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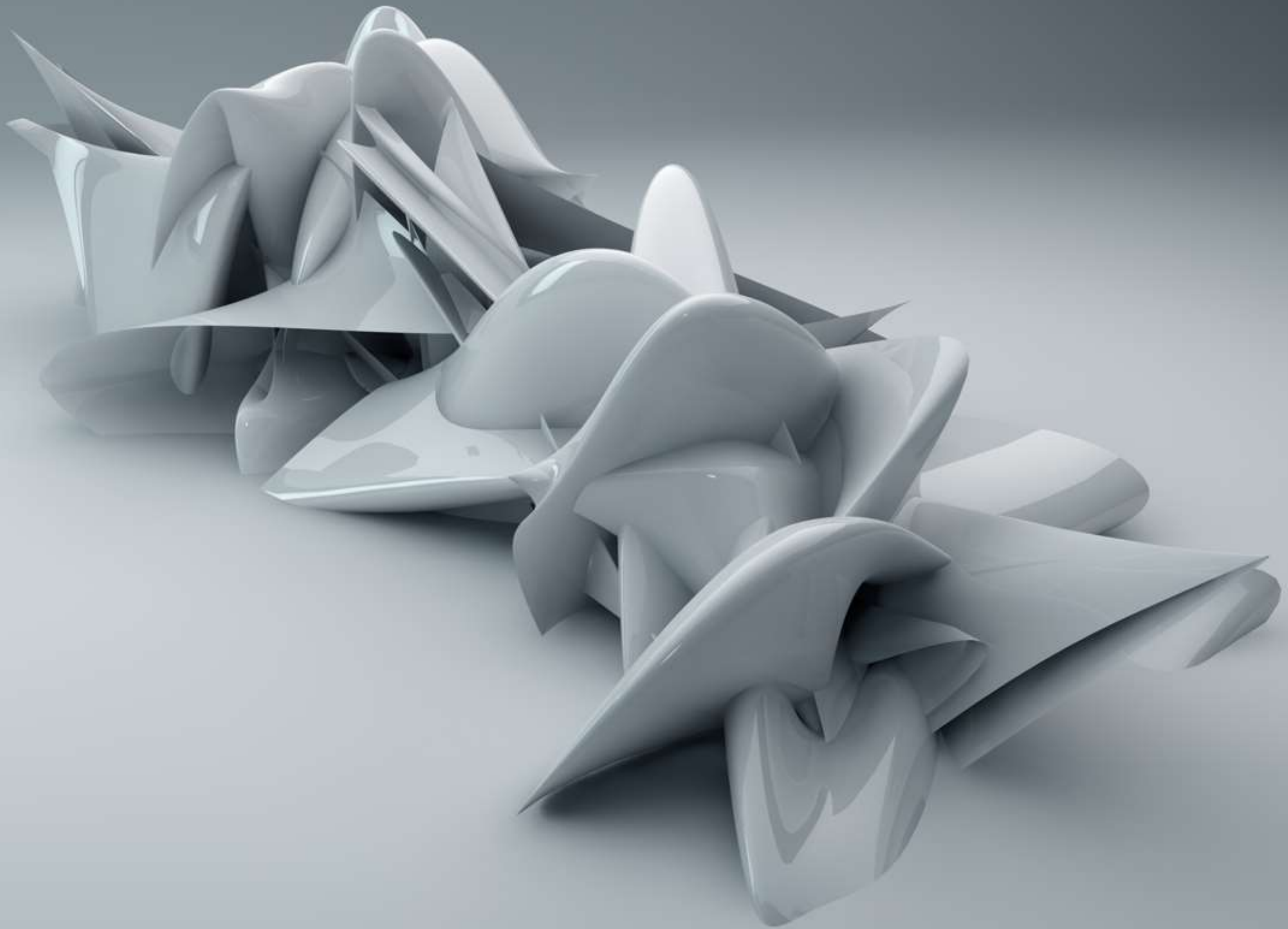
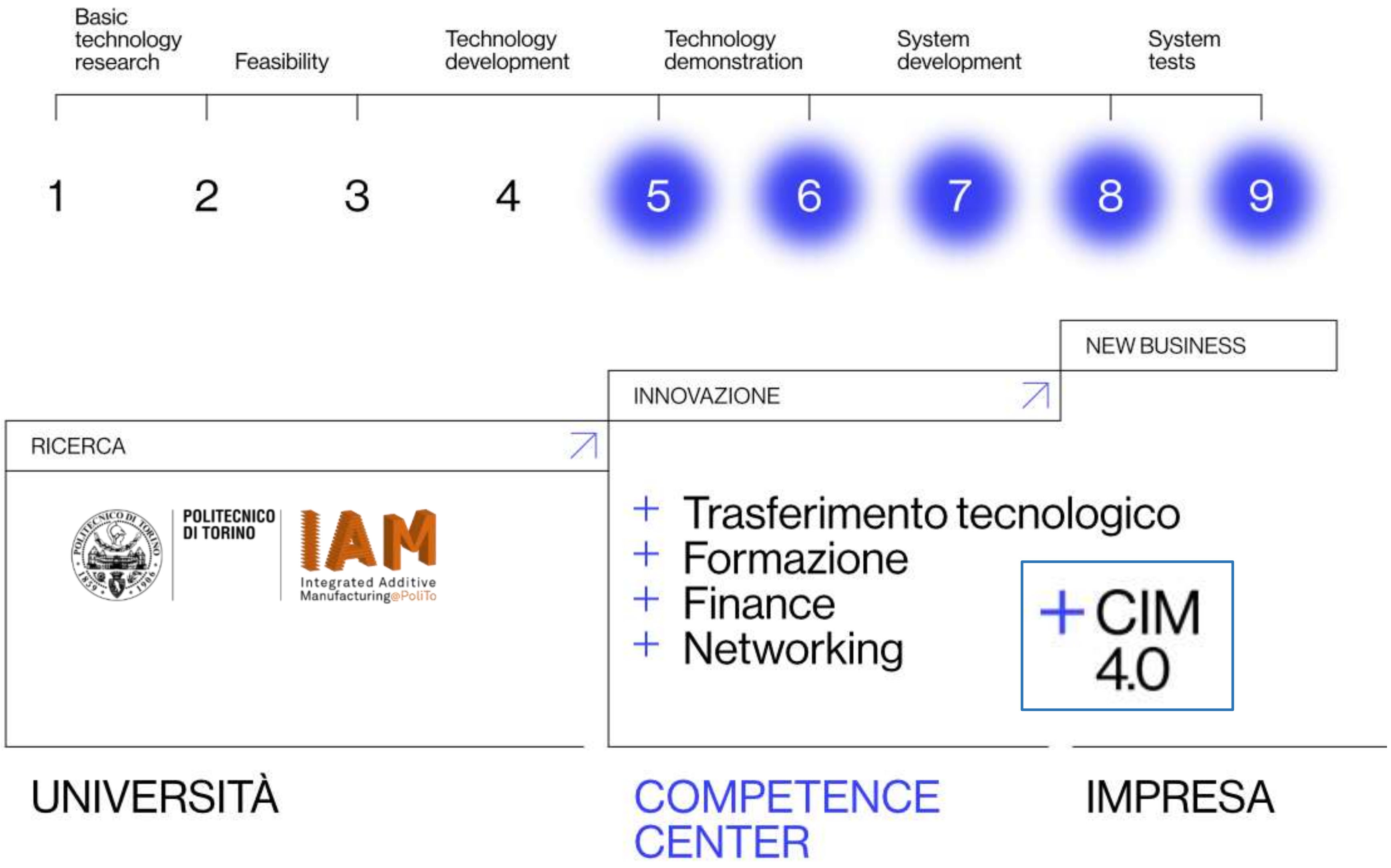
DI TORINO

IAM
Integrated Additive
Manufacturing@PoliTo



Approach and Focus



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GENESIS of SKILLS

At **Politecnico di Torino**, the **first studies** related to **AM** were carried out by the DIGEP research group of **Prof. Ippolito** and **Prof. Iuliano** in the **early 90's**, when layer-by-layer technologies were renowned as **Rapid Prototyping (RP)**...

1991 – **European project on Rapid Prototyping Program** BRITE – EURAM

1995 – **First paper of AM in the International Journal**[1]

1996 – **First paper of AM Metal**[2]

2004 – **First paper on DFAM in the International Conference**[3]

2005 – Start **collaboration** with the **materials research group** (**Prof. Fino**)

TECNOGRANDA innovazione tecnologica e servizi alle imprese

1. R. Ippolito, L. Iuliano, A. Gatto. Benchmarking of Rapid Prototyping Techniques in Terms of Dimensional Accuracy and Surface Finish. CIRP Annals Elsevier
2. R. Ippolito, L. Iuliano, A. Gatto. EDM tooling by solid freeform fabrication and electroplating techniques Proc. of 7th Solid Freeform Fabrication Symposium, Austin 12-14 August, Texas, USA
3. E. Bassoli, A. Gatto, L. Iuliano, F. Leali. Design for manufacturing of an ergonomic joystick handgrip TSI Press Proceedings of the Sixth Biannual World Automation Congress, Seville (Spain)

AM@PoliTo

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AMTech Research Group

Politecnico di Torino
Department of Management and Production Engineering

Prof. Luca Iuliano
Full Professor

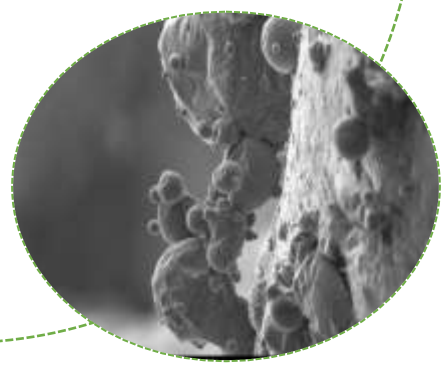
CAD/CAE/CAM
3D scanning systems
Advanced CNC machining
Additive manufacturing

THE γ TEAM

Politecnico di Torino
Applied Science and Technology Department

Prof. Paolo Fino
Full Professor

Material Science
and Technology



COLLABORATIVE ACTIVITIES WITH

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AM@POLITECNICO DI TORINO

2005

TECNOGRANDA
innovazione tecnologica e servizi alle imprese

EOSINT M250
(EOS GmbH)

2007

REGIONAL RESEARCH PROJECT
COLLABORATION WITH AVIO AERO IN THE DEVELOPMENT OF EBM PRODUCTION OF TITANIUM ALLUMINIDE BLADES.

Avio Aero
A GE Aviation Business

2010

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START OF COLLABORATIVE ACTIVITIES WITH IIT

EOSINT M270
(EOS GmbH)

2015

PARTNERSHIP
PRIMA INDUSTRIE – POLITO
EUROPEAN RESEARCH PROJECT
(**E-BREAK**, **AMAZE**, **HELMET**, **BOREALIS**, ETC)

PRIMA INDUSTRIE

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RESEARCH RESULTS

ARTICLES

Over 200 articles on International Conferences /Journals

PATENT 2012

HAND EXOSKELETON

Lightweight, Integrated joints

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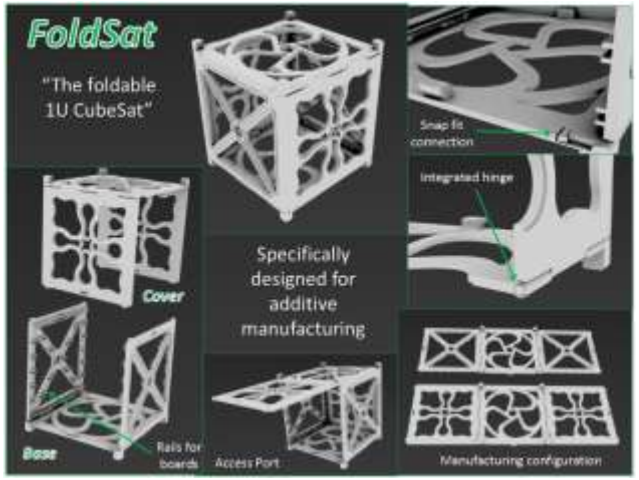
Inventors:
Eleonora ATZENI, Enrico BRUNO, Flaviana CALIGNANO, Diego MANFREDI, Elisa AMBROSIO

1ST PLACE CUBESAT CHALLENGE WINNER 2015



FOLDSAT *By Paolo MINETOLA, Giovanni MARCHIANDI*

3rd PRIZE

within Award for the best project from Partners and Consortia - 2017

JTI Clean Sky project GETREADY

Sara BIAMINO, Daniele UGUES

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ISTITUTO ITALIANO DI TECNOLOGIA

The acquired knowledge of the individual groups involved in the IAM@PoliTo centre represents an optimal starting point to begin a new, more ambitious and complicated route that can only be faced thanks to the skills of the various individuals that are involved

DIGEP *

Department of Management and Production Engineering

Prof. Luca Iuliano

Project Manager IAM@PoliTo

40 Researchers

60 Research Fellows / PhD Students

DAUIN

Department of Control and Computer Engineering

Prof. Enrico Macii

Persons in charge

IAM

Integrated Additive Manufacturing@PoliTo

DISAT *

Department of Applied Science and Technology

Prof. Paolo Fino

Persons in charge

DET

Department of Electronics and Telecommunications

Prof. Guido Perrone

Persons in charge

DIMEAS

Department of Mechanical and Aerospace Engineering

Prof. Massimo Rossetto e Prof. Terenziano Raparelli

Persons in charge

* **Excellence Departments**

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IAM Integrated Additive Manufacturing@PoliTo

DIGEP

DEPARTMENT OF MANAGEMENT AND PRODUCTION ENGINEERING

Luca Iuliano
Full Professor

Eleonora Atzeni
Associate Professor

Flaviana Calignano
Assistant Professor

Manuela Galati
Assistant Professor

Paolo Minetola
Associate Professor

Abdollah Saboori
Assistant professor

Alessandro Salmi
Associate Professor

Giovanni Marchiandi
Senion Technician

Paolo Antonioni
Research Fellow

Alessandro Bove
Research Fellow

Oscar Di Mauro
PhD student

Luca Fontana
PhD student

S. Khandpur Mankirat
Research Fellow

Erika Lannunziata
Research Fellow

Vincenza Mercurio
Research Fellow

Adriano Pilagatti
PhD student

Gabriele Piscopo
PhD

Mirna Poggi
PhD student

Giovanni Rizza
PhD student

Vito Stiuso
Research Fellow

Giuseppe Vecchi
Research Fellow

Marco Viccica
PhD student

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Avio Aero
A GE Aviation Business

TAL
TURIN ADDITIVE LABORATORY

IAM@POLITO METAL & POLIMER INVESTMENTS

2015
2016
2017
2018
2019
2020
2021
2022

PRIMA INDUSTRIE

IAM
Integrated Additive Manufacturing@PoliTo

HUB – DIMA Industria 4.0
Getready
Cluster
Borealis
Helmet
4D-Hybrid
STAMP
AMable
Newteam
HUC
MANUELA
EIT MANUFACTURING

METAL

POLYMER

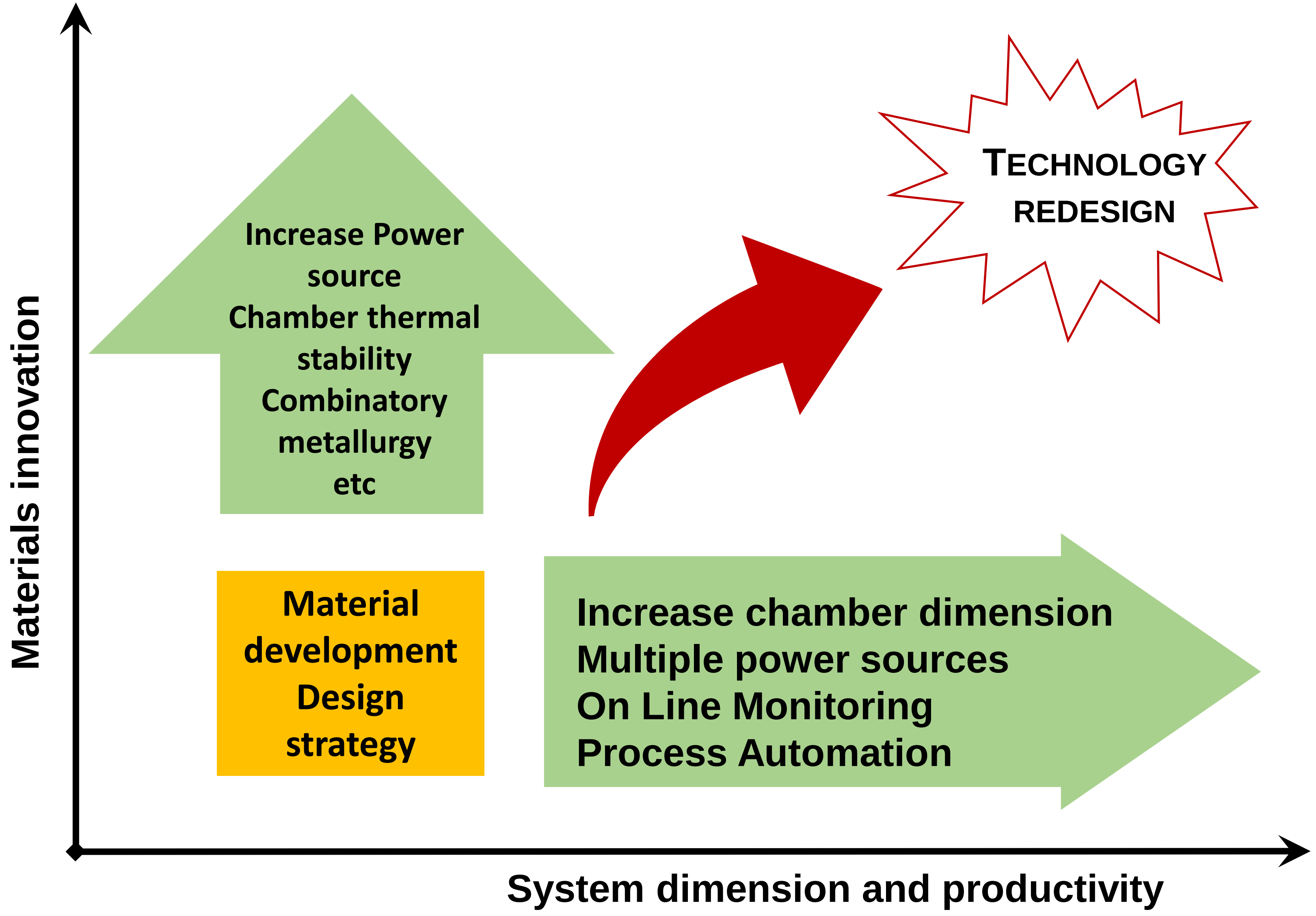
SUPPLY CHAIN

MATERIAL PRODUCTION → DESIGN OPTIMIZATION → PART PRODUCTION → ON LINE MONITORING → POST-PROCESSING (HIP, heat treatments, surface finishing) → CHARACTERIZATION

