laser** beam and **sintering** (low-melting secondary phase)
- Selective Laser Melting (SLM): **Laser** beam and **melting**
- Electron Beam Melting (EBM): **Electron** beam and **melting**

Process parameters:

Energy

- *Power*
- *Spot size*

Scanning

- *Speed*
- *Spacing*
- *Pattern*
- *Strategy*

Powder

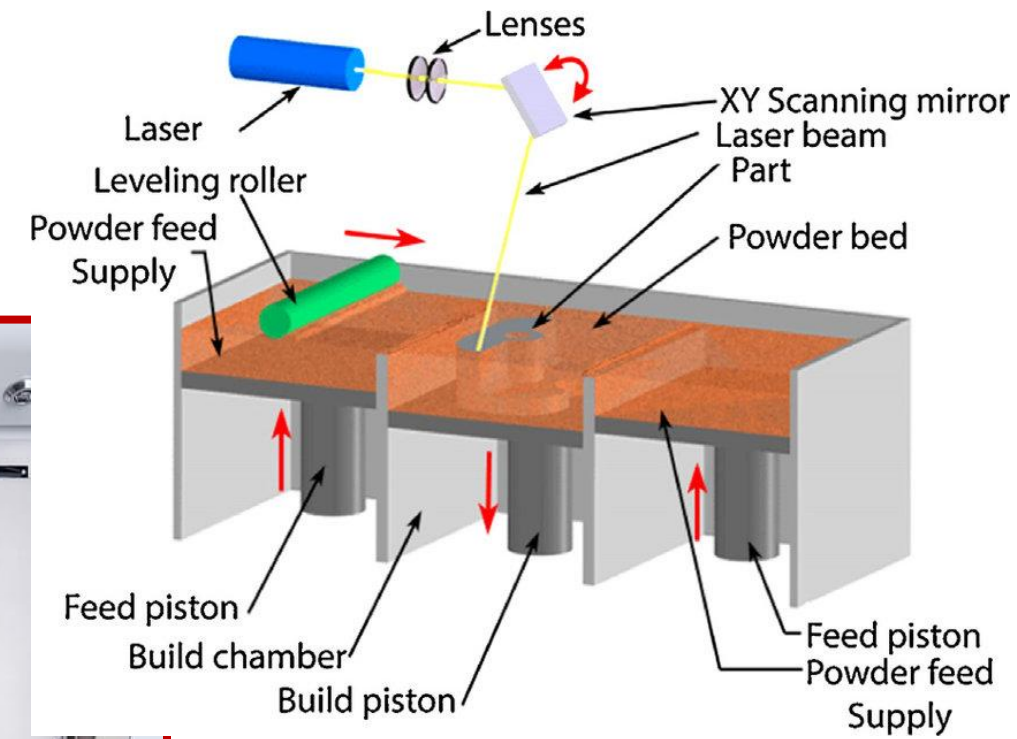
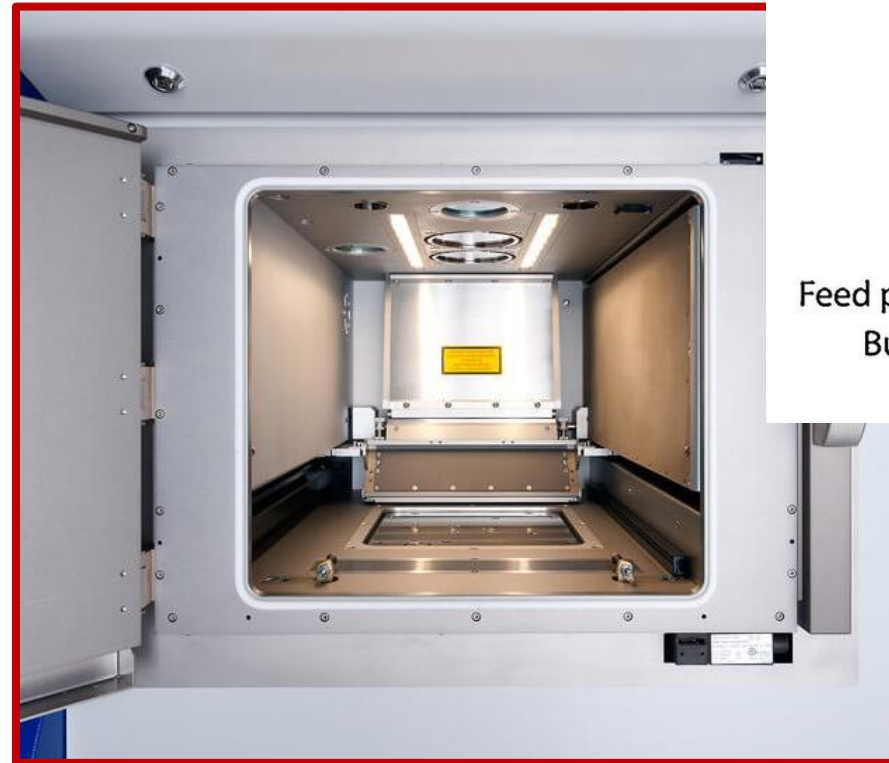
- *Form*
- *Size*
- *Size distribution*
- *Powder bed density*
- *Layer thickness*

Temperature

- *Powder bed*
- *Powder supply*
- *Uniformity*

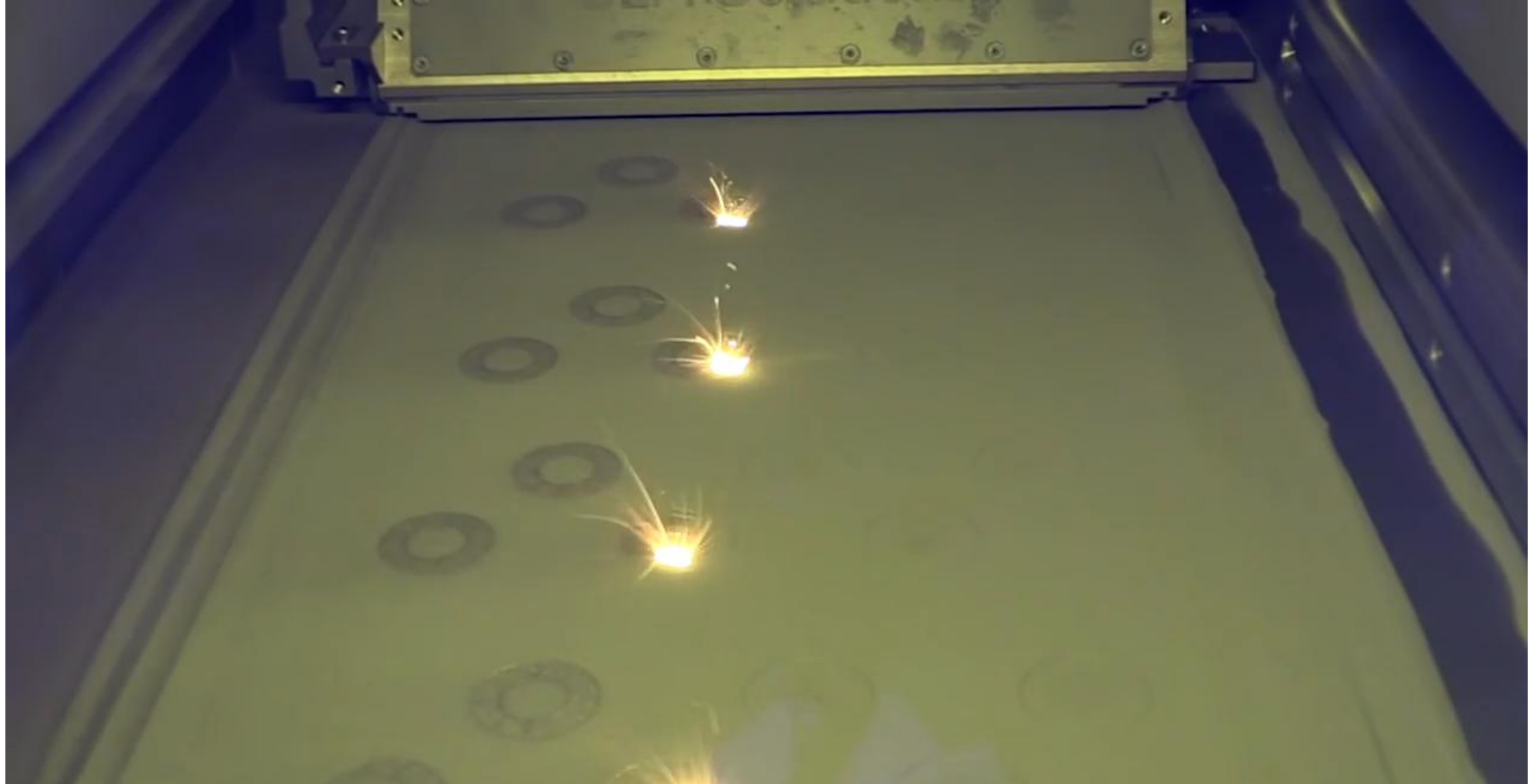
Powder Bed Fusion - PBF

Selective Laser Melting (SLM)



Powder Bed Fusion - PBF

Selective Laser Melting (SLM)

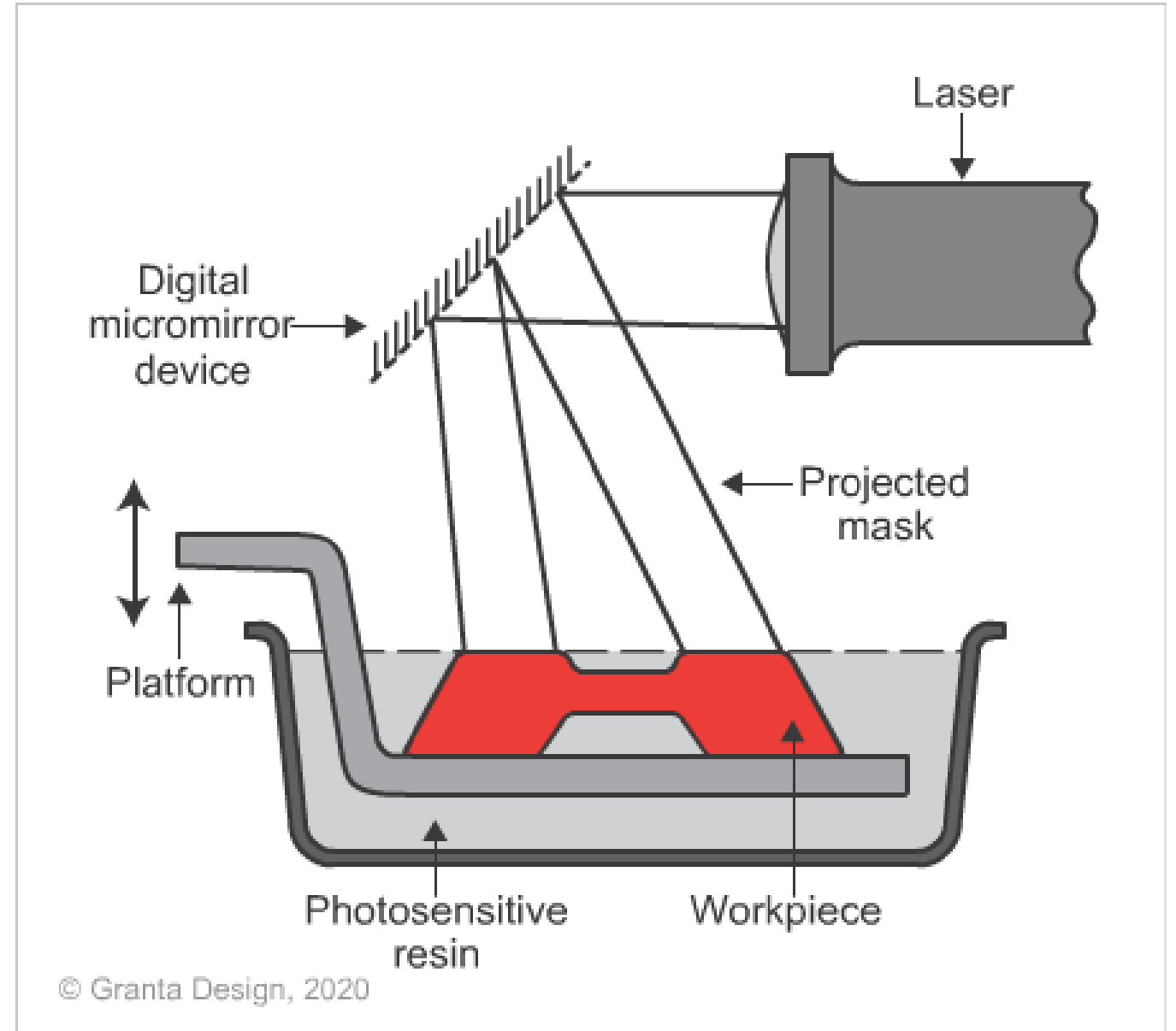


Vat-polymerization

Digital Light Processing (DLP)

- UV laser/lamp to project a cross-section of the object into a bath of liquid photo-sensitive polymer
- Cures an entire layer at once. When each layer is cured, the part is lowered on a platform into the bath to allow a new layer of liquid polymer to be wiped across the surface and the process repeated
- Cleaning followed by post-production UV curing is required to completely solidify the prototype

Process parameters?



Design for Additive Manufacturing (DfAM)