Resources for facilities
€ 6.500.000,00

Resources for people
€ 600.000

STRATEGY FOR THE GROWTH



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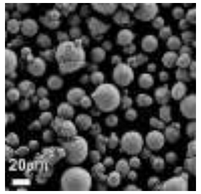
METAL INVESTMENTS

Hot Isostatic Pressing

Prima Additive
Laserdyne 430
5 axis

Direct Energy Deposition

Sistema di vibrofinitura



Gas Atomizer
Metal powders production

Freemelt One

GE Arcam A2x

Electron Beam Powder Bed Melting

Concept Laser Mlab
Materials development

Prima Additive
Print Sharp 150
Blue/Green laser

EOS
EOSINT M270

Prima Additive
Print Sharp 250

Laser Powder Bed Melting Systems

POLYMER INVESTMENTS

Stereolithography

Direct Ligth Processing

Polyjet

Photopolymers
Materials development

Selective Laser Sintering

EOS Formiga

Materials
Nylon
Nylon glass filled
Nylon Al filled
Nylon carbon filled

Fused Deposition Modeling

3ntr
A4

Stratasys
Dimension Elite

Stratasys
F370

Markforged
Mark Two

Materials
ABS M30
ABS ASA
PC-ABS
PLA
HIPS
Nylon Carbon
PA66 GF
PETG
TPU
Nylon
Onyx
Carbon fiber
Fiberglass
Kevlar

CERAMIC

INVESTMENTS

Direct Ligth Processing

Materials

Photopolymer + Ceramic

Characterization

Investments

Scan Box

Equator

GOM Atos Core

Computer Tomography

SEM Microscope

Sistema per la valutazione delle tensioni residue

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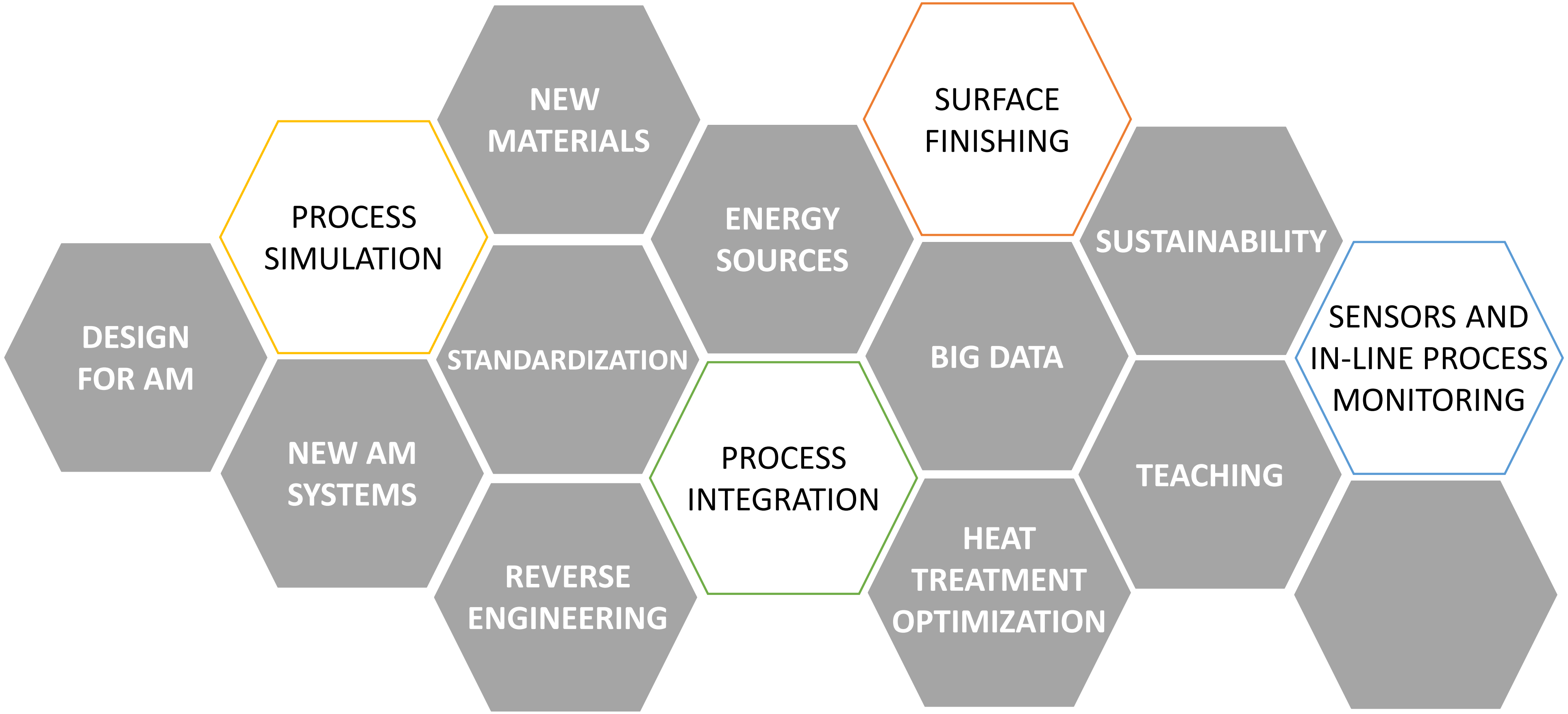
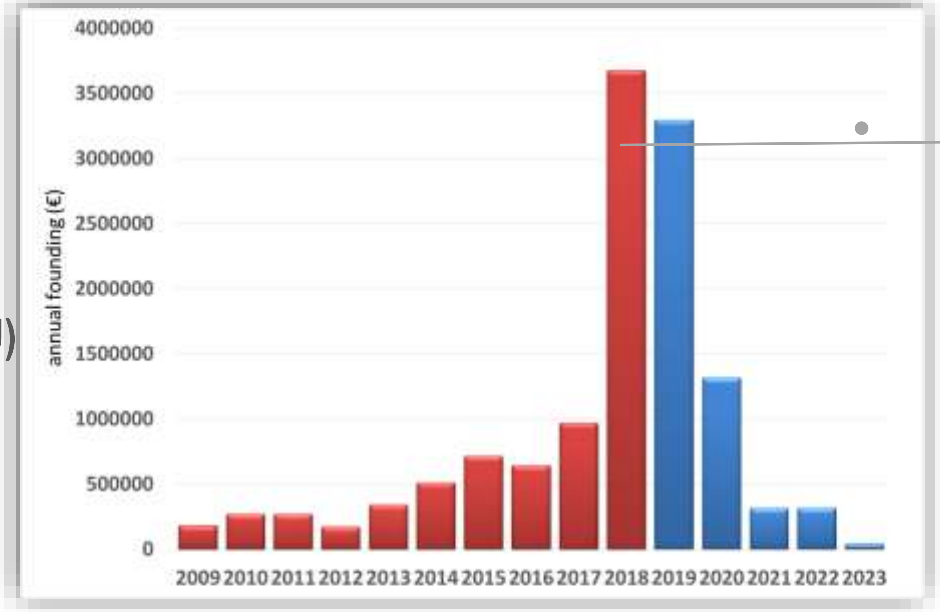
IAM ACTIVITIES



FUNDING

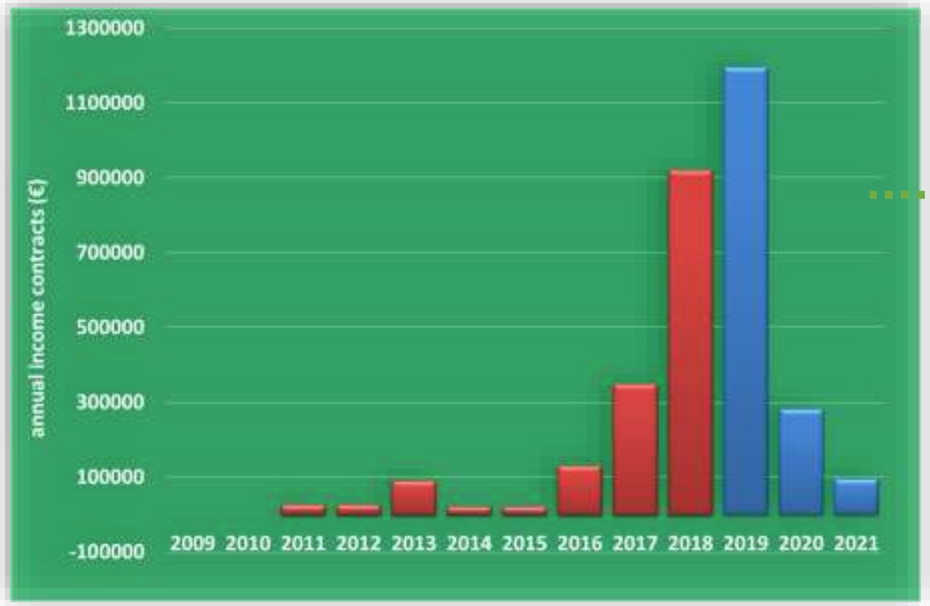
SOME EXAMPLES

4D HYBRID – Horizon 2020 (EU)
Novel hybrid approaches for additive and subtractive manufacturing machines
Budget 10M€, IAM 1M€



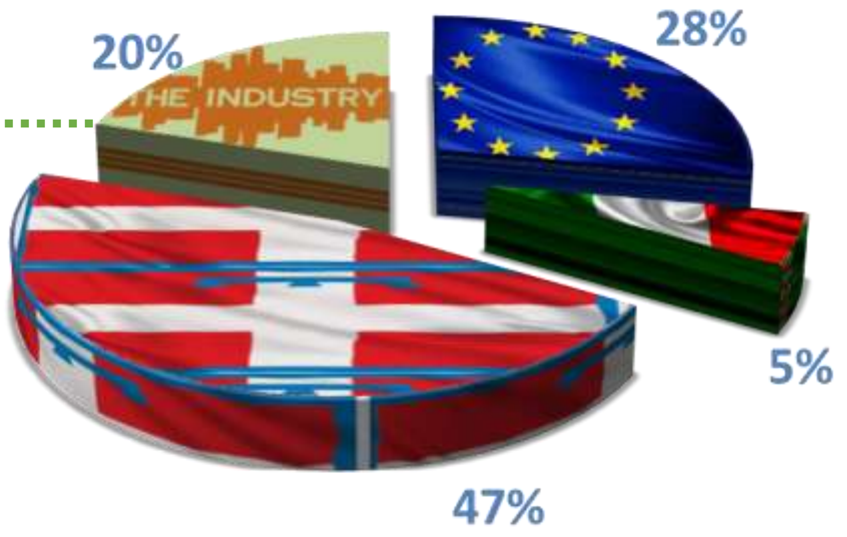
INFRA-P Call: 2 M€
Support for projects for the construction, strengthening and expansion of public research infrastructures

STAMP (Regional)
Development of AM Technology in Piemonte
Budget 12M€, IAM 1.5M€



AVIONICA
Design for AM
Budget IAM 0.5M€

Cumulative amount from 2009
External resources € 14.392.500,00
Internal resources for facilities € 3.000.000,00



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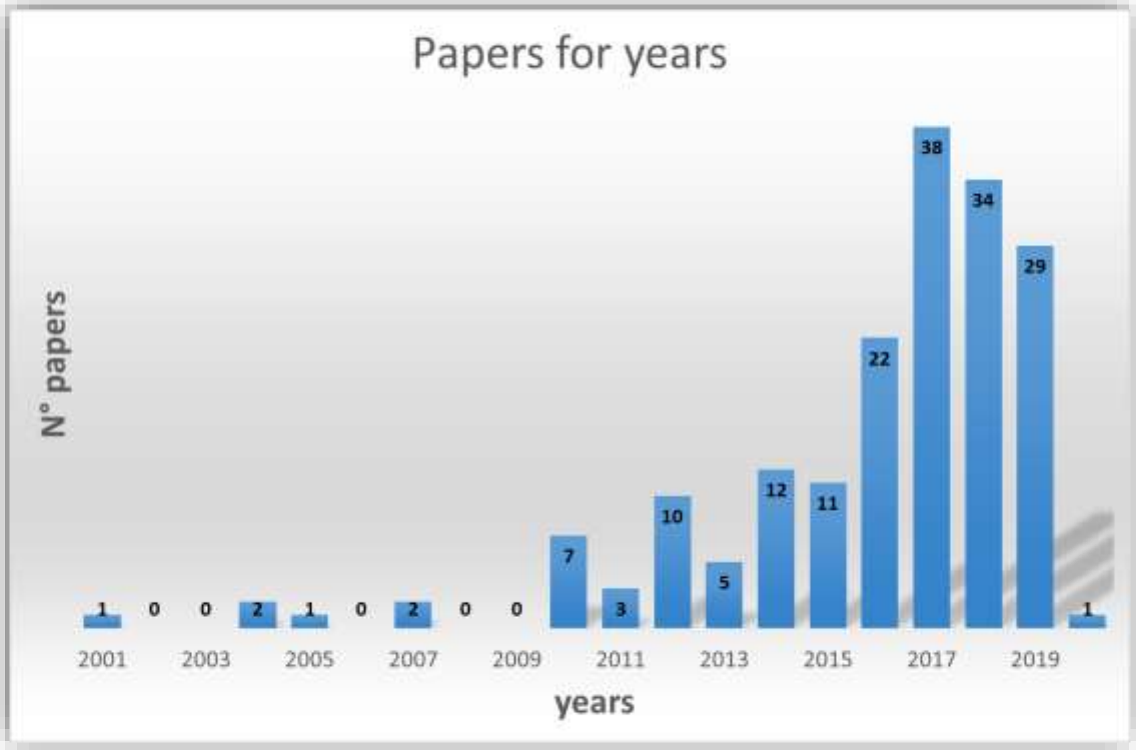
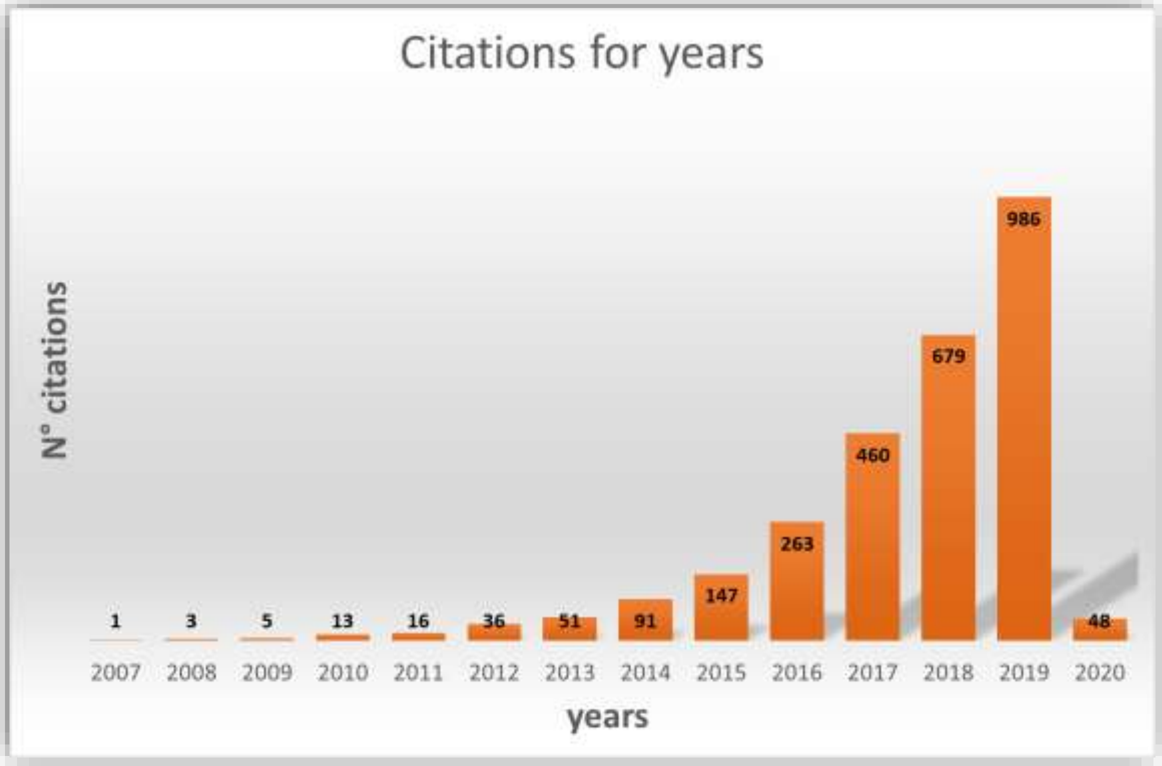
181 papers on AM topics
2795 citations in the last 10 years