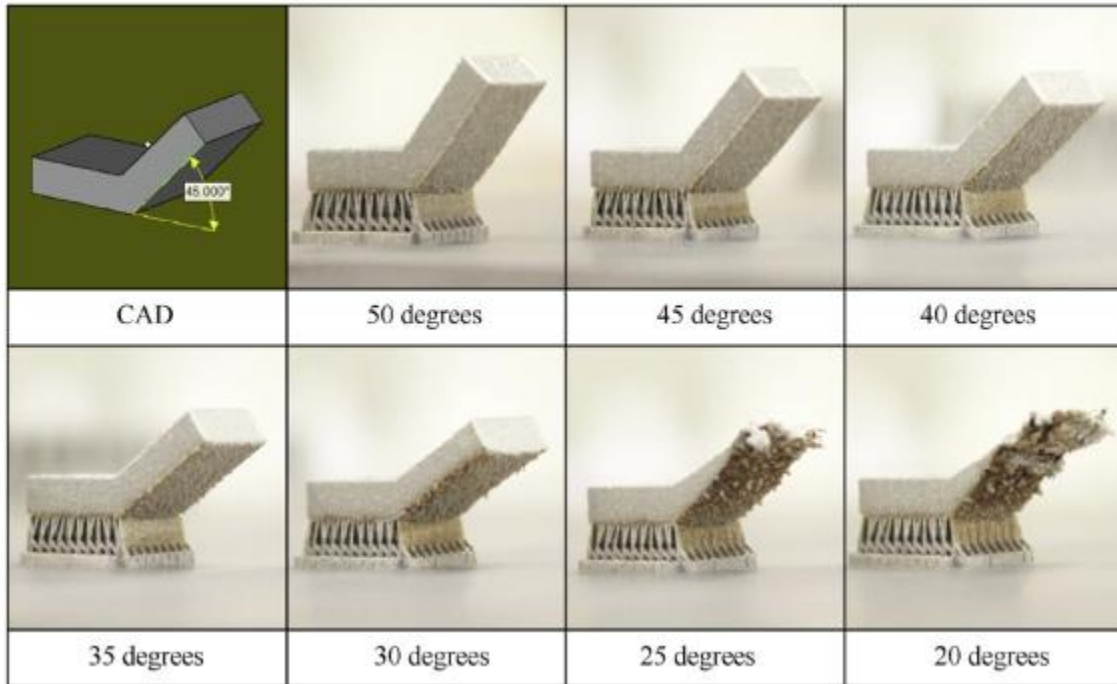
Desing aspects

Same problem → Multiple optimal design solutions



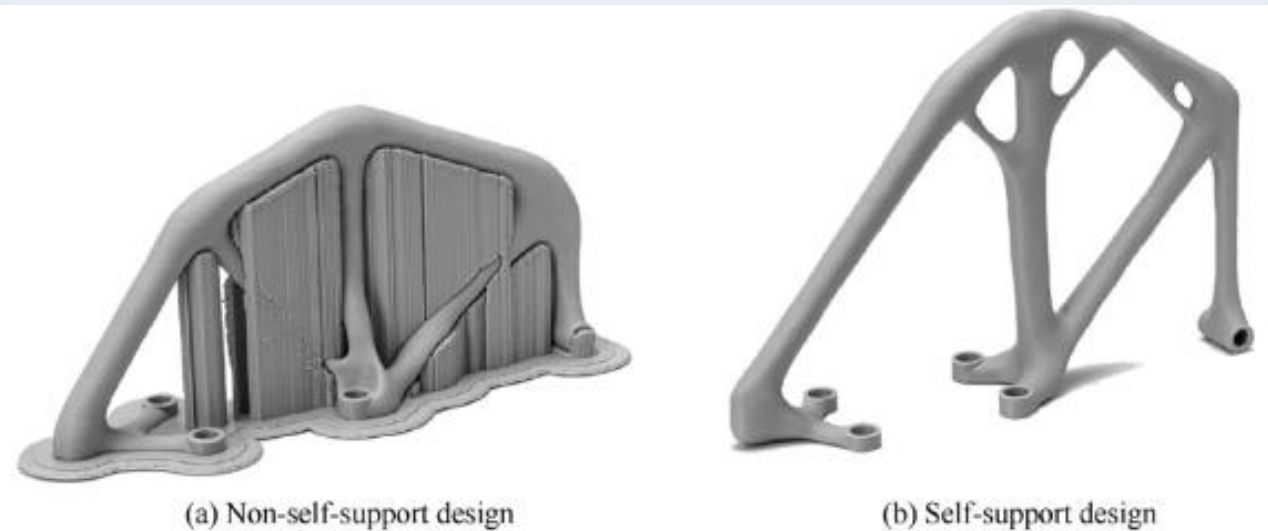
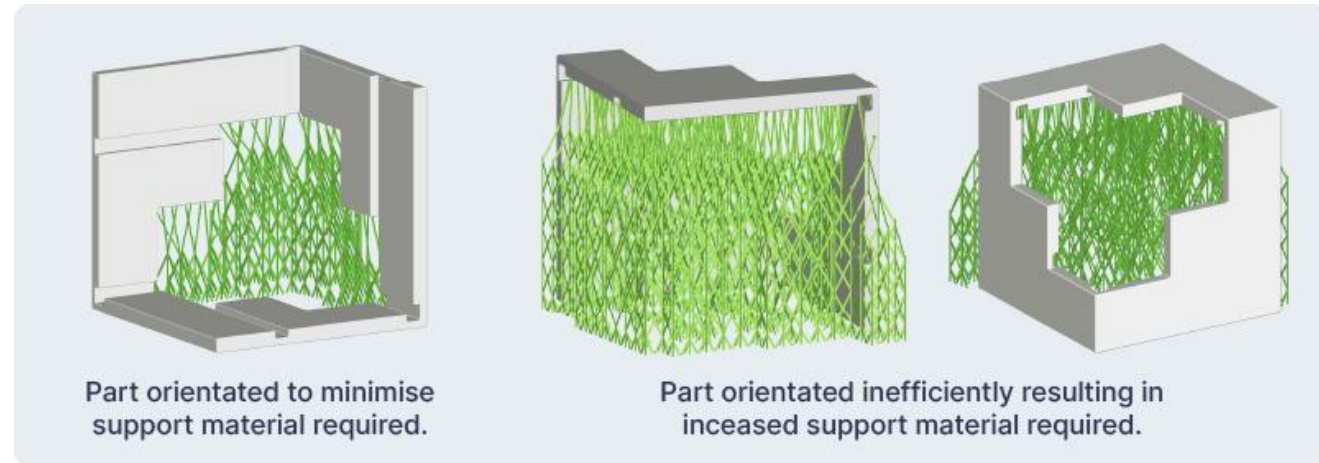
Design restrictions

Overhangs and supports



Correct overhang angle is crucial for AM

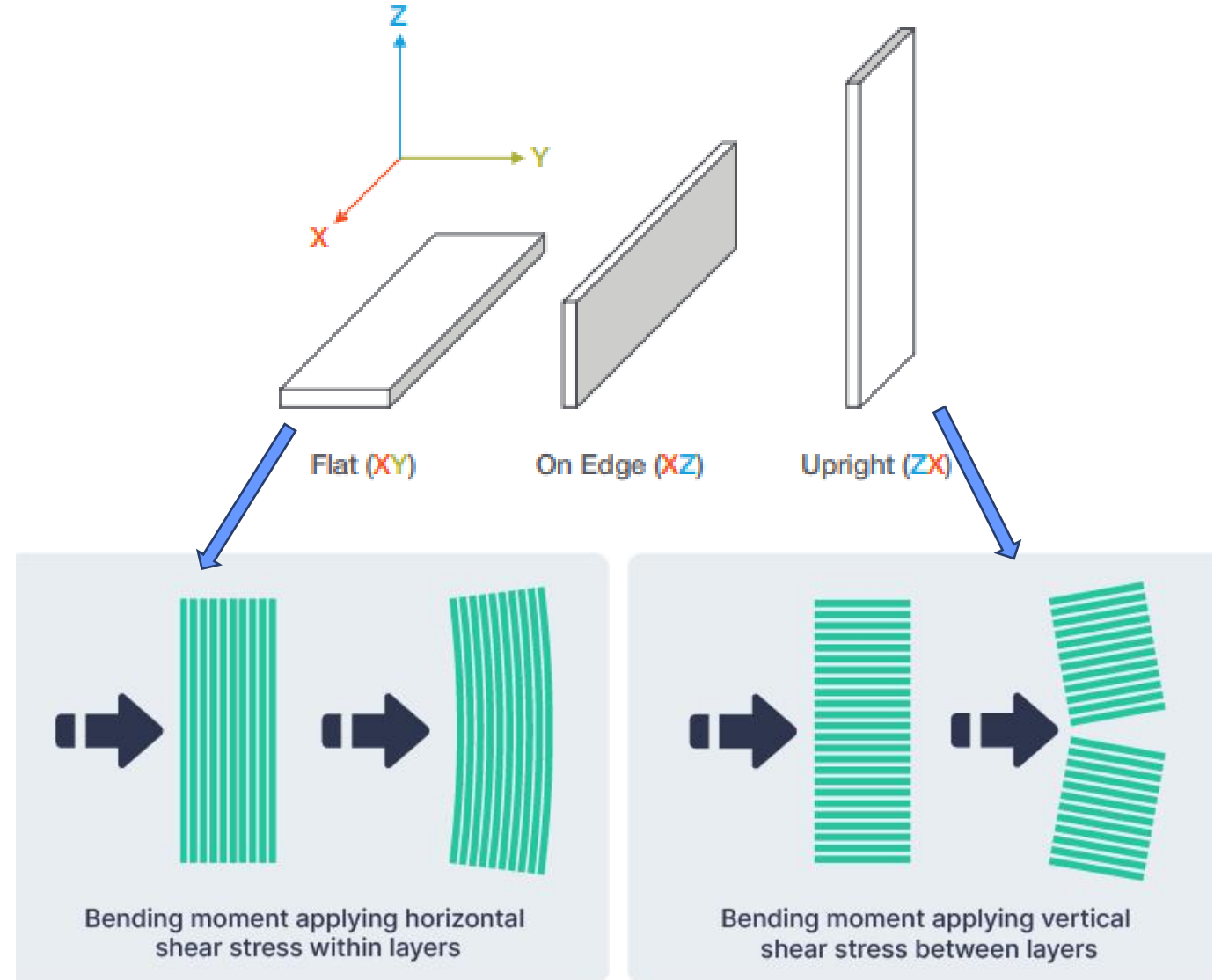
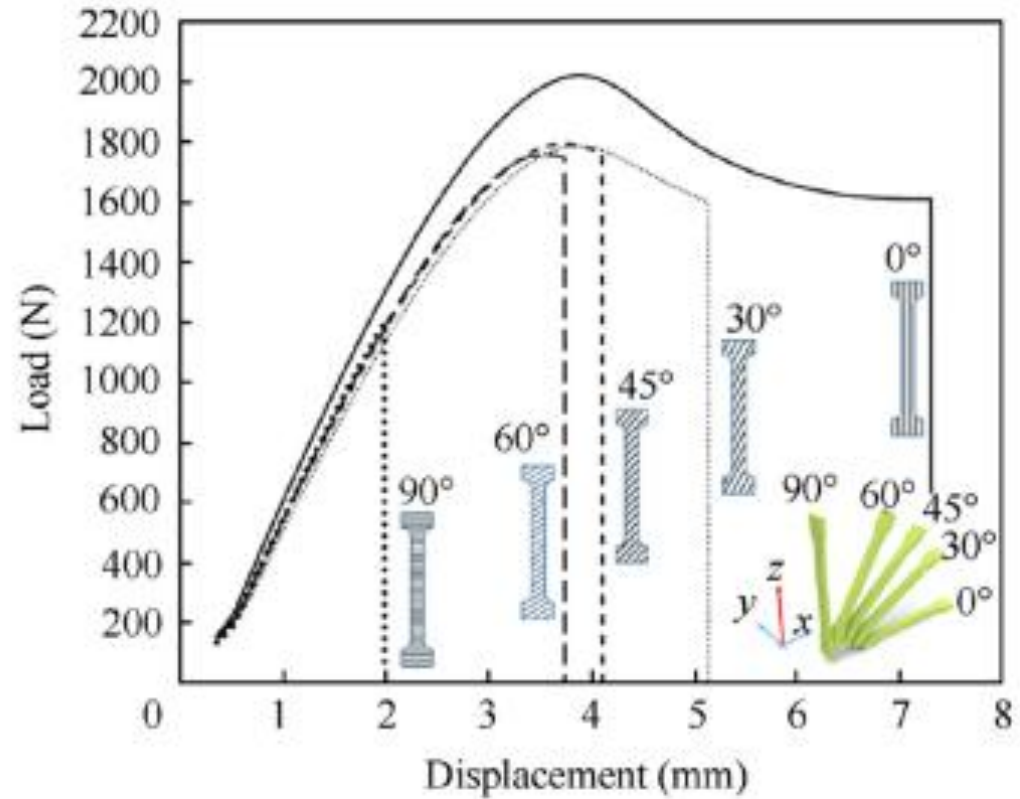
Zhu, J., et al. (2021). A review of topology optimization for additive manufacturing: Status and challenges. <https://doi.org/10.1016/j.cja.2020.09.020>