Most cited papers:

2012 International Journal of Advanced Manufacturing Technology	254 citations
2011 Intermetallics	195 citations
2007 Rapid Prototyping Journal	163 citations
2013 Materials	162 citations

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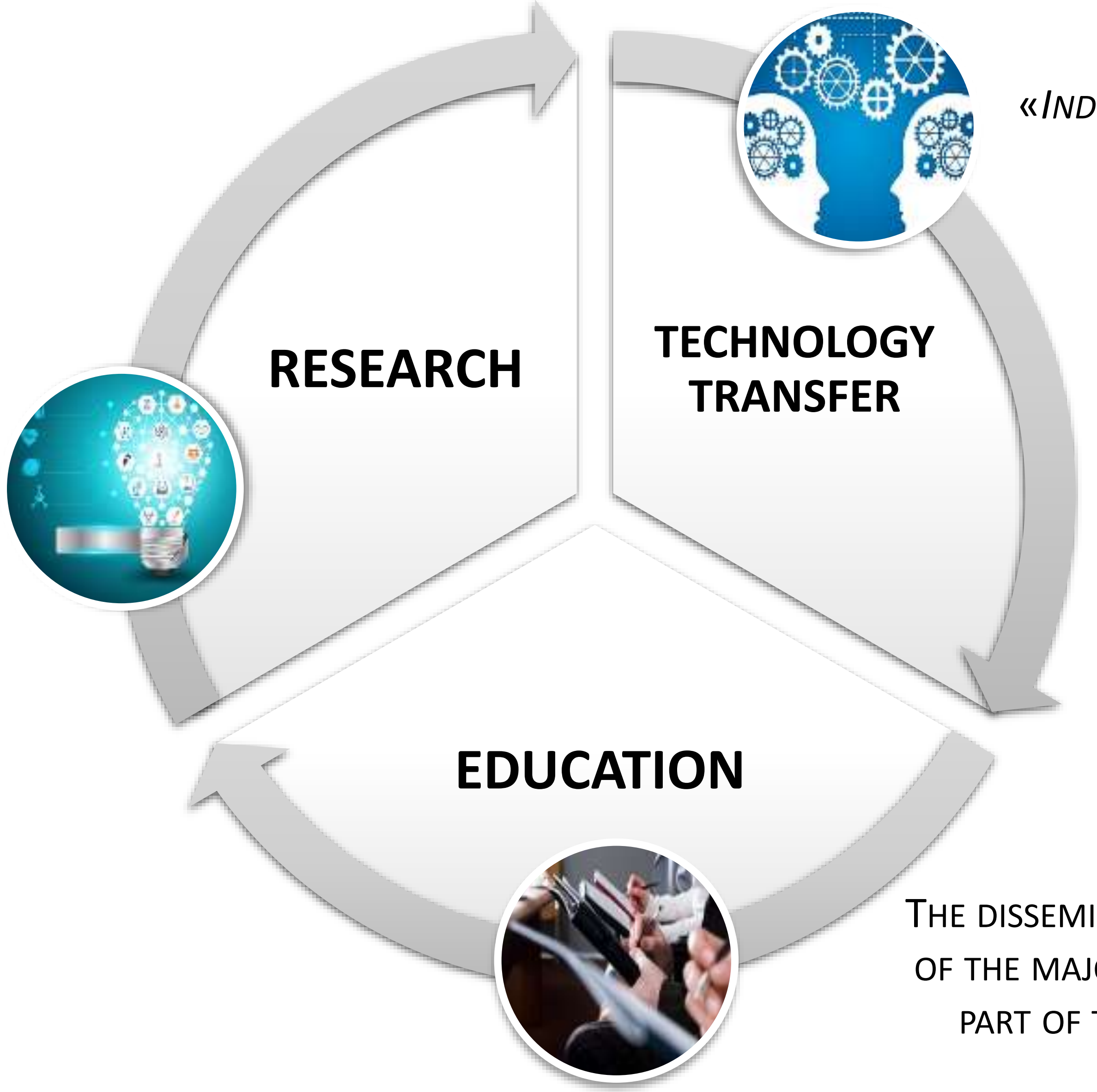
Research with the involvement of companies such as FCA, GE Avio, Prima Industrie,…



«Industry-funded academic inventions boost innovation»
Nature Comment,
Brian D. Wrigh et al.

The dissemination of knowledge is one of the major focuses and an integral part of the Center IAM@PoliTo

Research with the involvement of companies such as FCA, GE Avio, Prima Industrie,...

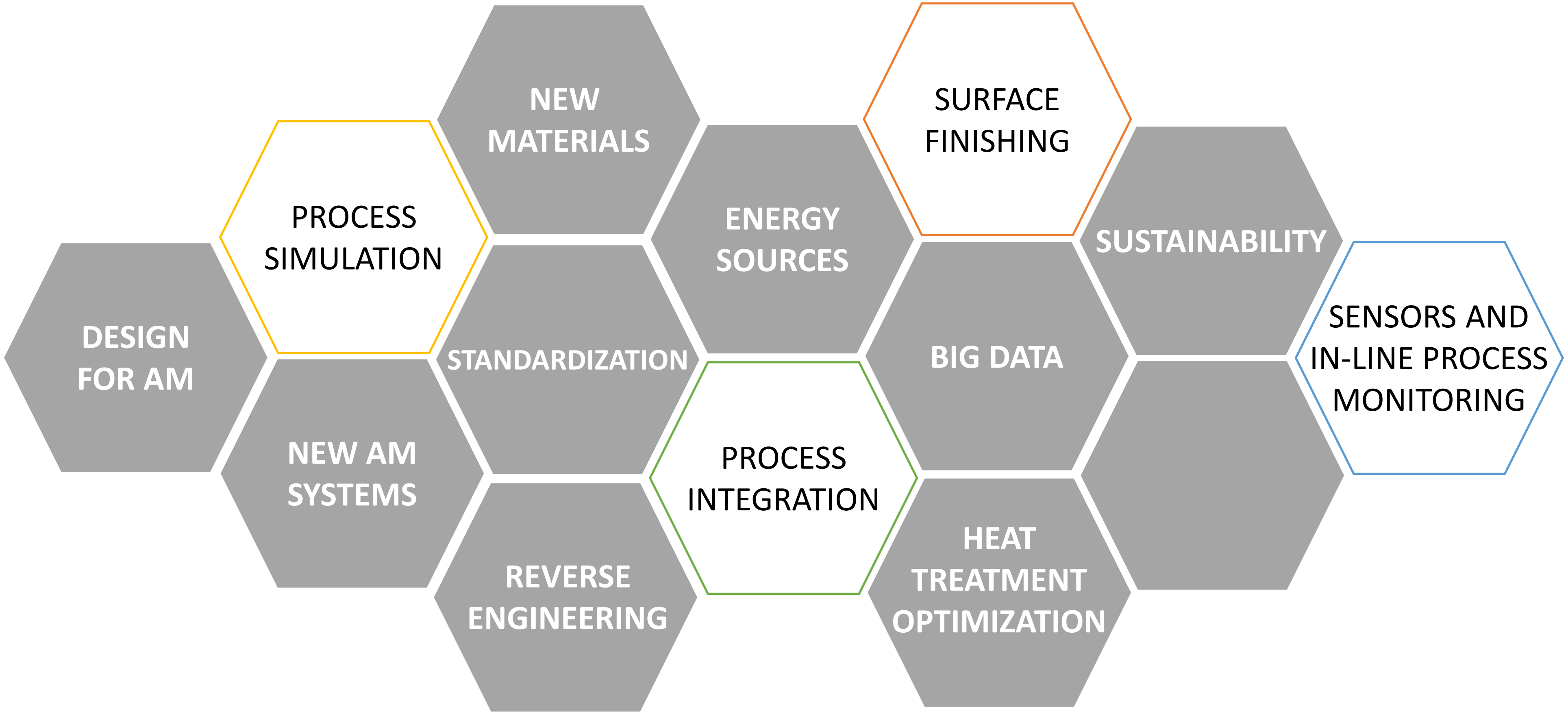
RESEARCH

- **SCOUTING** and **TECHNOLOGICAL ASSESSMENT**
- **INVESTMENTS** in **INFRASTRUCTURES**
- **SUPPLY CHAIN PROJECTS**
- **PILOT LINE** for **RESEARCH**

Field for interest:

- Metal
- Polymer
- Reverse Engineering

RESEARCH ACTIVITIES



EBM

Ti6Al4V
TiAl 4822
TiAl Hi Nb
Superalloys
Steels

SLM

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Lightweight

Al Alloys

Harsh conditions

Ti6Al4V
Ni superalloys

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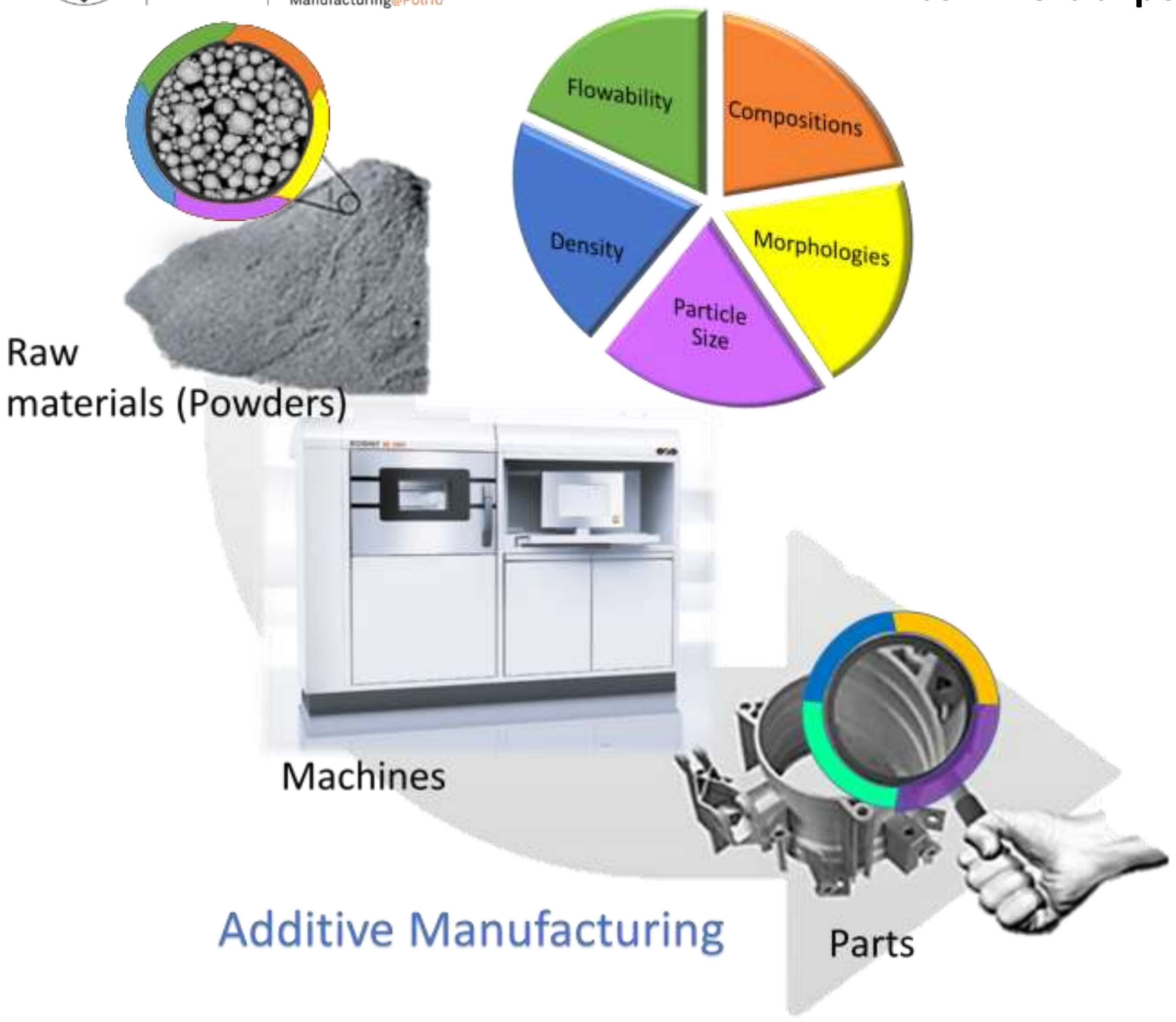
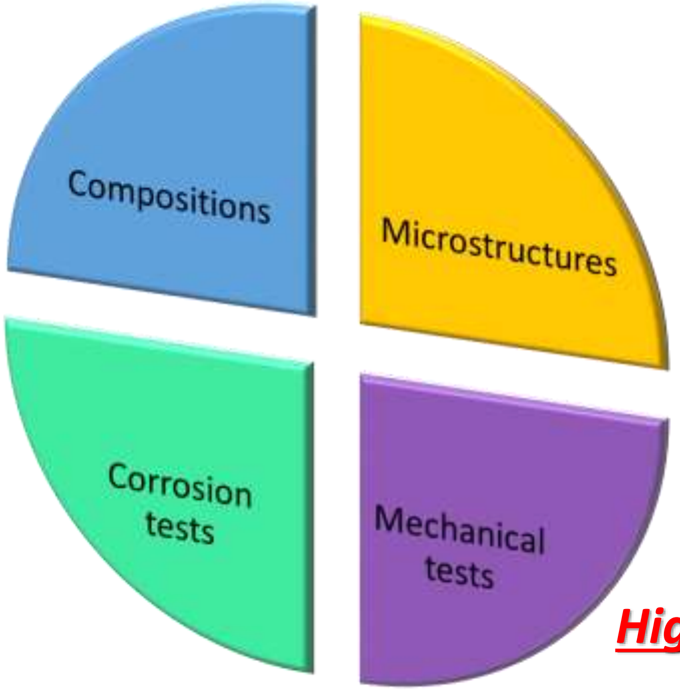
Selection of process parameters for commercial powders

RESEARCH METAL

SLM Approach





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Light alloys

Scalmalloy®

AlSi10Mg

7075

A357

F357

A20X™ (AM205)

6061

Biomedical alloys

Ti64

High Temperature alloys (> 600 °C)

Steel 316L

Inconel 718

Inconel 625

POLITECNICO DI TORINO | IAM Integrated Additive Manufacturing@PoliTo

Selection of process parameters for commercial powders

RESEARCH | METAL

SLM Approach

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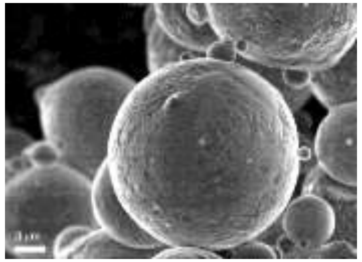
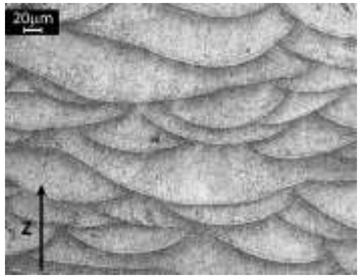
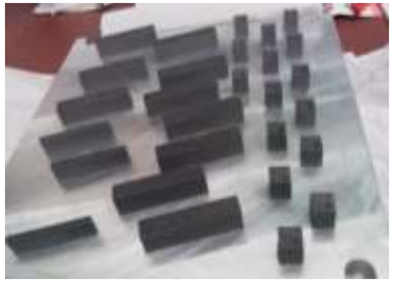
Design and production → Alloy selection or production → Process optimization



Post – processing → Heat treatmet setup → Surface finishing



Mechanical and thermal tests



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Development of customized compositions of AM powders

RESEARCH METAL

SLM

Process optimization

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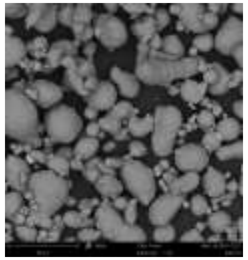
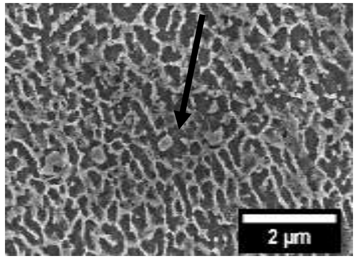
The advances of AM technologies give the possibility to develop new materials specifically designed for AM. This opens the way for a new metallurgy.