Effective support design is crucial to minimize post-processing and save material

Design restrictions / freedom

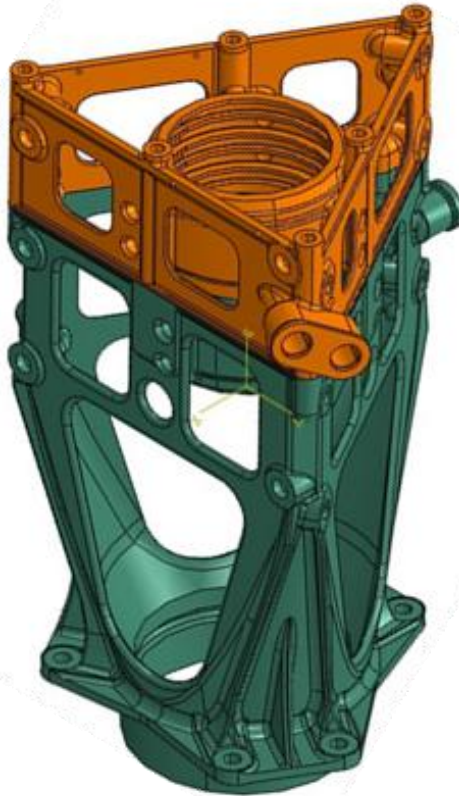
Printing orientation



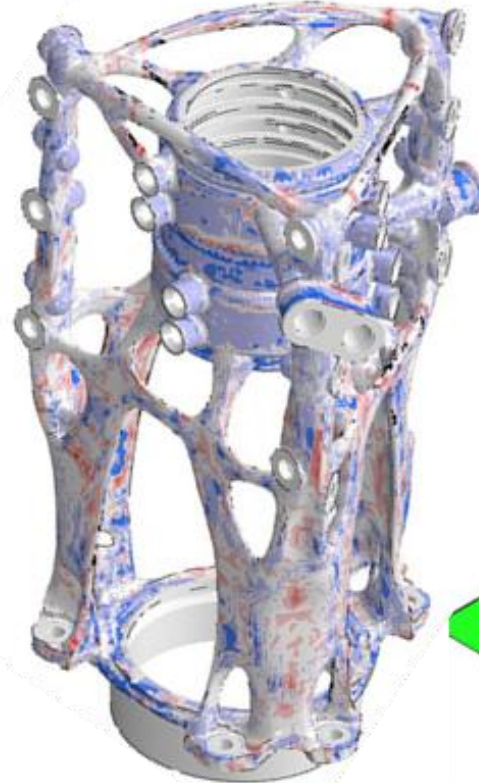
Design freedom

Design optimization (structural, functional, process ...)

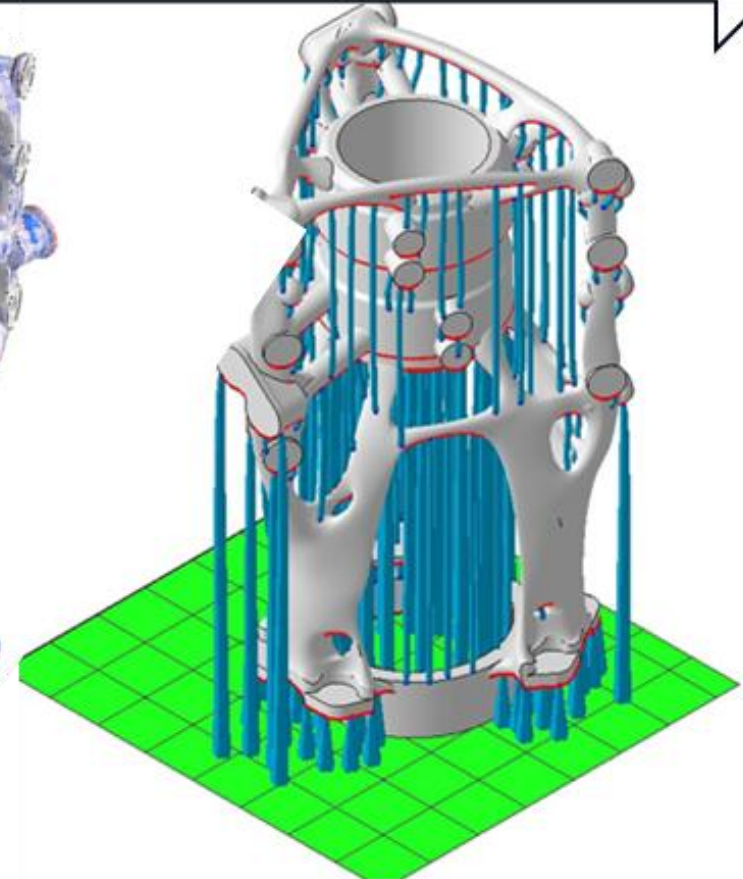
Traditional design



TO design



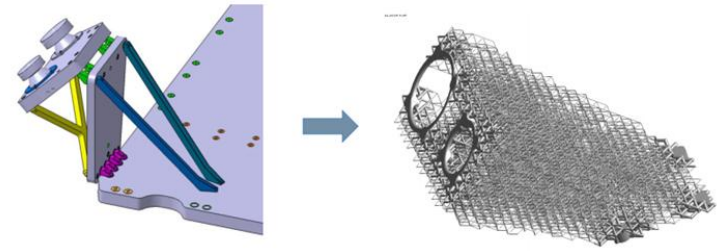
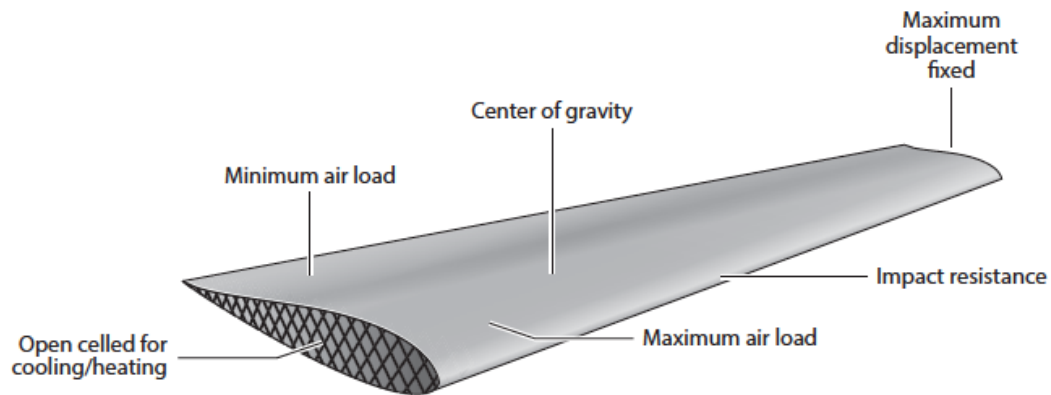
AM process optimization



Ferreira, R. J., Grande, A. M., Guedes, J. M., Deus, A. M., & Sala, G. (2023). Combination of topology and shape optimization with finite element modeling in the case of an aerospace component produced by laser based additive manufacturing. *Journal of Laser Applications*, 35(2).