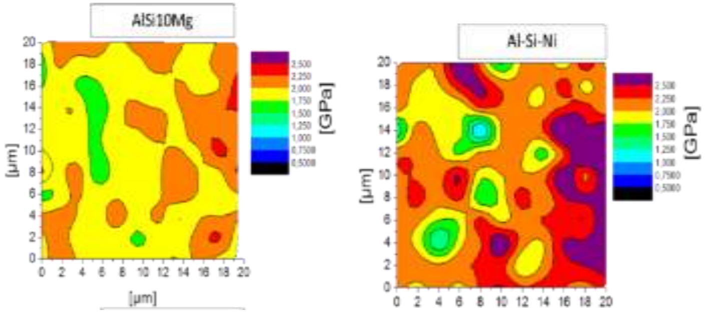
Design of a new composition
Powder production and characterization
Feasibility of AM processing
Microstructural and mechanical characterization of as-built parts

Gas-atomized powder



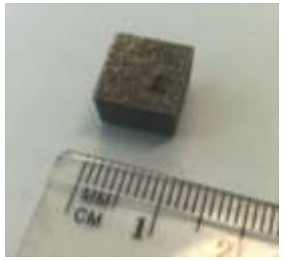
Strengthening phase



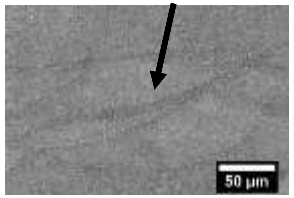


Nanoindentation maps

AM materials



Melt pool



Development of customized compositions of AM powders

SLM

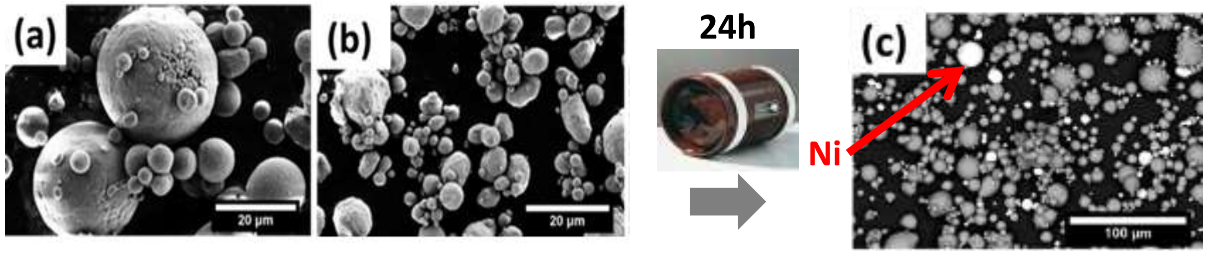
Process optimization

Design of a new composition through 2 strategies:

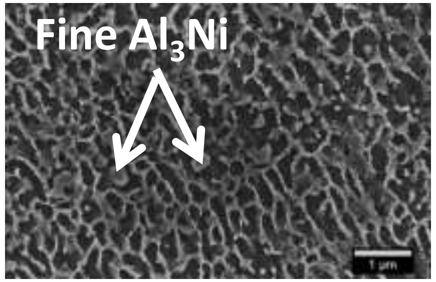
Powder mixing

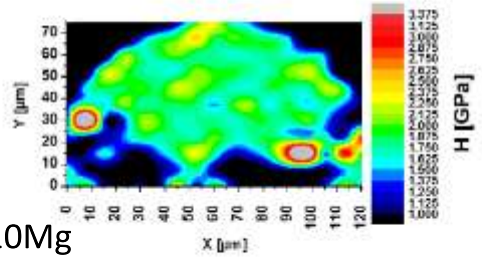
AlSi10Mg + Nickel

AlSi10Mg+Ni

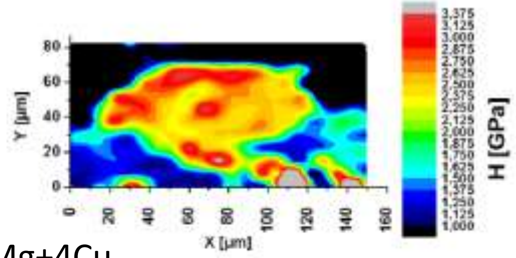


Alloy	HB		HV	
	Value	St. Dev.	Value	St.Dev.
AlSi10Mg	128.6	1.9	135.0	0.9
Al-Si-Ni	158.7	3.0	179.5	3.0
Al-Si-Cu	149.2	2.0		





AlSi10Mg



AlSi10Mg+4Cu

Gas-atomization

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Starting from ingots, pellets, powders, wires (8-10 kg)

Feasibility of AM processing of metallic powders

RESEARCH

METAL

SLM

Process optimization

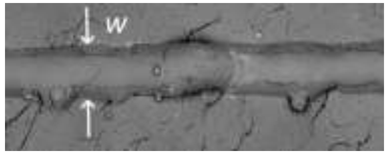
ISTITUTO ITALIANO DI TECNOLOGIA

The comprehension of the complex phenomena that arise during the building process is a key factor for understanding the AM processability of a metallic powder.

These phenomena were studies by performing and analyzing single laser scan tracks on a powder bed.

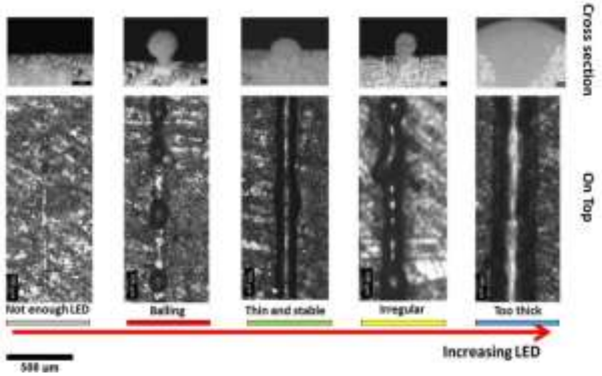
The analyses showed that, depending on the parameters, the material melts according to different melting modes. The identification of the melting mode allows the process window definition.

$$h_d = w \cdot \left(1 - \frac{\varphi}{100}\right)$$

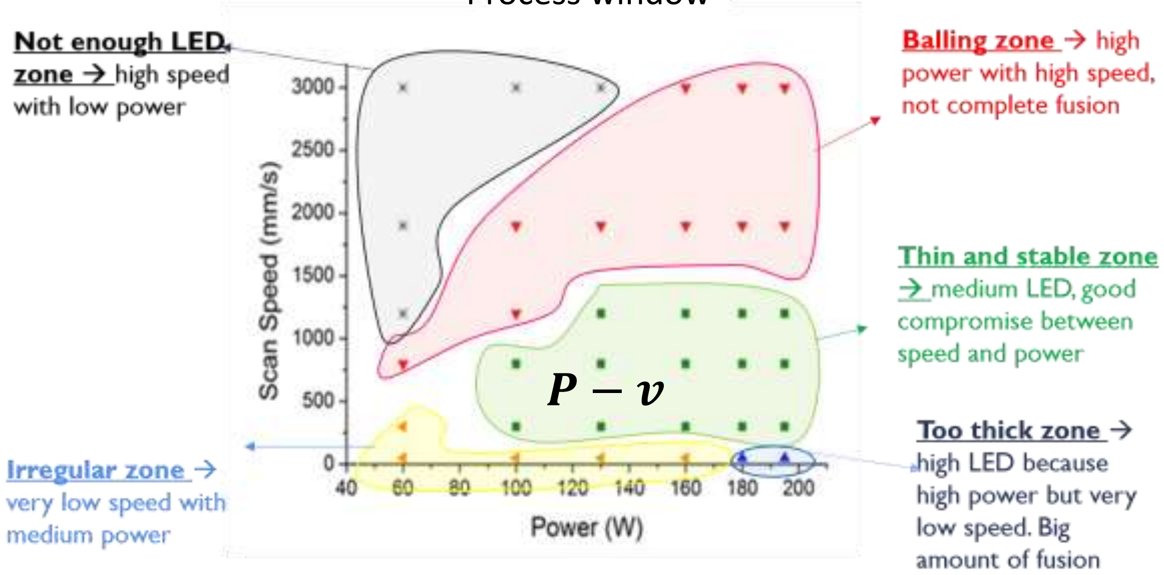


$$0 \leq \varphi \leq 20\%$$

Melting modes



Process window



Aversa, A.; Moshiri, M.; Librera, E.; Hadi, M.; Marchese, G.; Manfredi, D.; Lorusso, M.; Calignano, F.; Biamino, S.; Lombardi, M.; Pavese, M. Single scan track analyses on aluminium based powders. J. Mater. Process. Technol. 2018, 255, 17–25, doi:10.1016/j.jmatprotec.2017.11.05

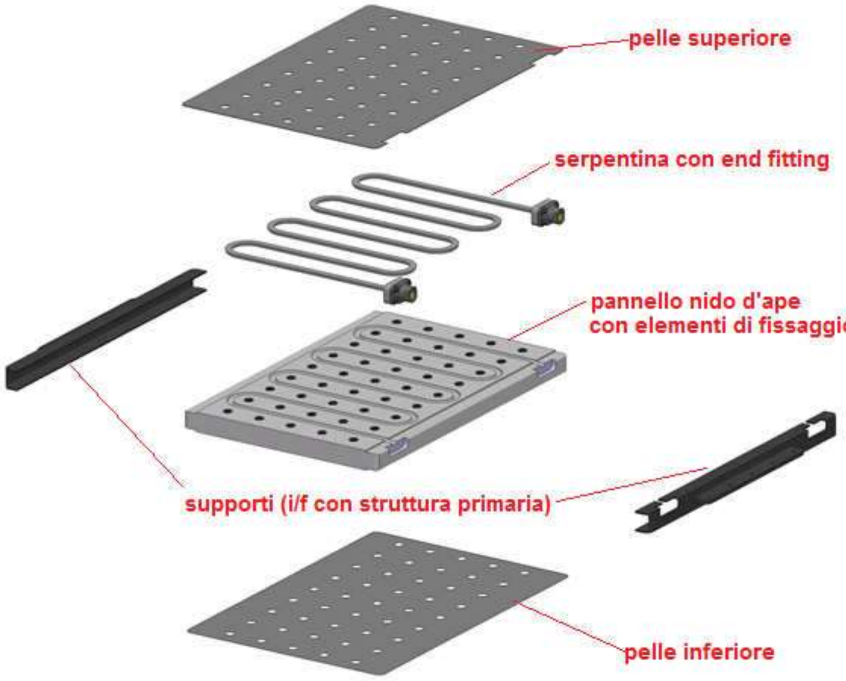
Bosio, F.; Aversa, A.; Lorusso, M.; Marola, S.; Gianoglio, D.; Battezzati, L.; Fino, P.; Manfredi, D.; Lombardi, M. A time-saving and cost-effective method to process alloys by Laser Powder Bed Fusion. Materials and Design 2019, 181, art. no. 107949. doi: 10.1016/j.matdes.2019.107949

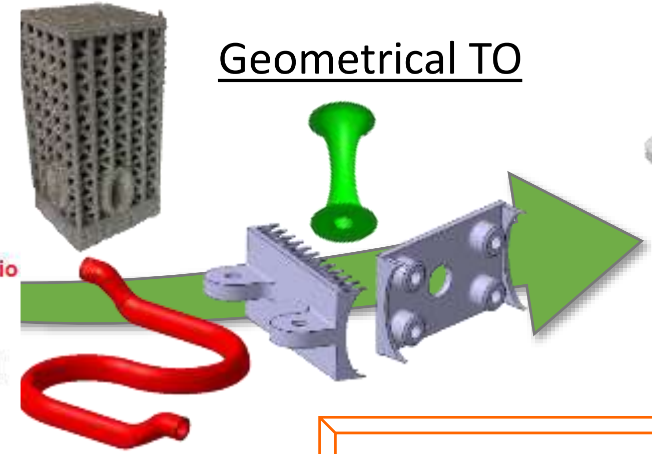
Multifunctional panel

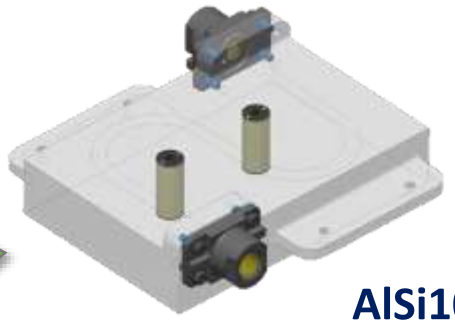
RESEARCH METAL

SLM

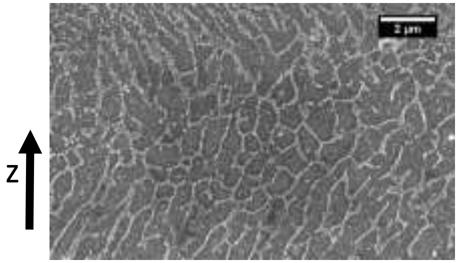
Design for Additive Manufacturing of a heat exchangers



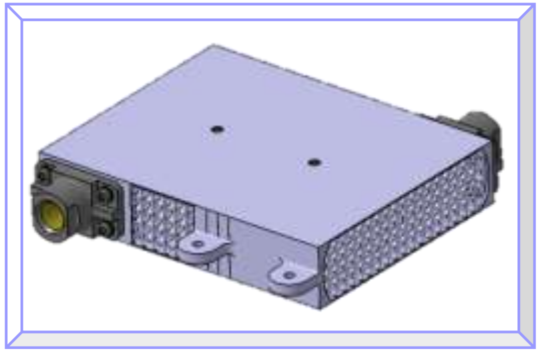


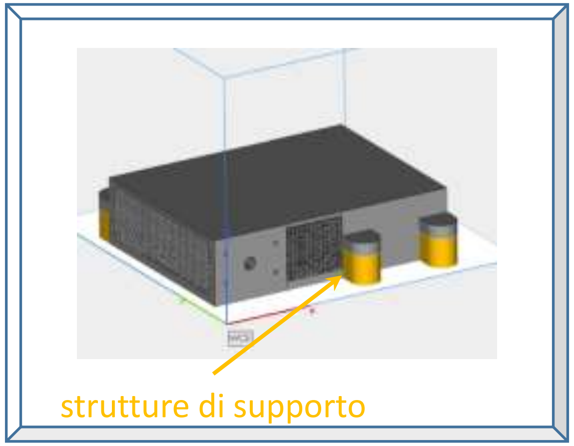


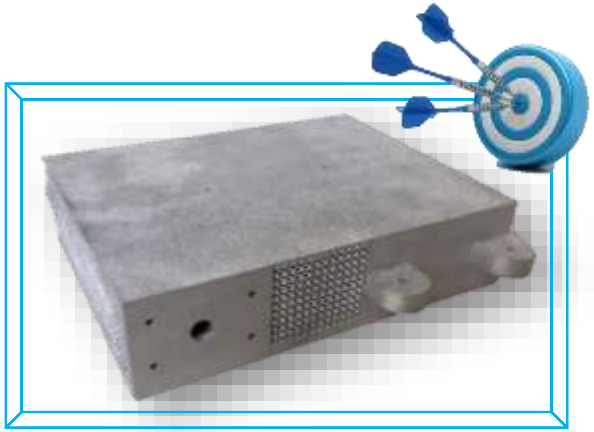
AlSi10Mg



Stress relieved (SR)

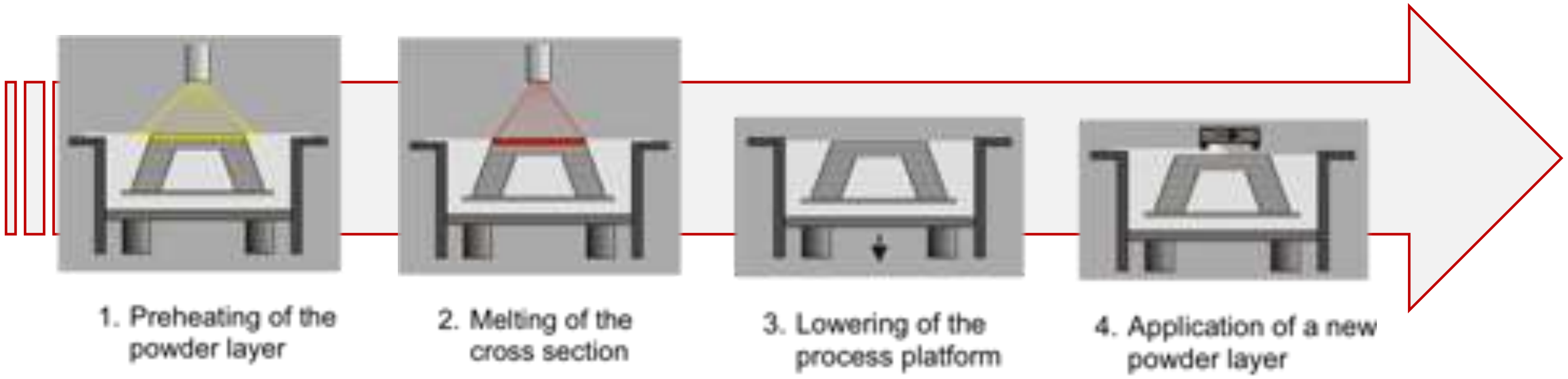






RESEARCH METAL

EBM



Strong interaction with GE-AvioAero

TiAl 4822 / TiAl Hi Nb

- **Powder evaluation** (composition/morphology/behavior in process)
- Sample evaluation and support in the **optimization process**
- **Heat treatment** setup/correlation microstructure-properties
- **Failure analysis/mechanism**

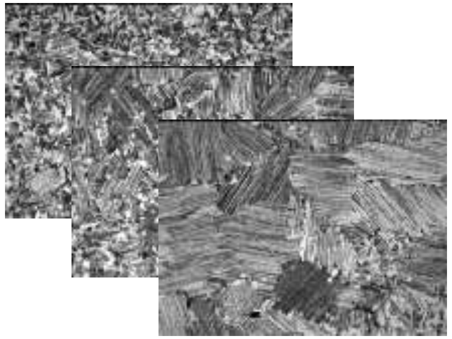
Renè 80

- **Powder evaluation** (composition/morphology)
- Sample evaluation and first indications for the **optimization process**
- **Heat treatment** setup