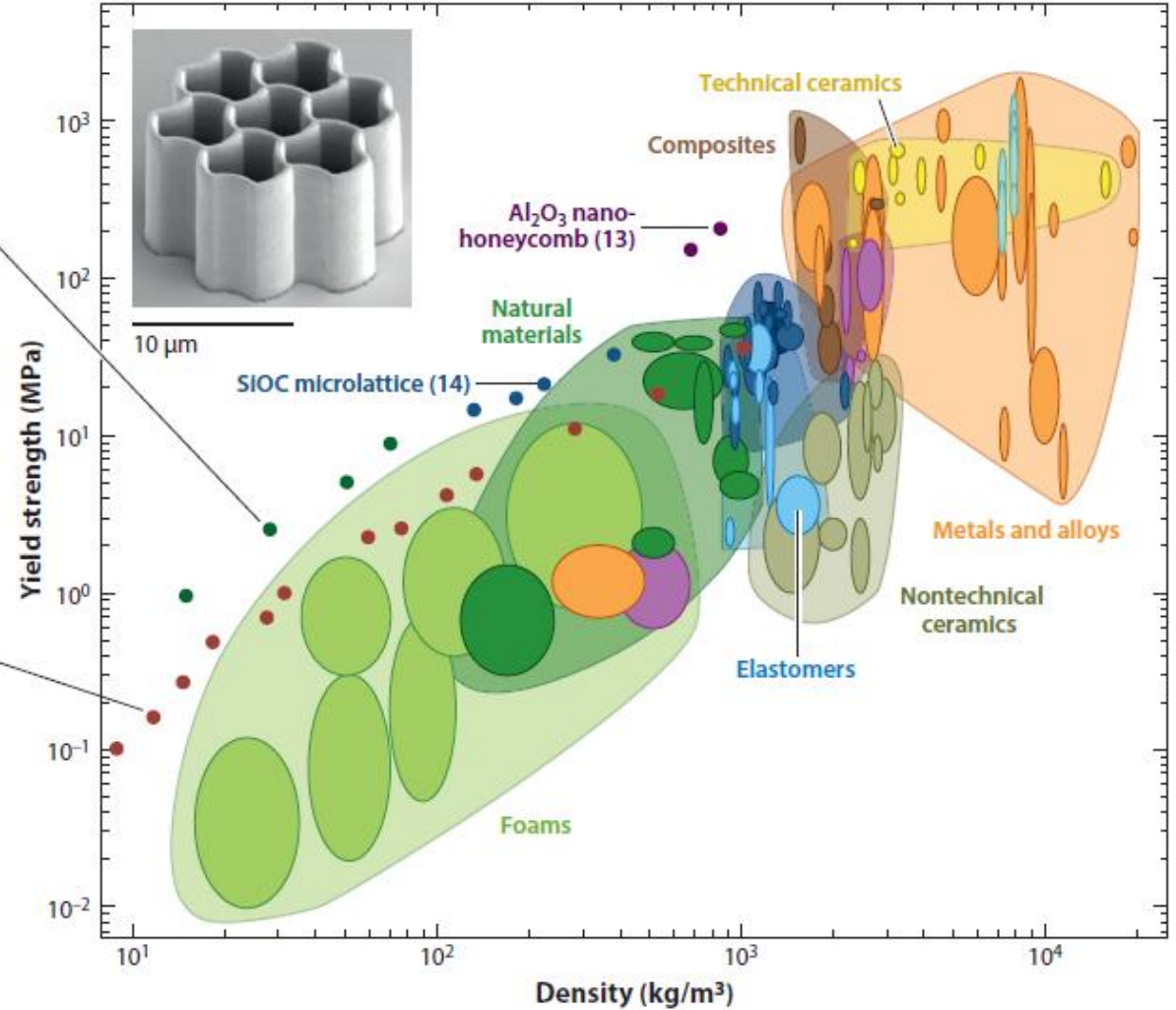
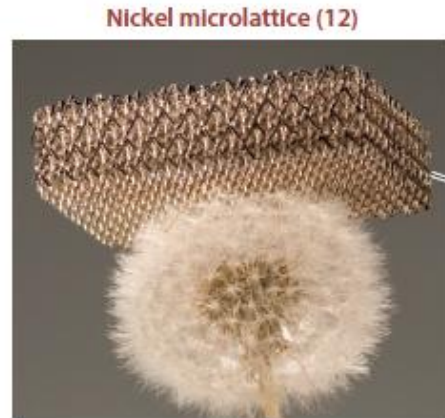
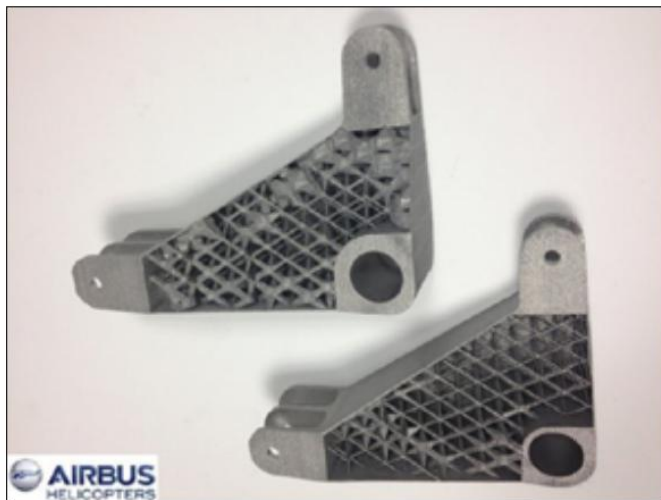
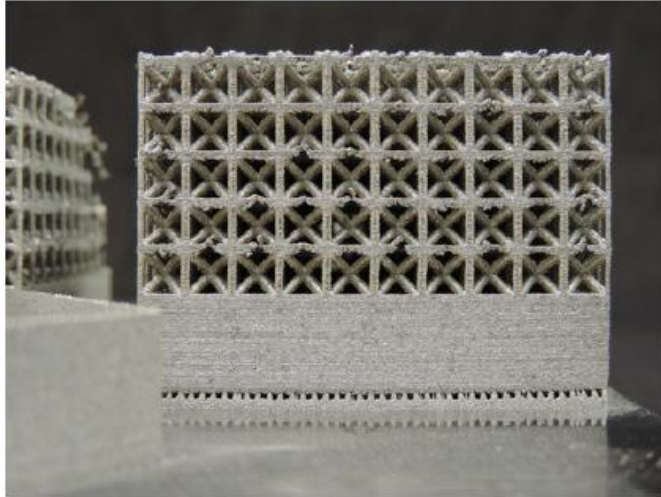
Design freedom