EBM
Approach

Production → Alloy selection → Process optimization

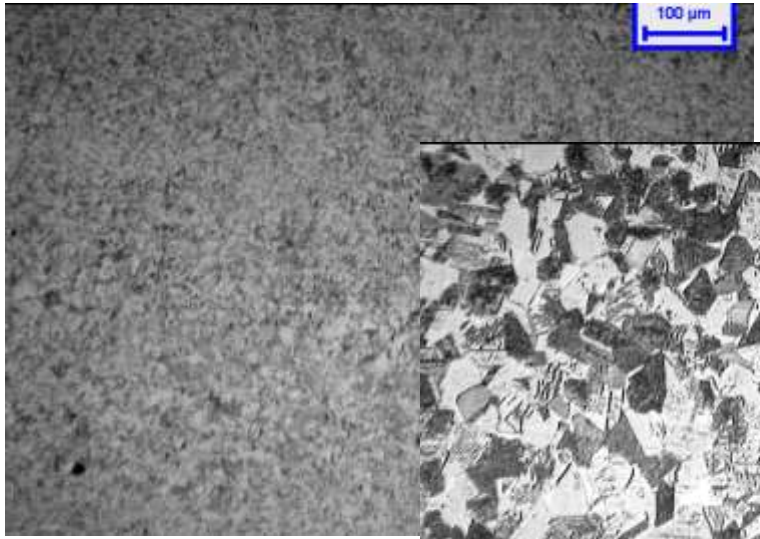
Heat treatment setup → Microstructure selection → Optimal microstructure definition



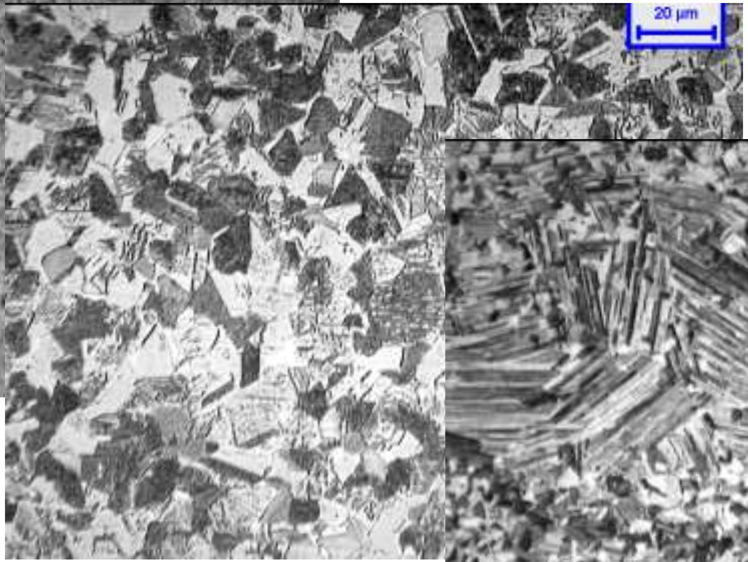
Mechanical and thermal properties tests

EBM
Approach

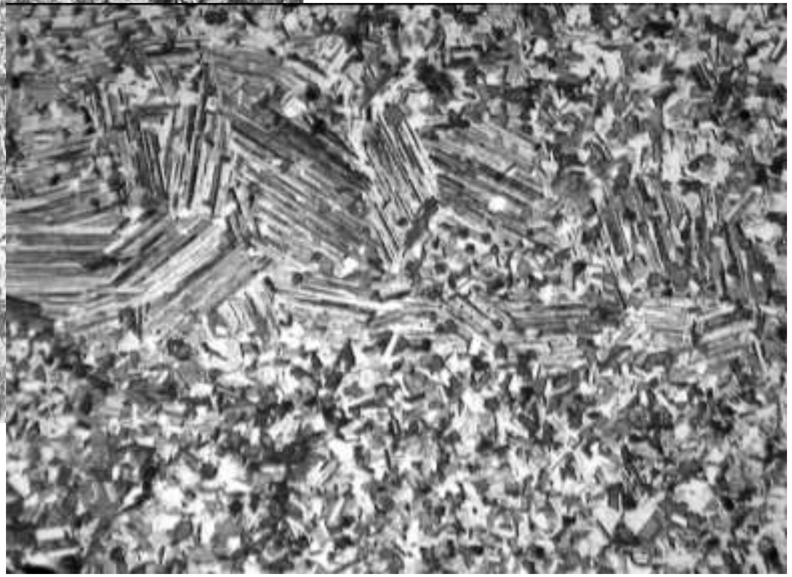
EBM Ti-48Al-2Cr-2Nb Microstructures



As-built by EBM

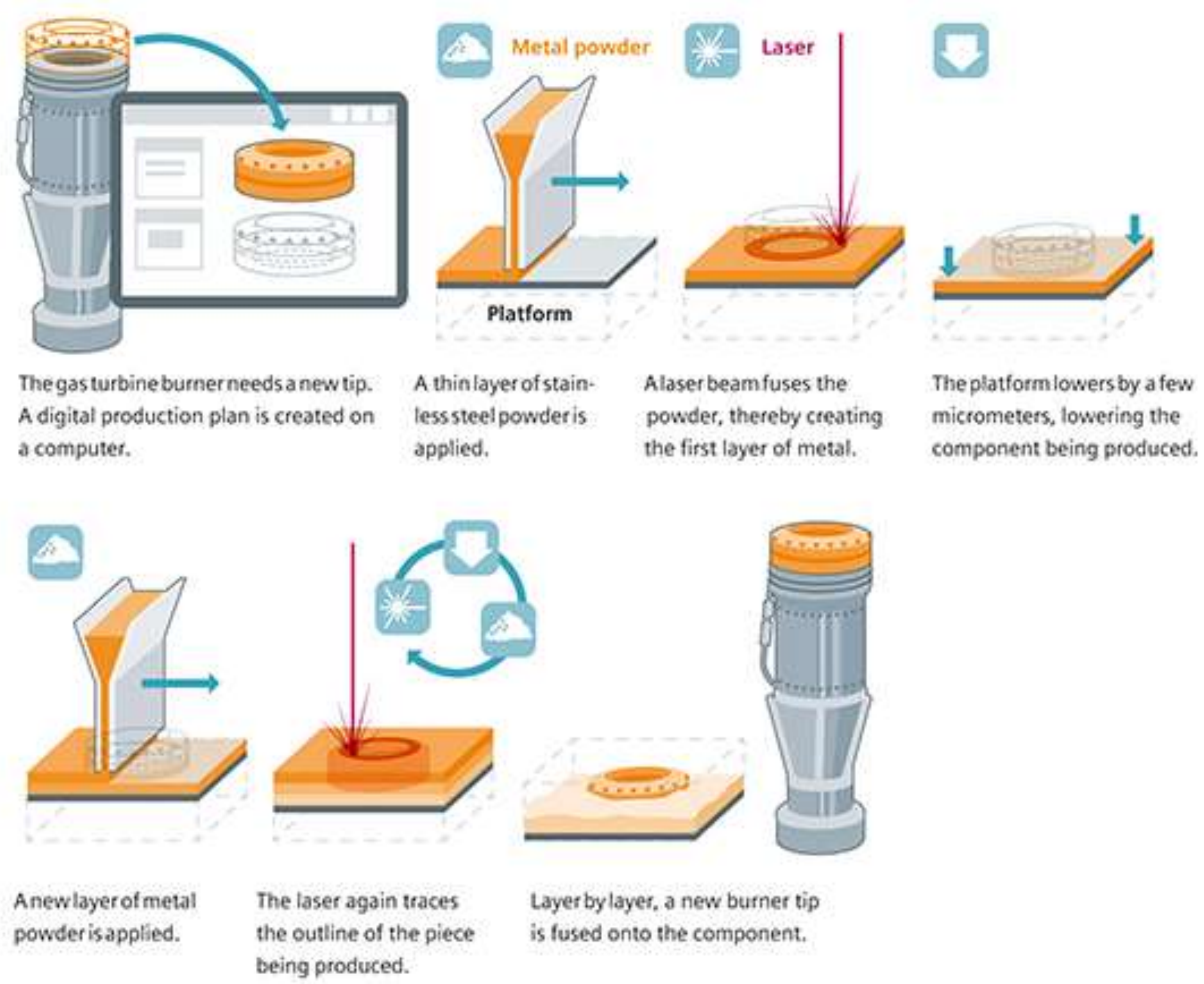


HIP
Fully equiaxed
Grain size <50 μm



Heat Treatment
Duplex structure
Lamellar colonies ~150 μm
Lamellar phase fraction ~ 40%

SLM



In **Selective Laser Melting (SLM)** a laser source selectively scans a powder bed according to the CAD-data of the part to be produced. The high intensity laser beam makes it possible to completely melt and fuse the metal powder particles together to obtain almost fully dense parts.

Trade name for the process:

- direct metal laser sintering (DMLS) for EOS Gmbh,
- LaserCUSING for Concept Laser,
- Direct metal printing (DMP) for 3D System,
- Selective Laser Melting (SLM) for SLM Solutions, Realizer, Matsuura and Renishaw

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SLM Approach

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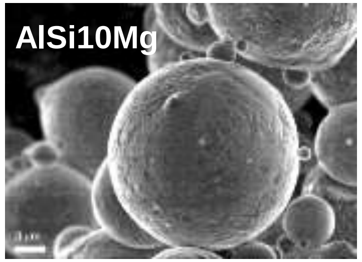
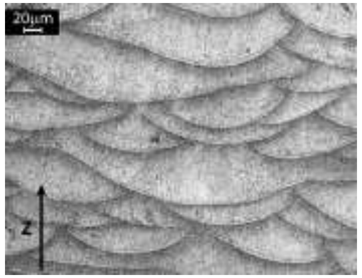
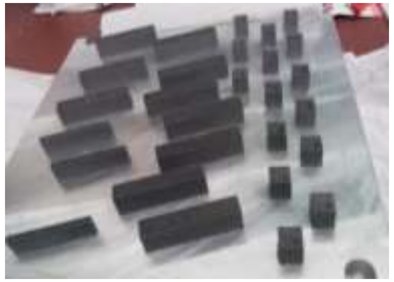
Design and production → Alloy selection and design → Process optimization



Heat treatmet setup and surf. finishing → Microstr. selection → Optimal Microstructure definition



Mechanical and thermal properties tests



SLM

Process optimization

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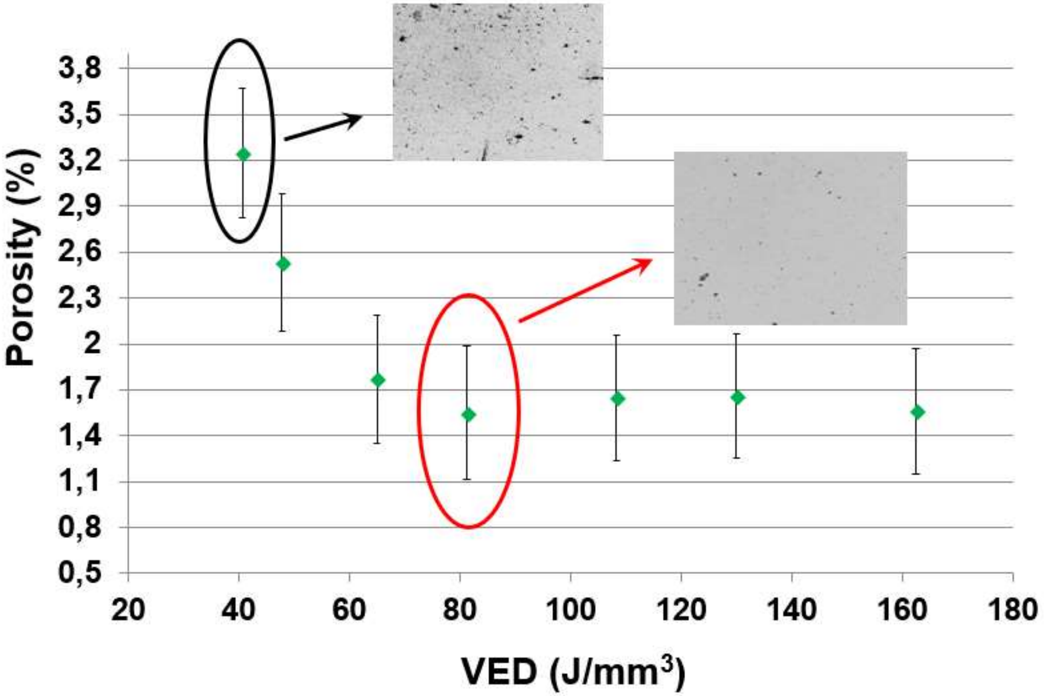
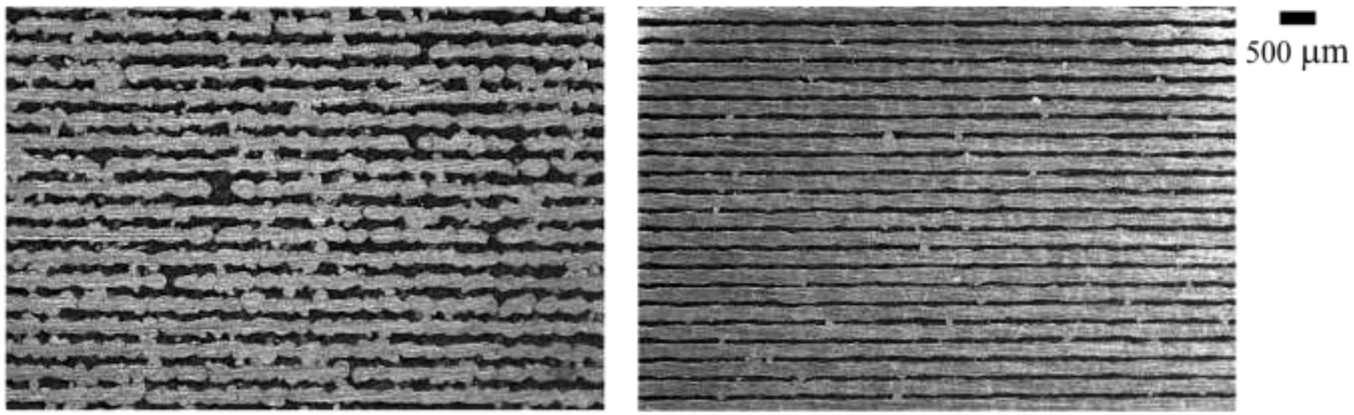


It is possible to read in the literature “**Fundamental to find the best process window**”…. **but it is not correct….**

Laser power and scanning speed have a significant influence on the stability of the scan tracks. However, their ratio expressed as a linear energy (P/v), as well as a volumetric energy density (VED) does not capture the kinetics of the melt pool and therefore fails to accurately describe many other properties such as track shape (height and depth) and the resulting melting mode.

Samples with same VED, but they have different track morphologies.

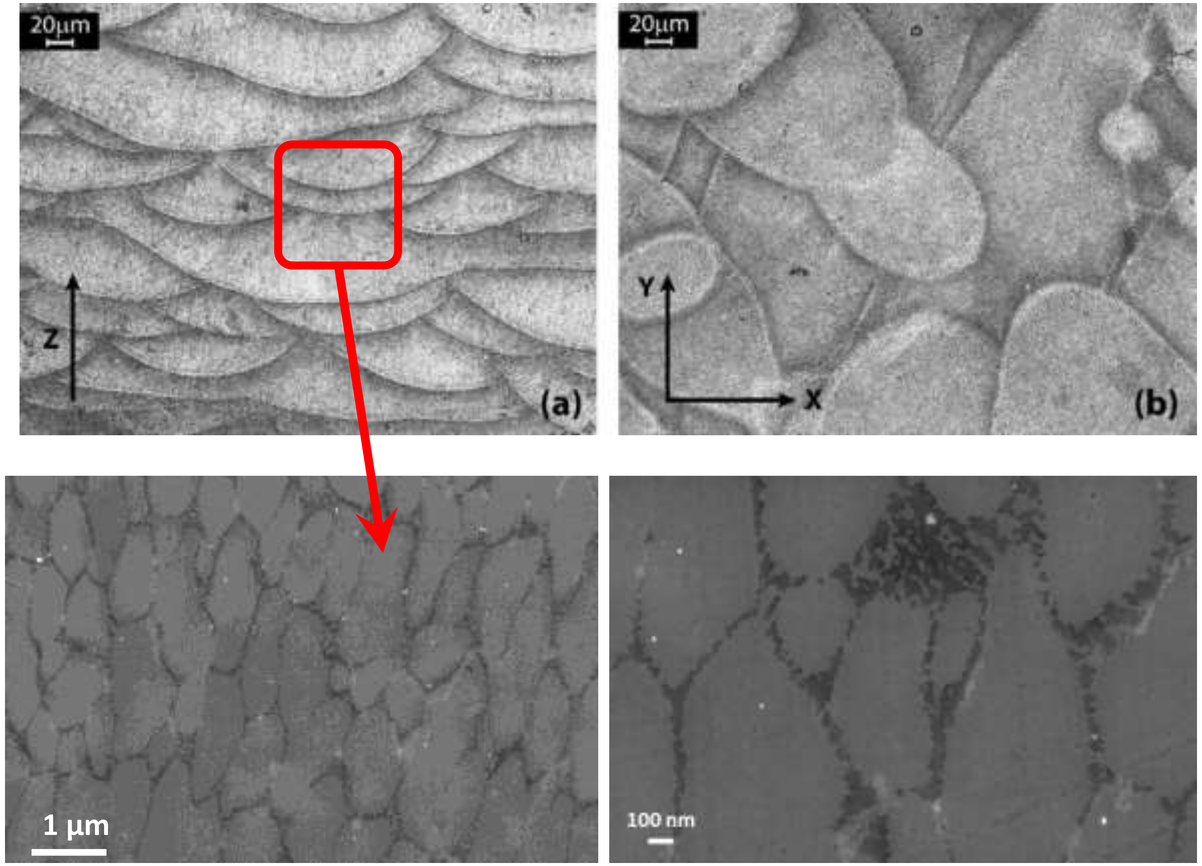


$P = 60$ W, $v = 100$ mm/s $P = 180$ W, $v = 300$ mm/s

$E = 50$ J/mm^3

Calignano F., Cattano G., Manfredi D, 2018. Manufacturing of thin wall structures in AlSi10Mg alloy by laser powder bed fusion through process parameters. Journal of Materials Processing Tech. 255, 773–783 https://doi.org/10.1016/j.jmatprotec.2018.01.029