Bio-inspired structures

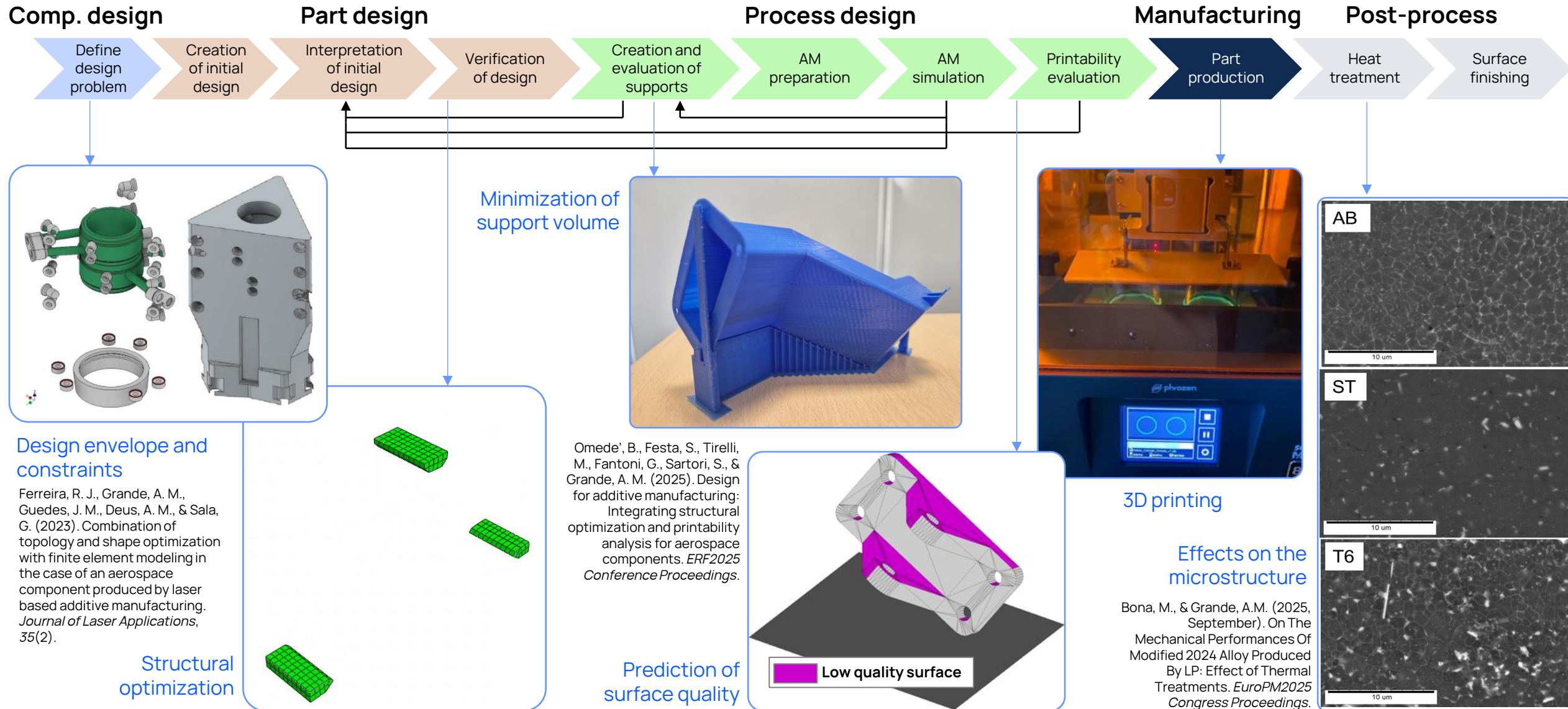


Design freedom

Lattice structures



DfAM workflow

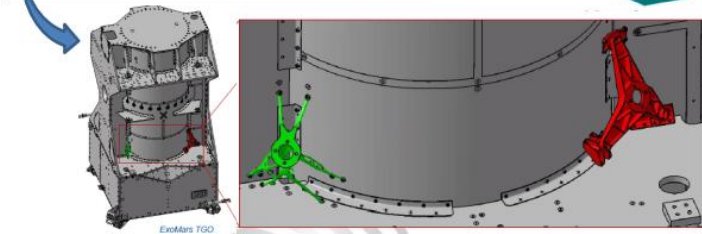
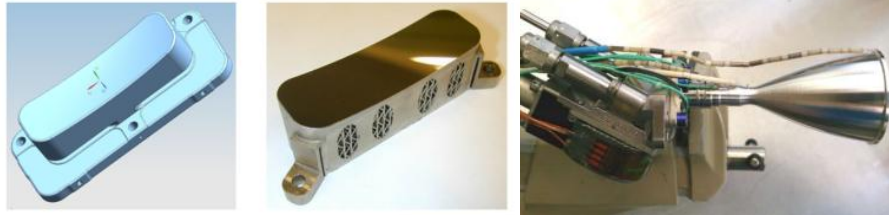




Future perspectives

AM for space

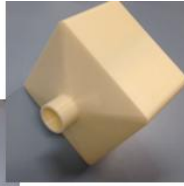
On Earth



On-Orbit



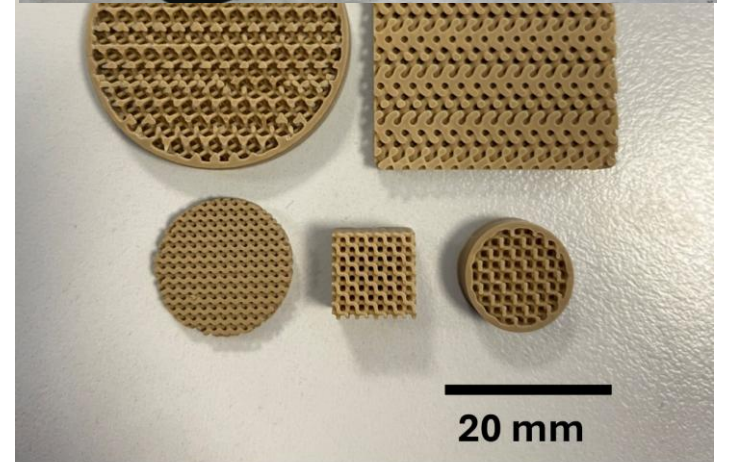
Source: NASA



Source: ESA contract 4000120112



On Planet (ISRU)



SMA by 3D printing

Optimization of printing parameters

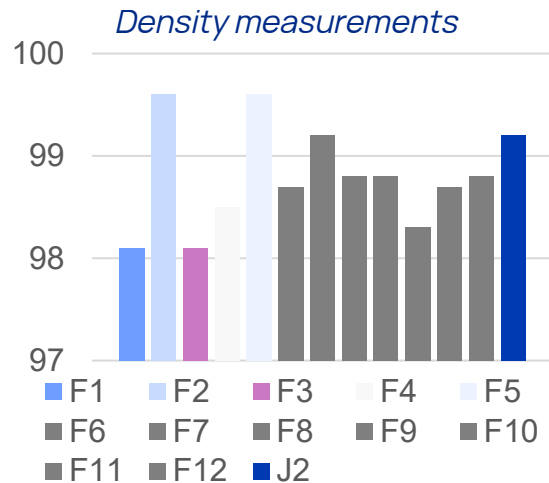
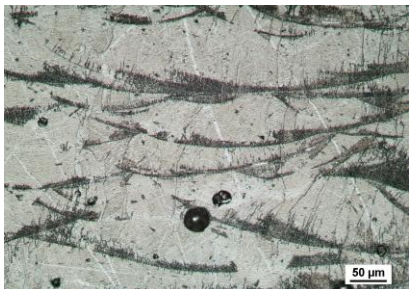
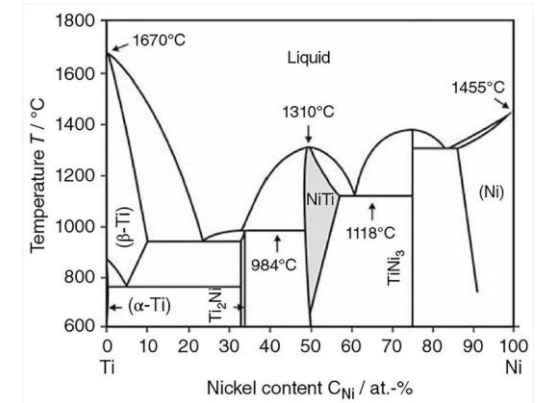
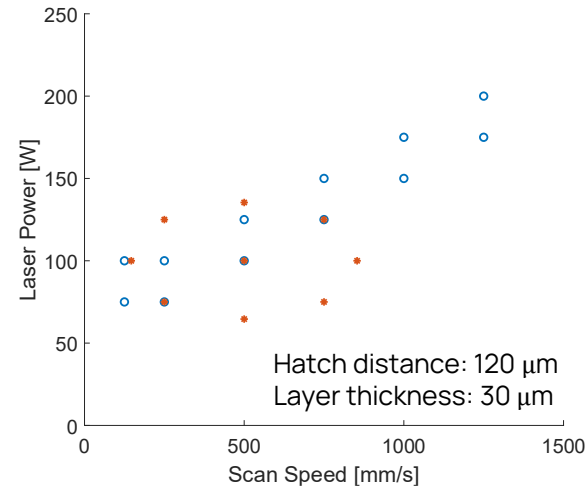
to avoid presence of **defects**

to optimize material **functionality**

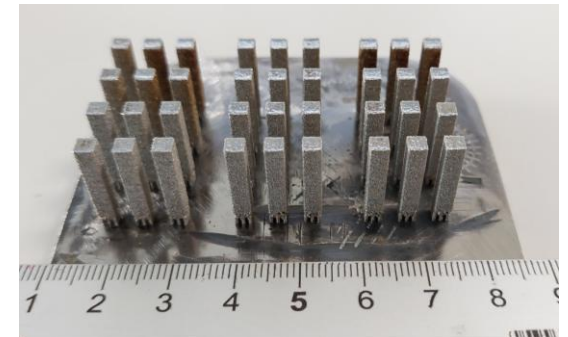
- Functionality of material depends on **Ni-Ti percentage** that changes during SLM process
- Two distinguished analyses for **pseudoelastic** and **shape memory effects**