SLM
Microstructures



Typical microstructural details of the Al alloy by DMLS highlighted by chemical etching:
(a) scan tracks signs, **melt pools** (along z axis)
(b) melt pools on xy section

Darker areas → Si rich
Grey areas → Al euctectic zones

EXTREMLY FINE

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Characterization at the nanoscale

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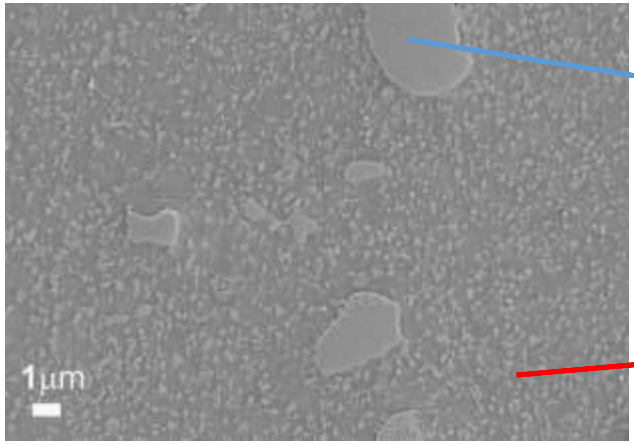
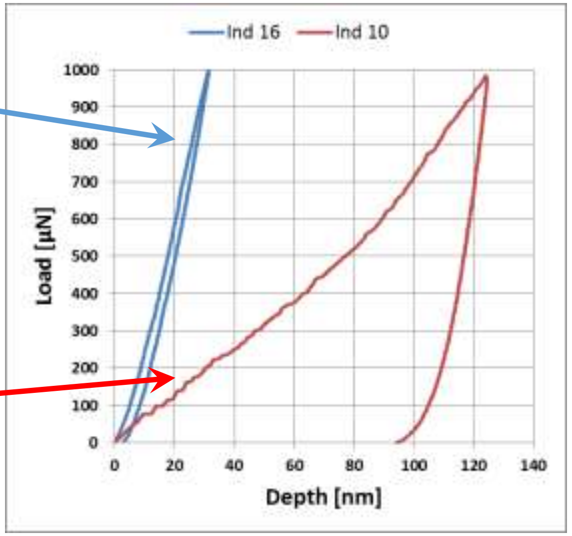
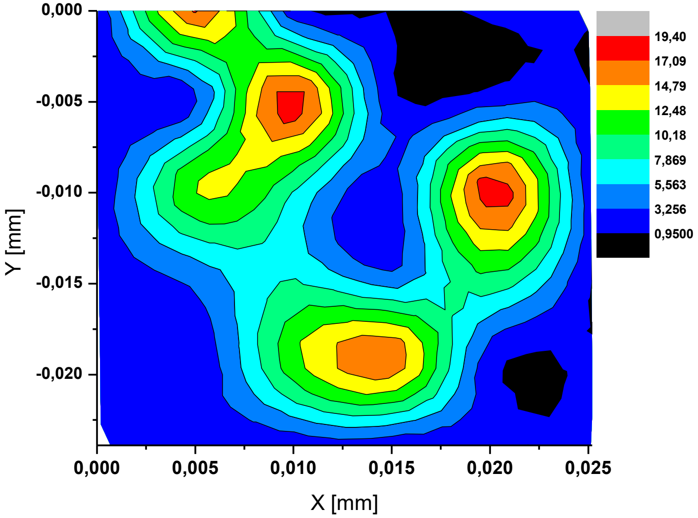


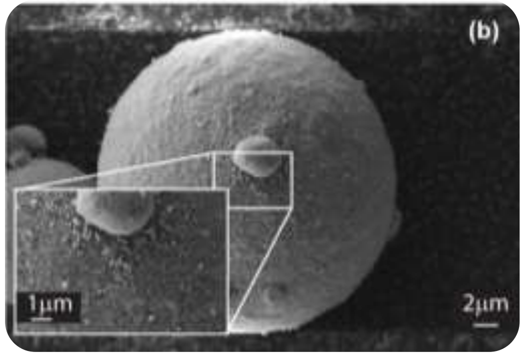


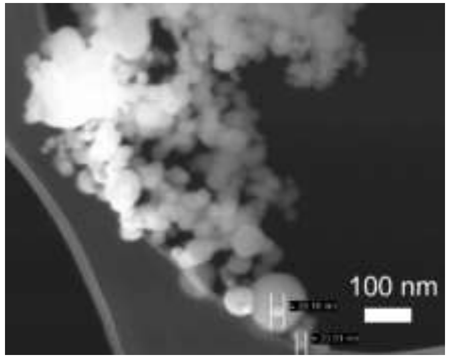
Nanoindentation technique



Study of micro ceramic-reinforced (TiB_2) in Aluminium alloy matrix

SEM & TEM:
from the micrometer to the nanometer level.





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SLM Materials

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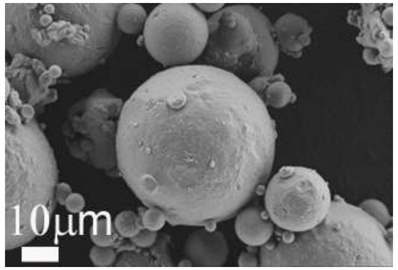
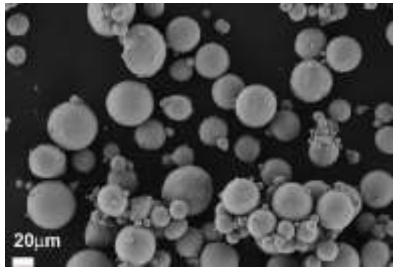
AL ALLOY AND COMPOSITES



- **Powder evaluation** (composition/morphology/behavior in process)
- **Powder mixing** (If necessary)
- Study of the **process parameter** influence on mechanical properties
- **Post treatment** setup
- **Mechanical and microstructural tests**

TI ALLOY



- **Powder evaluation** (composition/morphology)
- Study of the **process parameter** influence on mechanical properties
- **Heat treatment** setup
- **Post treatment** setup

RESEARCH METAL

SLM

Materials developed

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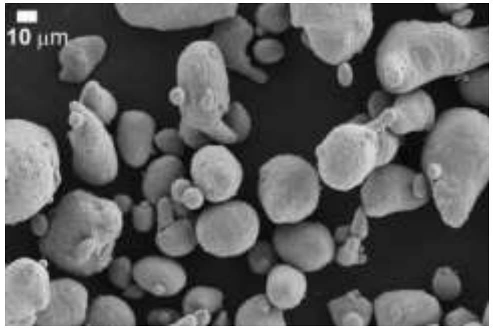
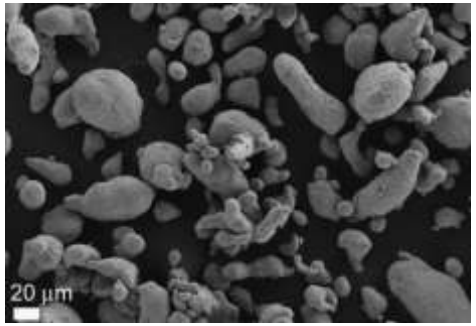
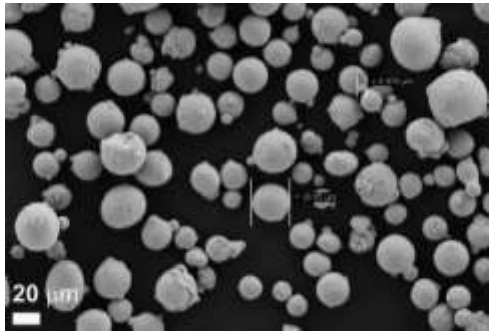


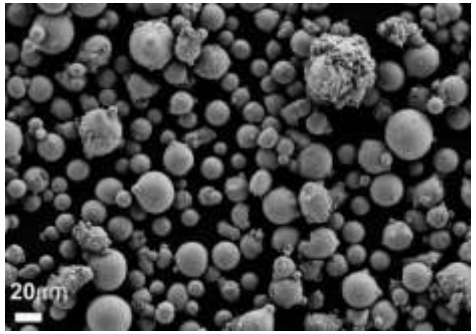
7075



In718



In625



MATERIALS TO BE DEVELOPED

- Other Al alloys for aerospace (2xxx, 6xxx, etc)
- Other Al based Composites
- Ti based Composites
- Cu and Cu based alloys
- Functional materials (e.g. SMA)

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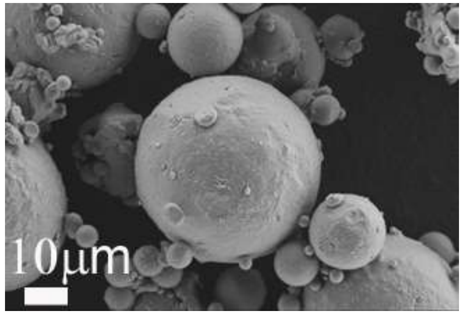
RESEARCH | METAL

SLM
Way to composites

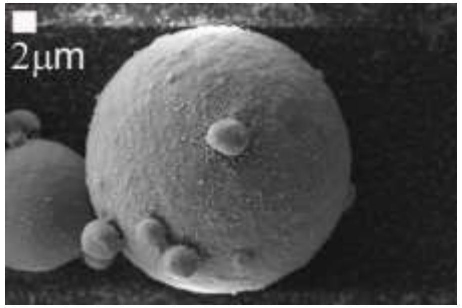
Aluminum powder	+	Reactive ceramic powder Inert ceramic powder	= ?

- Homogeneity
- Stability
- Flowability
- Densification parameter
- Reactivity control

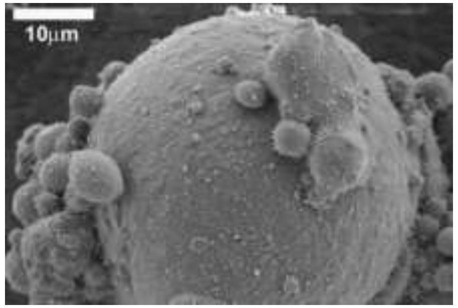


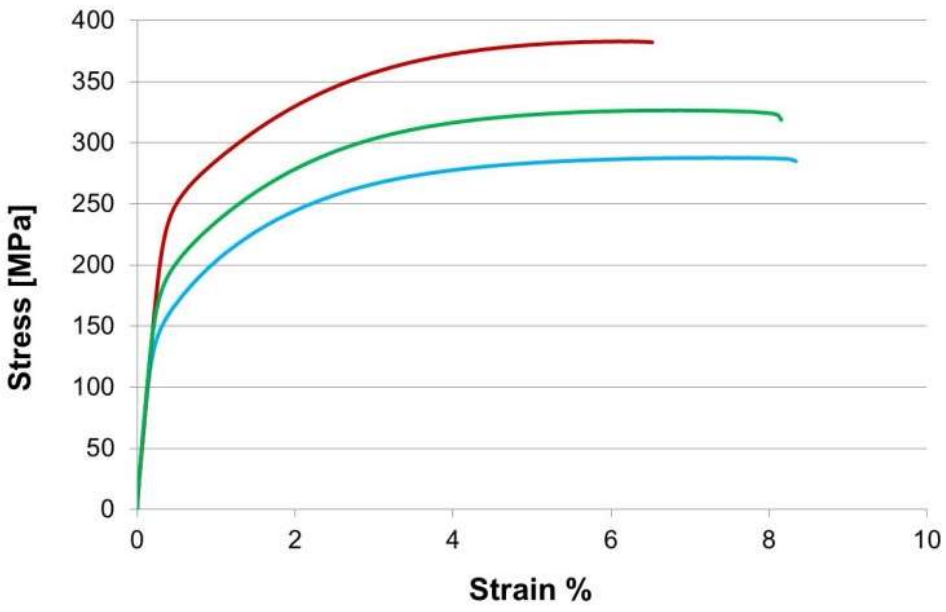
AlSi10Mg

AlSiMg / nano$MgAl_2O_4$



AlSiMg / nanoTiB_2





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With DMLS : ***ex situ*** and ***in situ*** composites

Gu et al., Int Mat Reviews, vol 57 n.3 (2012)

- Ceramic reinforcing phases are added exteriorly into the metal matrix
- Normally obtained by mechanically alloying a mixture of different powder components → "**simple**" approach

➢ Micro and nano $MgAl_2O_4$ reinforced AlSi10Mg alloy
➢ Micro and nano TiB_2 reinforced AlSi10Mg alloy

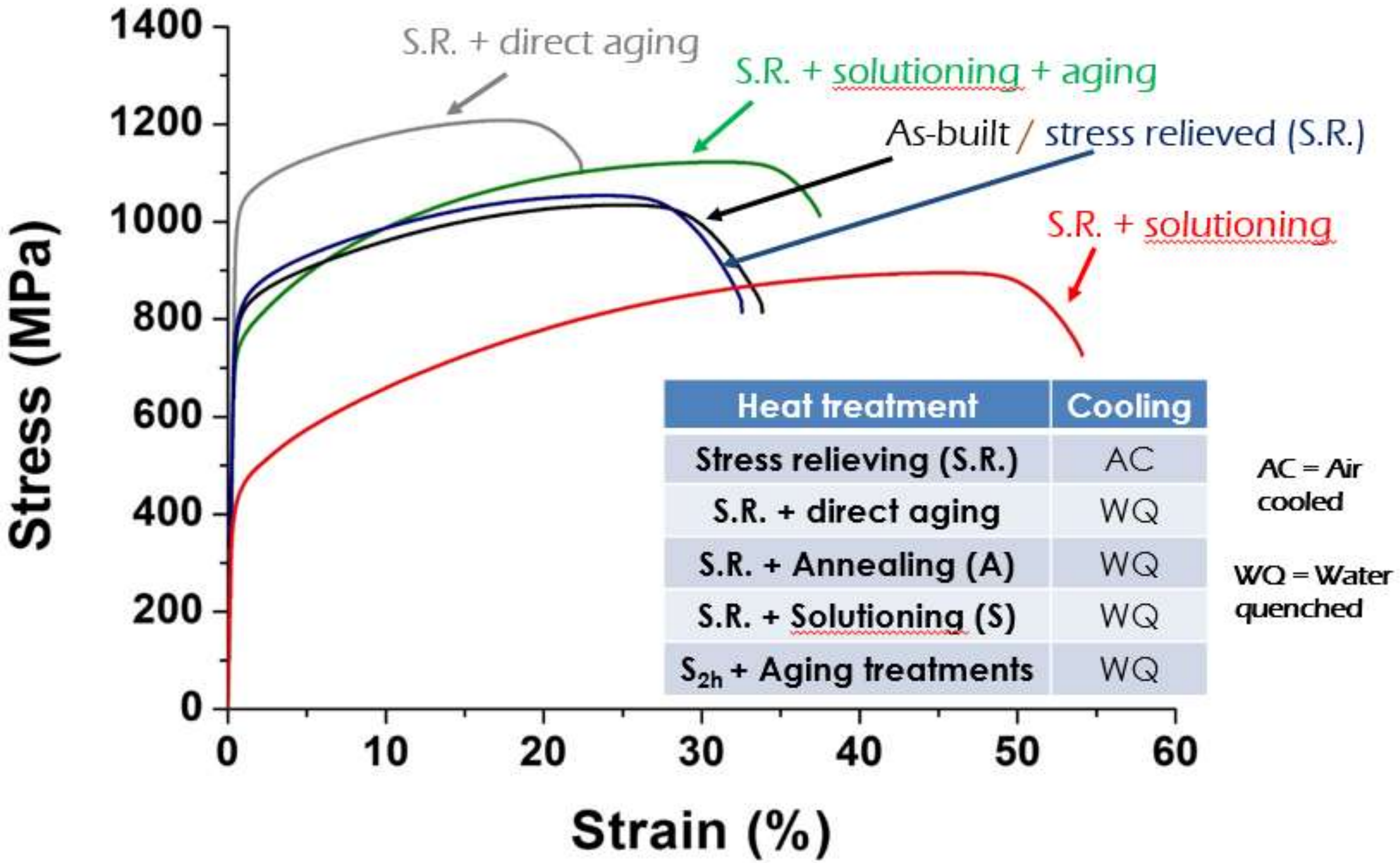
Dadbakhsh et al., J. Alloys and Compound, 541 (2012)

- The constituents are synthesised by chemical reaction between elements during rapid solidification → a sort of "bottom up approach"
- There is still **little understanding** on the consolidation behaviour and in situ formed microstructure

➢ nano SiO_2 reinforced AlSi10Mg alloy → → should produce $Al\text{-}Al_2O_3$

SLM
Thermal treatments

Study of the effect of thermal treatments on tensile behaviour



Heat treatment	Cooling
Stress relieving (S.R.)	AC
S.R. + direct aging	WQ
S.R. + Annealing (A)	WQ
S.R. + Solutioning (S)	WQ
S_{2h} + Aging treatments	WQ

AC = Air cooled

WQ = Water quenched

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EBM

Simulation of the process

Thermal Model of the EBM Process

Heat Transfer Analysis

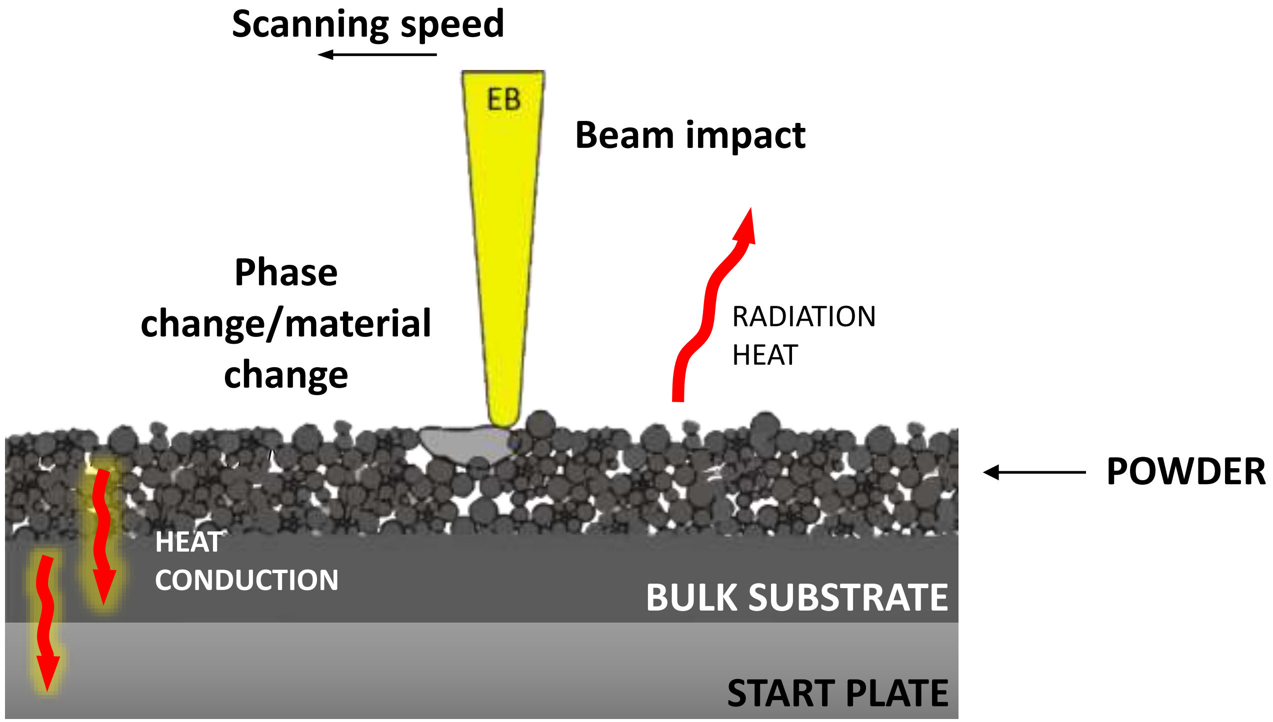
$$-\nabla \cdot \mathbf{q} = \rho \frac{De}{Dt}$$

$$e = c\,T + \Delta h$$

$$\Delta h = \begin{cases} L & T \geq T_l \\ f_s L = \dfrac{T - T_s}{T_l - T_s} L & T_s < T < T_l \\ 0 & T \leq T_s \end{cases}$$

$$\mathbf{q} = -\lambda\, \nabla T$$

$$T = T\,(x_1, x_2, x_3)$$



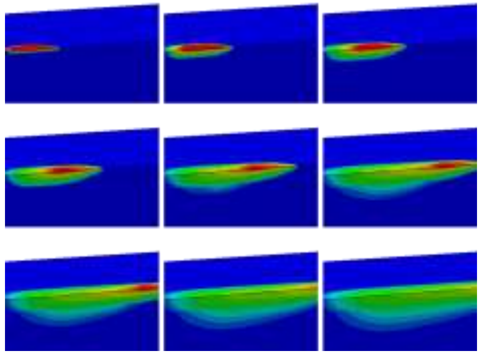
EBM

Simulation of the process

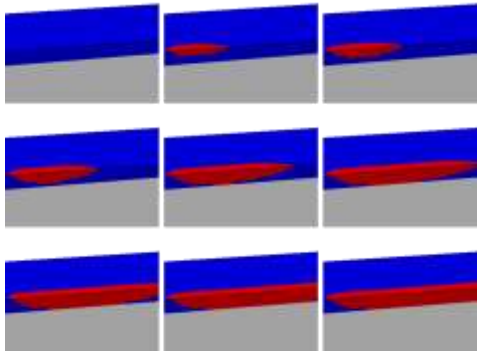
Thermal Model of the EBM Process

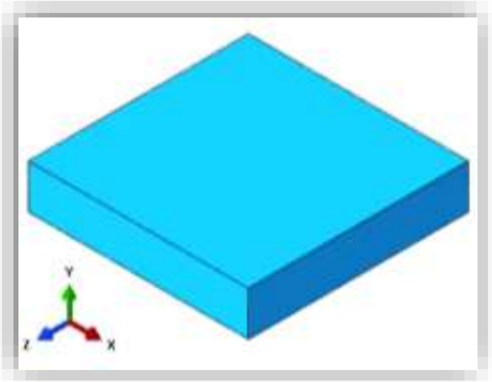
Work Flow

Temperature distribution



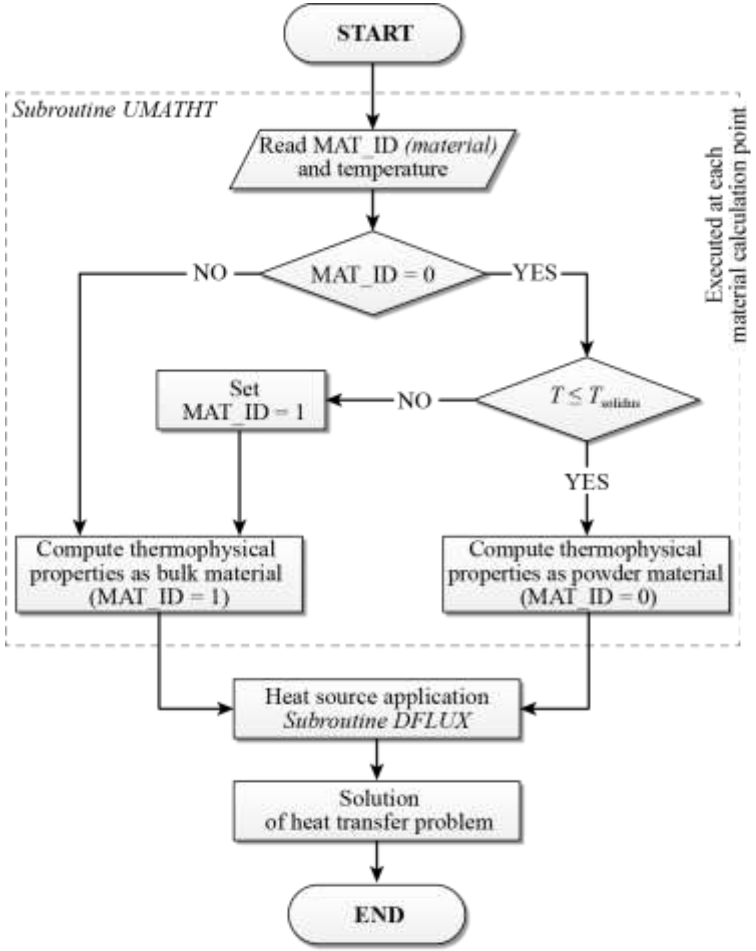
MAT_ID





$$q(x_1, x_2, x_3, v, t) = \eta \frac{UI}{S}$$

For each increment…



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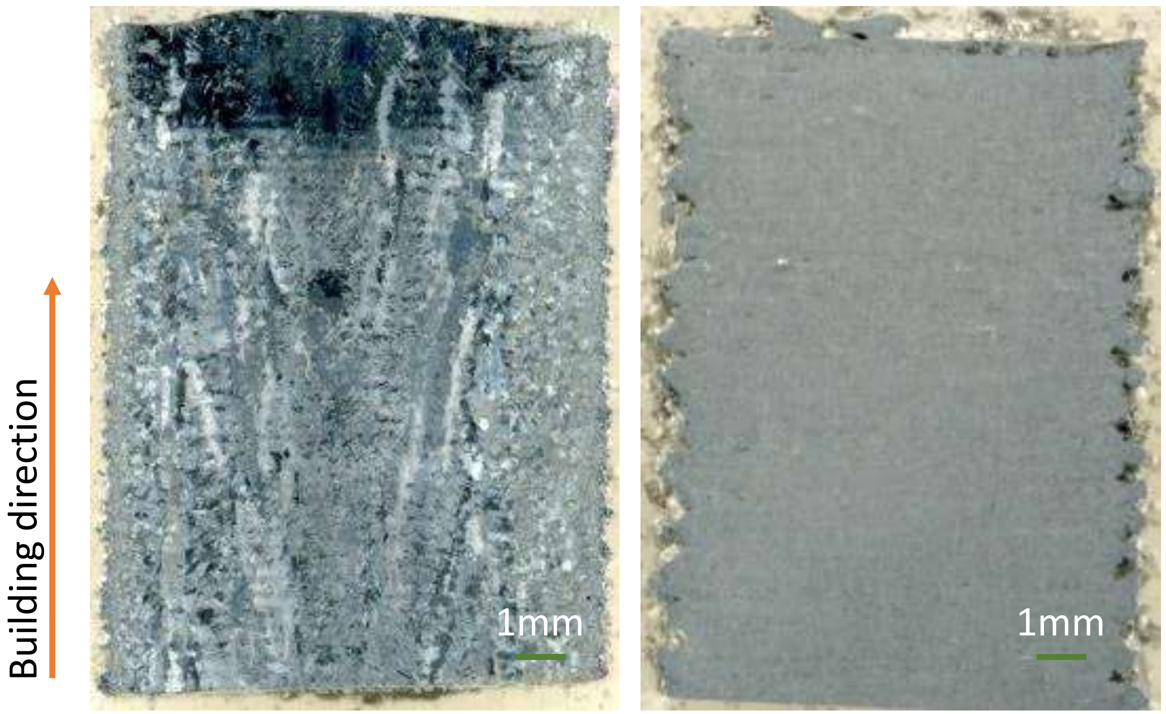
EBM

Simulation of the process

Thermal Model of the EBM Process

Observation

Sample 1- Line offset 2 units *Sample 2- Line offset 6 units*

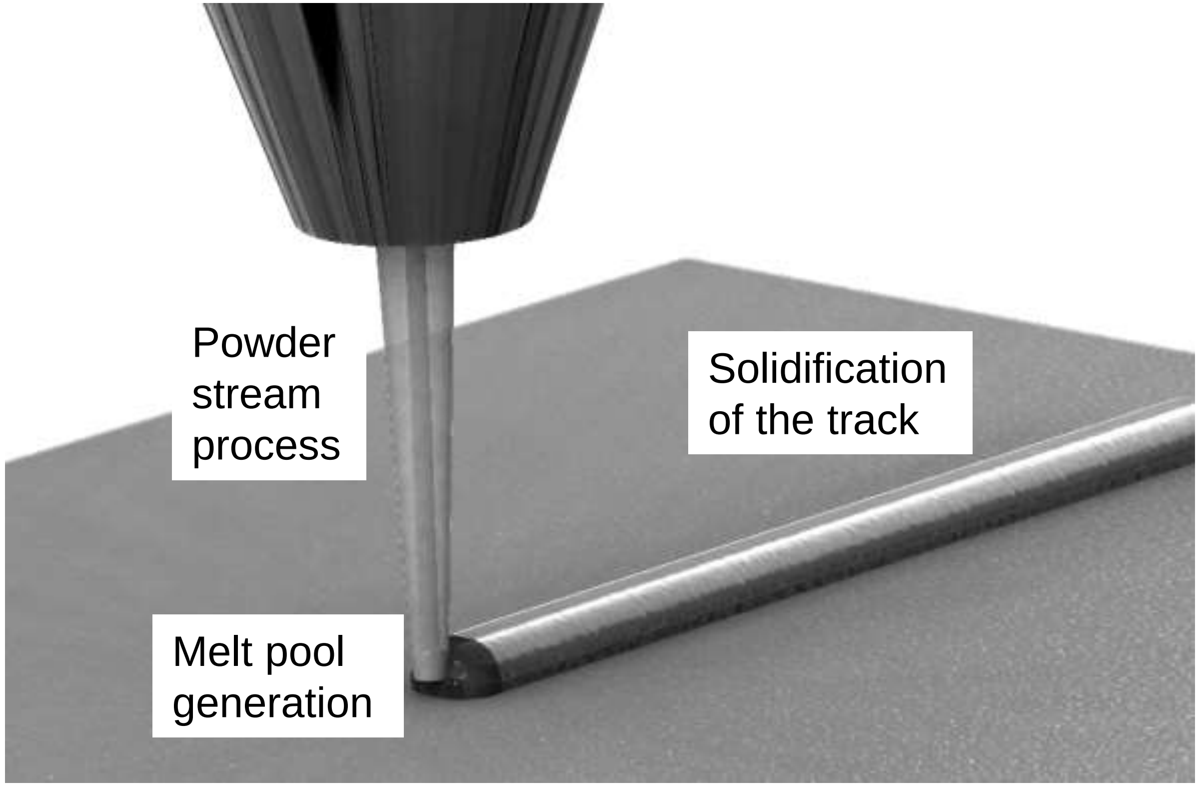


Effects of line offset:

- Microstructure
- Aluminum content

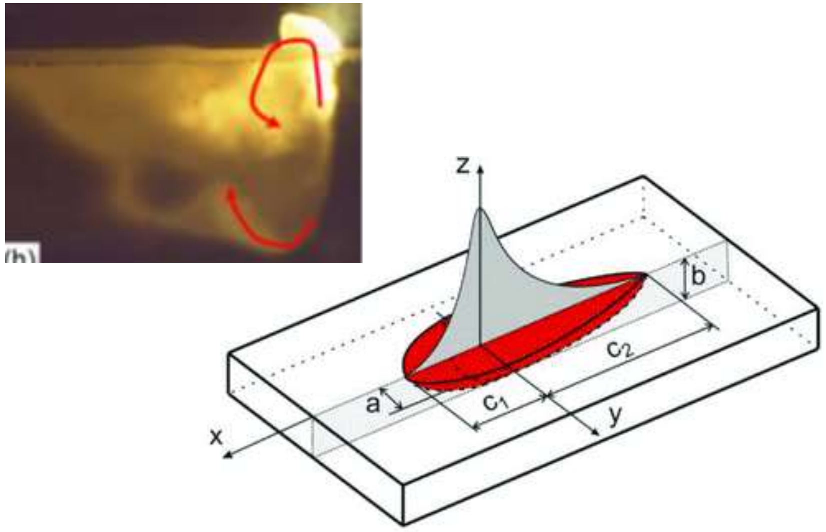
Three main mechanisms are involved in the LP-DED:

- powder stream process
- melt pool generation
- solidification of the track

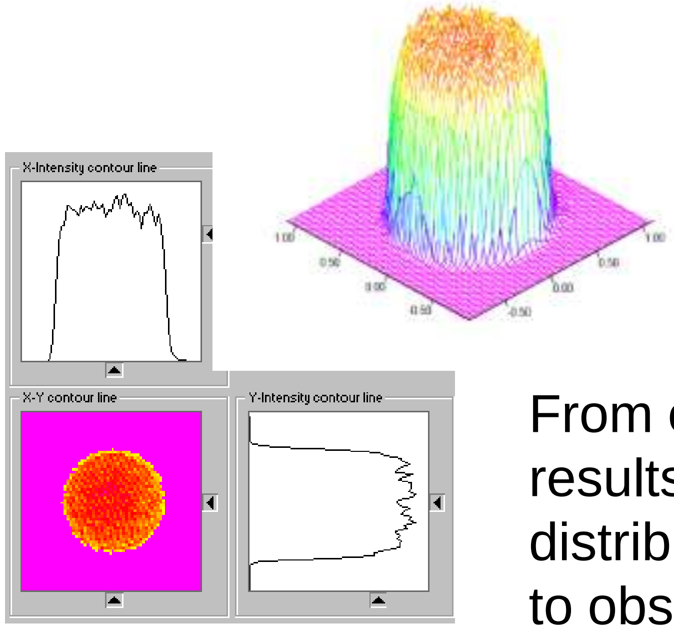


Assumptions

Heat Source distribution



The four parameters of the Goldak distribution are determined using experimental results of melt pool or as a function of weld width



From experimental results of laser beam distribution it is possible to observe that the spatial distribution on the focal plane is almost uniform

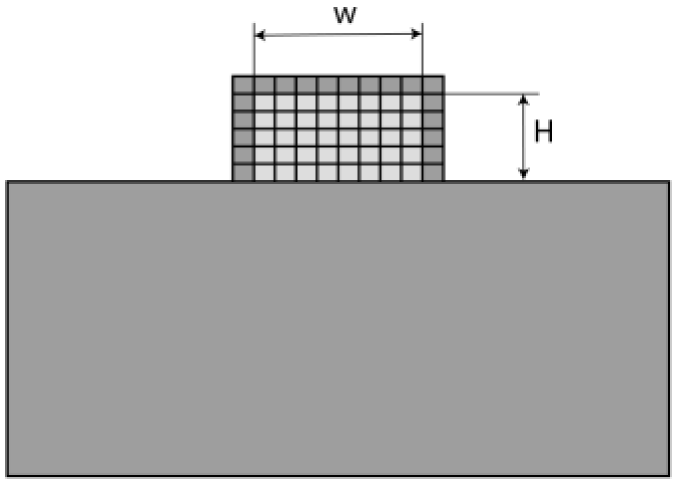
PROCESS SIMULATION

Assumptions

Activation strategy

The element activation allows simulating the addition of deposited material by adding elements into the computational domain.