Limits of SMA:

- **Poor workability** through traditional production processes
- **Sensitivity to composition**



Reduced presence of defects



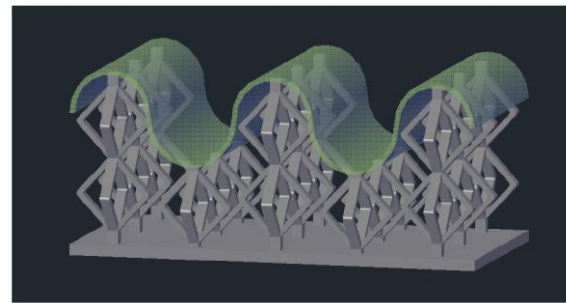
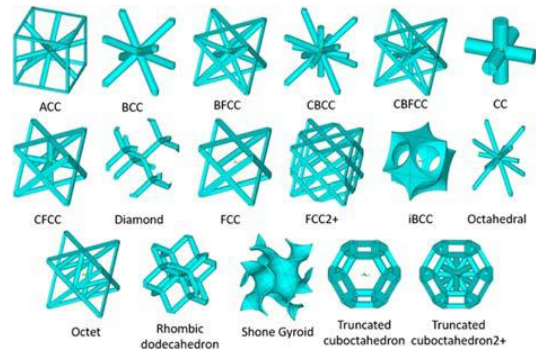
A. Nespoli, A.M. Grande; N. Bennato, D. Rigamonti, P. Bettini et al. (2021). Towards an understanding of the functional properties of NiTi by powder bed fusion. PROGRESS IN ADDITIVE MANUFACTURING, Vol. 6, 2021, p. 321-337

in collaboration with CNR – ICMATE

SMA by 3D printing

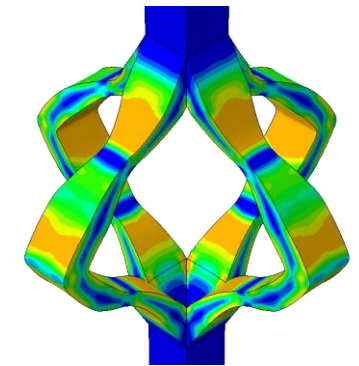
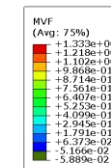
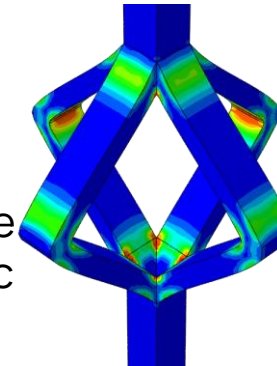
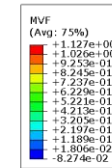
Study of Pseudoelastic effect

Target: Analyses **single cells** and then study their combination in a damping plate

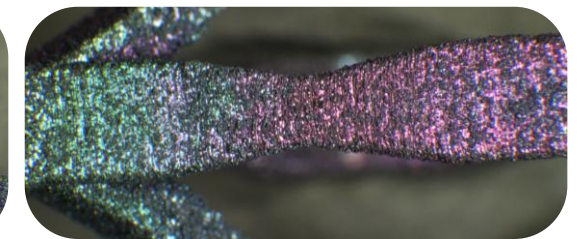
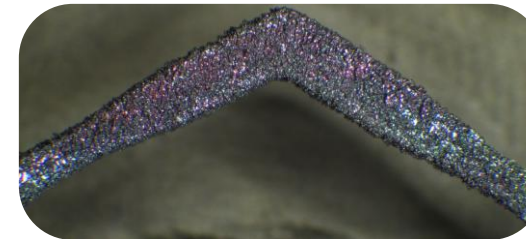


Selected parameters used to manufacture **octahedral cell**

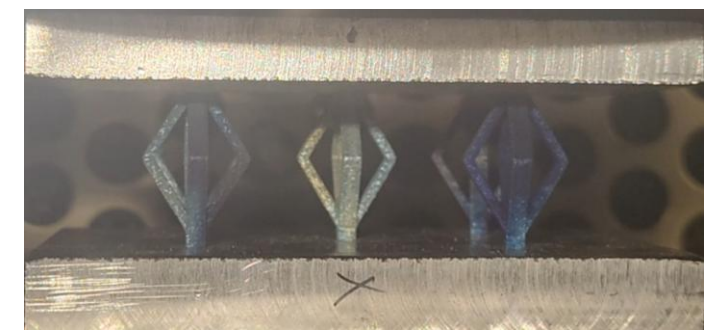
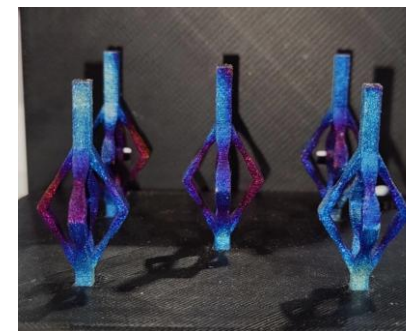
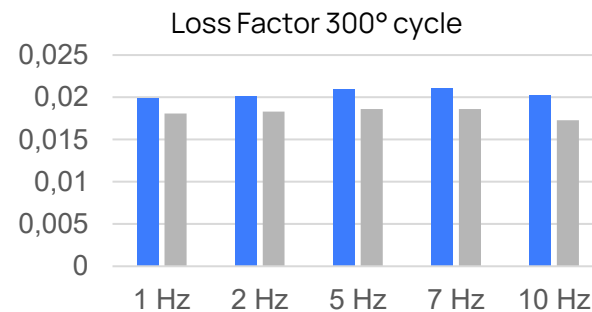
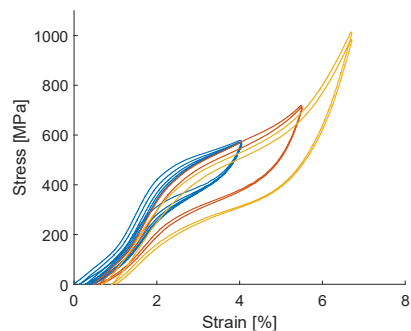
❖ Geometry optimization to increase structure functionality



Martensite
Volumetric
Fraction



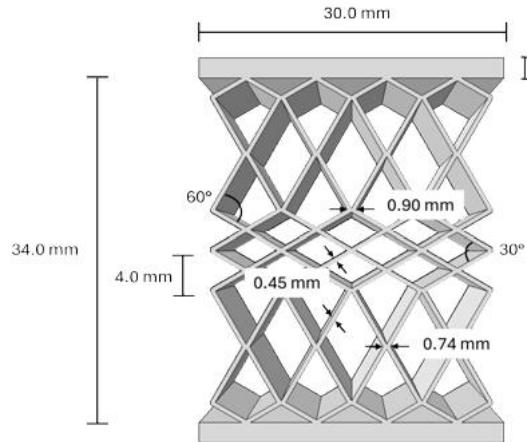
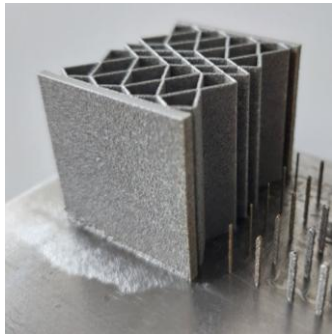
❖ Tests on a damping plate



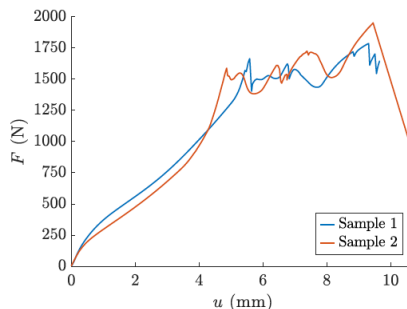
SMA by 3D printing

Study of Shape Memory Effect

Target: Selected parameters used to manufacture **origami structure** for shape memory effect

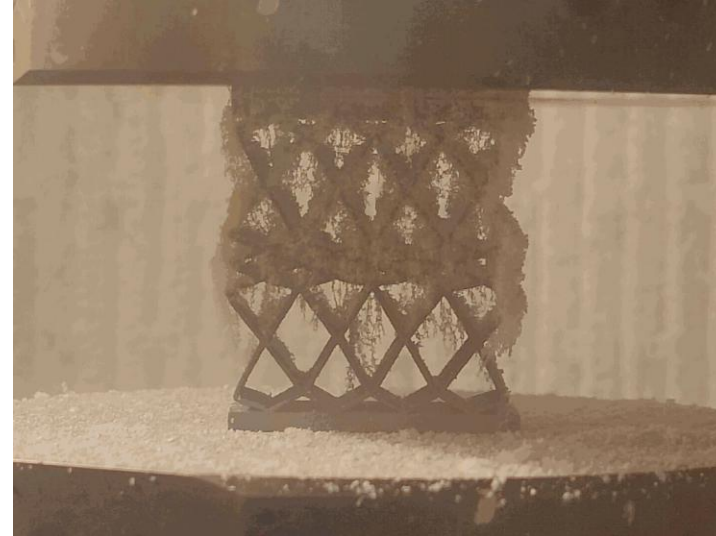


Control the **mechanical characteristics** of the structure changing the **temperature**



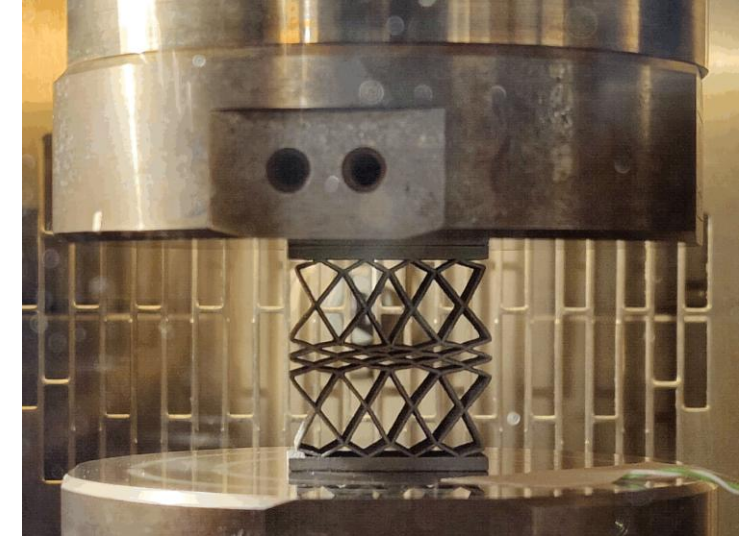
❖ Deployment of an origami structure after compression

Free recovery
(actuator works free)



- Initial deformation: 4 mm through the application of 1000 N at -40°C (**MARTENSITE microstructure**)
- Activation: heating from -40°C at $+80^{\circ}\text{C}$ (to guarantee complete transformation in Austenite)
- Received deformation: 4mm (50% of initial length of central part)

Constrained recovery
(actuator works against a load)



- Initial deformation: 1,9 mm through the application of 1000 N at $+25^{\circ}\text{C}$ (**ROMBOEDRIC microstructure**)
- Activation: heating from 25°C at $+80^{\circ}\text{C}$ (to guarantee complete transformation in Austenite)
- Received deformation: 1,9 mm (24% of initial length of central part)

Lunar Regolith by 3D printing

Ceramics by VAT photopolymerization

Research problem:

- **Optical properties** of lunar regolith, lead to **slow printing speeds and limit its processability** via VP AM.
- **Heterogeneous mineral composition** of LR narrows fabrication and exploitation parameters (**low strength and working temperatures**)

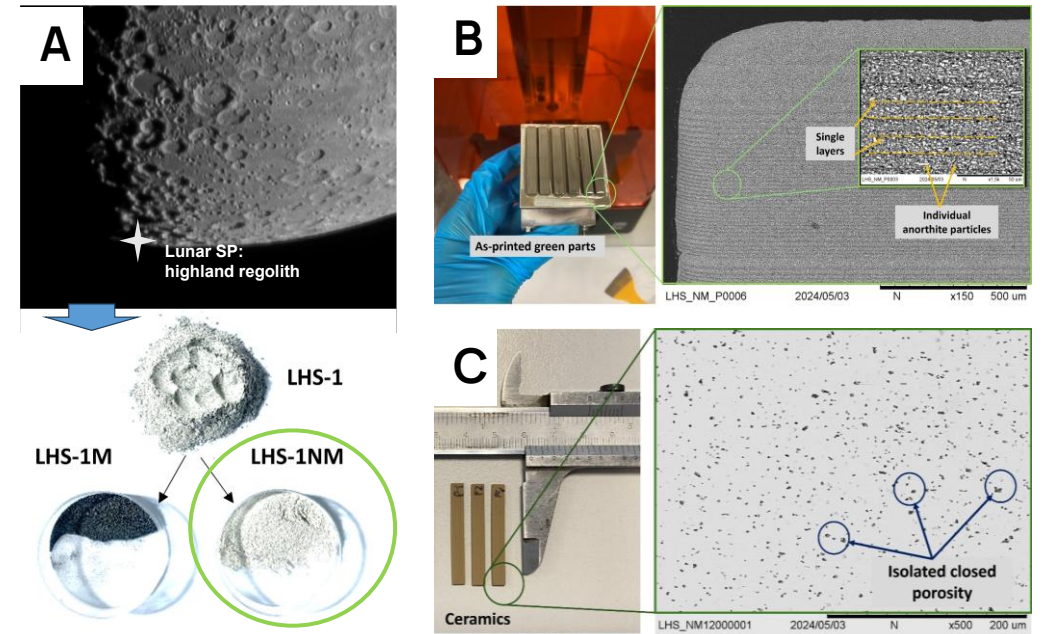
Our solution:

- **Magnetic refinement** of highland LR composition to increase the content of **non-magnetic anorthite ($\text{CaAl}_2\text{Si}_2\text{O}_8$)**

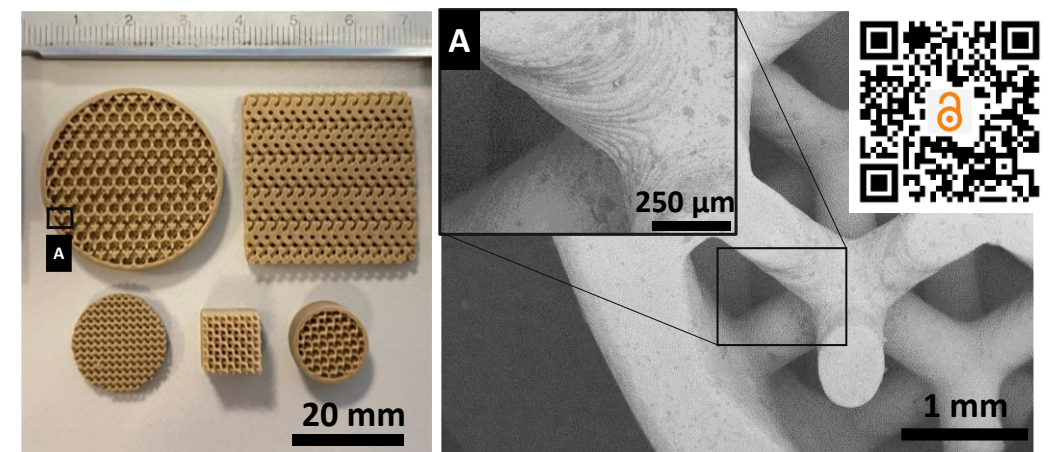
Outcomes:

- **10x faster prints** (potentially 15-20x faster with thicker layers and optimal printing settings)
- **Increased mechanical strength and operating temperature (up to 1500°C)**

Isachenkov, M., Grande, A. M., Mariani, M., Lecis, N., Casati, R., Silvestroni, L., & Sala, G. (2025). Magnetic beneficiation – A novel approach to facilitate additive manufacturing of lunar regolith ceramics by vat photopolymerization. *Additive Manufacturing*, 109, 104863. <https://doi.org/10.1016/j.addma.2025.104863>



Principle of regolith beneficiation (A), As-printed green parts (B) and sintered (C) ceramic specimens, produced from beneficiated regolith



Demonstrative ceramic lattice parts (left) and their microstructure (right)

Conclusions

Why AM is good for the space industry (applicable to other fields)?

1. Perfect for a very small parts' series
2. Very complex geometries possible
3. Large variety of materials: metals, polymers, composites, ceramics, even living cells, and organs
4. Dimensions range from a few micrometers to meters
5. Gains in performances with 2 digits: mass saving 40 to 90%, lead time reduced by weeks, suppress complex assemblies and controls
6. Environmentally friendly
7. Could be used in-orbit or on other planets



Thanks for your attention

Contact: antoniomattia.grande@polimi.it