The dimensions of the deposited track depend on the process parameters used.

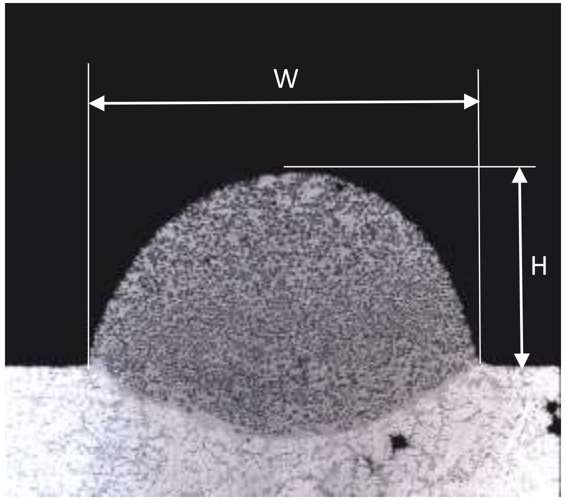


$$H = 0.0074 \times \tau_1 + 0.0461$$

$$W = 0.0030 \times \tau_2 - 0.0108$$

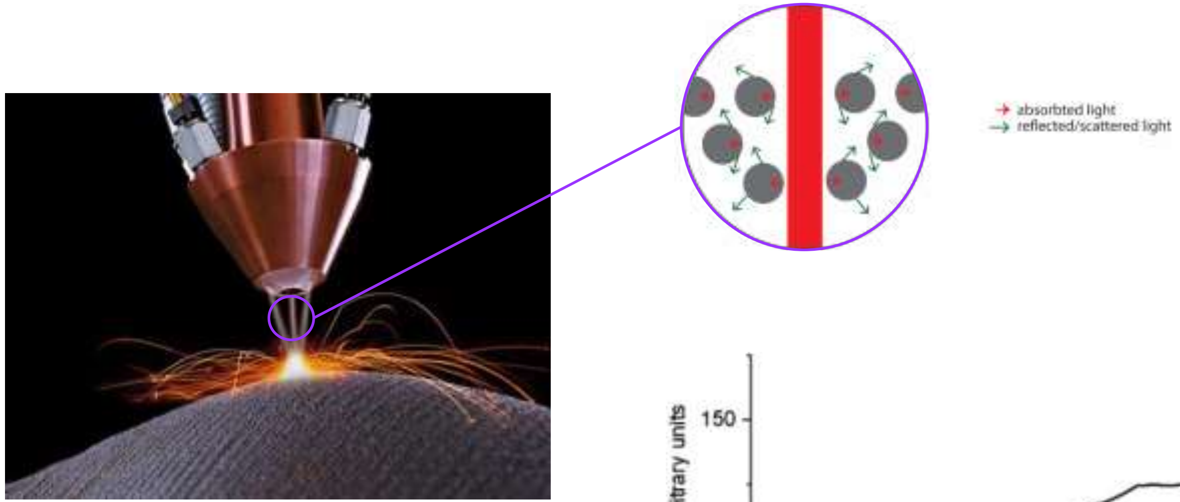
$$\tau_1 = \frac{P^{1/4} Q^{3/4}}{V^{-1}}$$

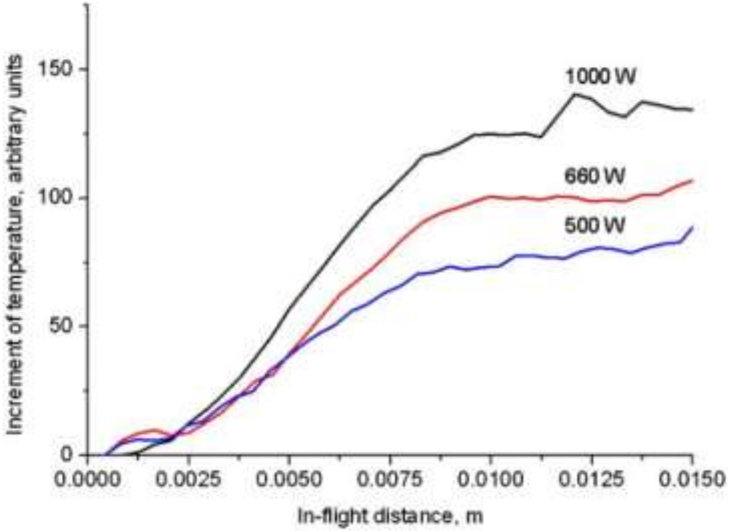
$$\tau_2 = \frac{P^{\frac{3}{4}}}{V^{\frac{1}{4}}}$$



El Cheikh et al., Analysis and prediction of single laser tracks geometrical characteristics in coaxial laser cladding process

Activating Temperature





The increment of temperature depends on laser power, in-flight distance, laser focus plane, powder focus plane.

No analytical relation allows to establish the increment of temperature.

According to experimental results a mean increment of temperature is

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Residual stresses

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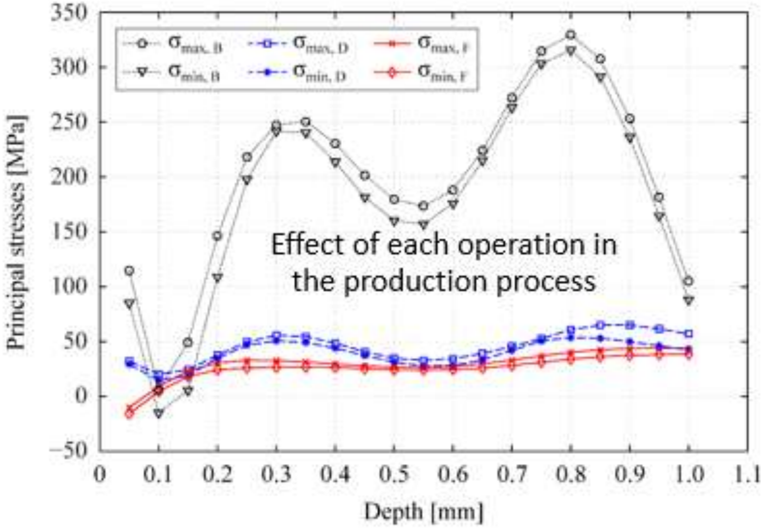
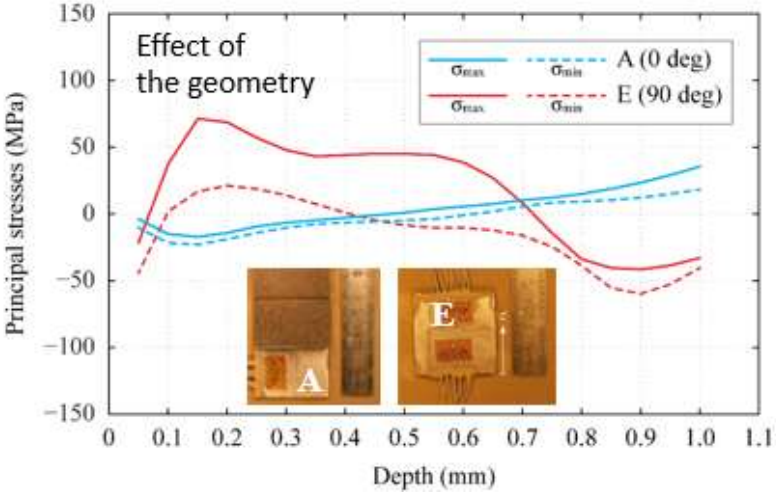
Evaluation of residual stresses at the macro-scale
By hole drilling strain gauge method

as-built | post thermal treatment | after the shot-peening





RESEARCH METAL

SLM

Surface finishing

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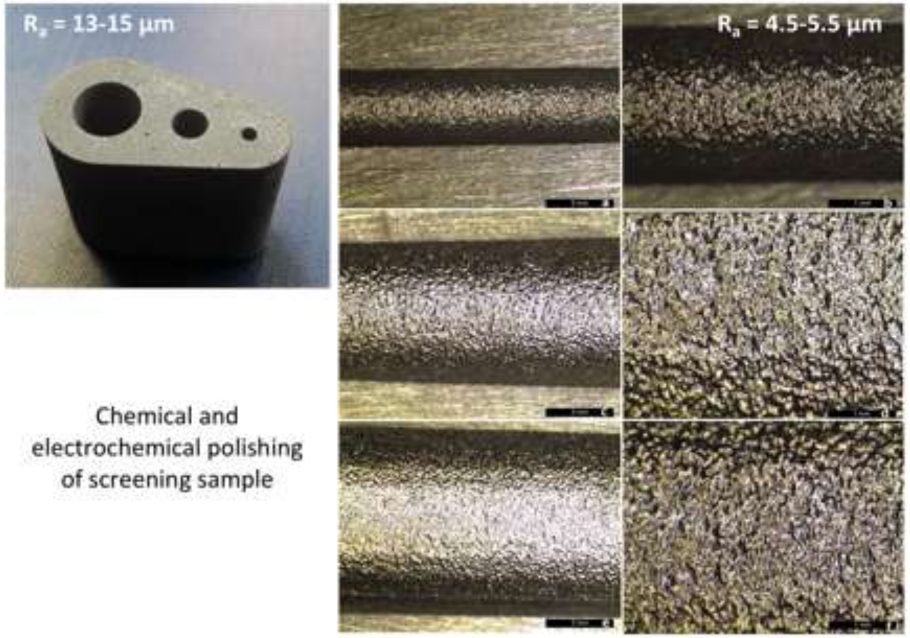
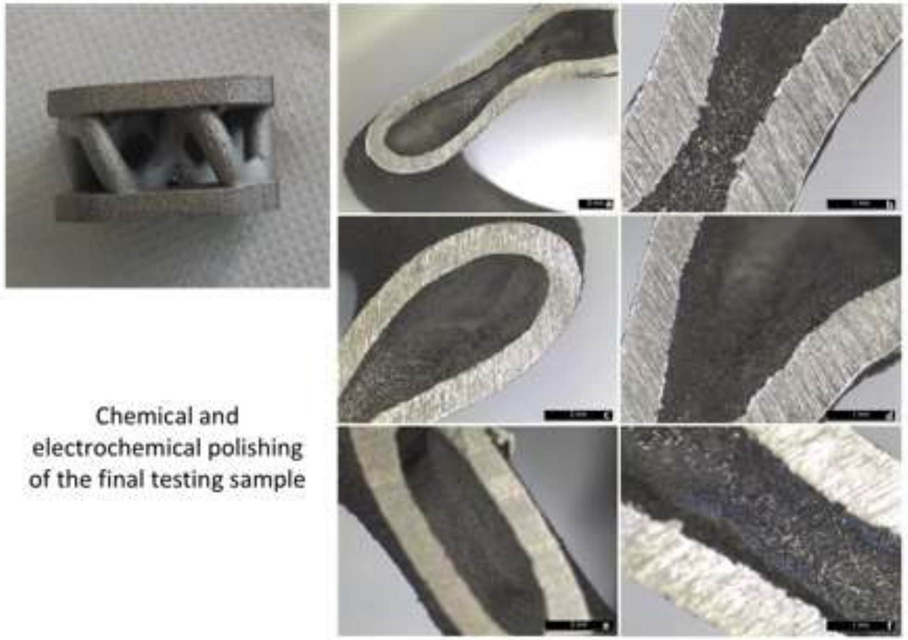
FIAMME - ASP Project
Finishing processes for additive manufactured metal components



Chemical and electrochemical polishing of screening sample



Chemical and electrochemical polishing of the final testing sample

Finishing to improve:

- Aesthetic features
- Dimensional tolerances
- Roughness
- Specific functionalities
- Fatigue resistance

Set-up of conditions for traditional and not traditional methods

SLM

Surface finishing

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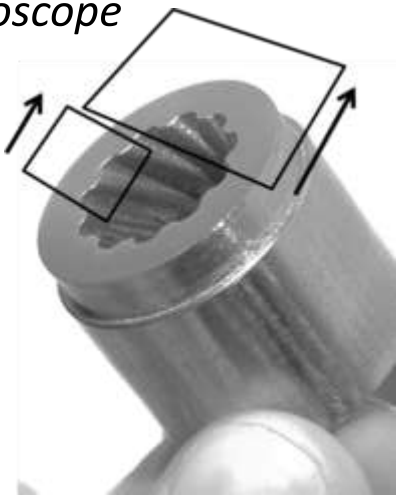
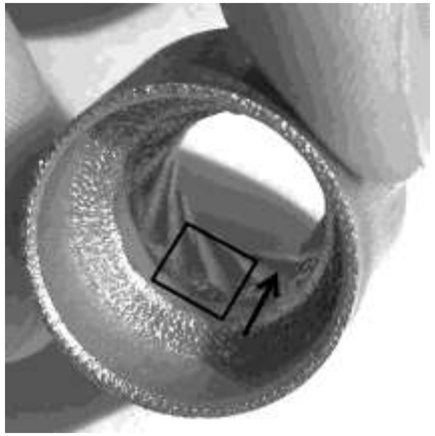
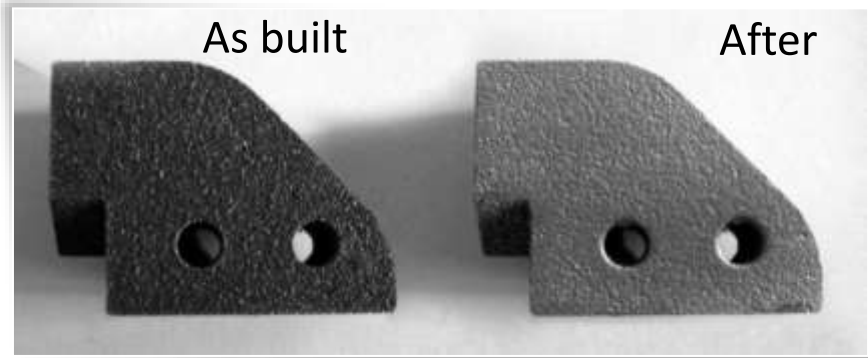
Combination of mechanical and electrochemical polishing, abrasive flow machining

Surface post processing → and subsequent stereomicroscope analysis and 3D scanning







Shot peening with glass microspheres (200μm) at 8 bar

R_a: from 17 μm to 5 μm

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Surface finishing

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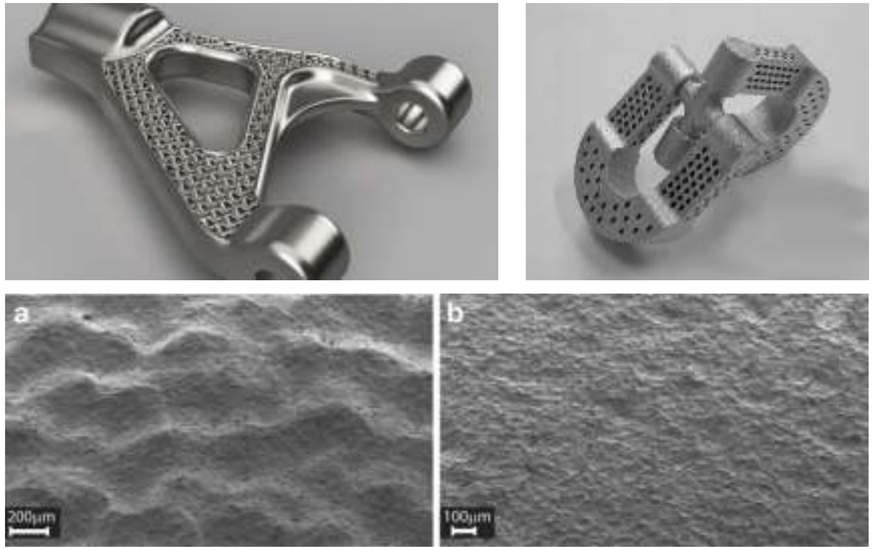
Finishing required for improving

- Aesthetics
- Dimensional accuracy
- Superficial roughness
- Mating surfaces and features
- Part functionality
- Tribological properties
- Fatigue life



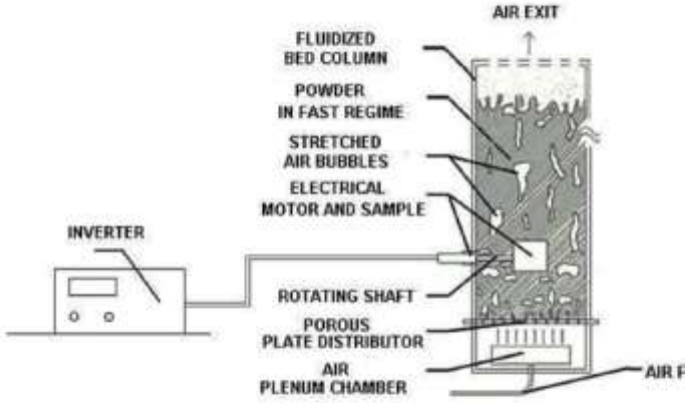
Current activities: conventional processes (polishing, etc.) and unconventional processes (abrasive flow machining, etc.)

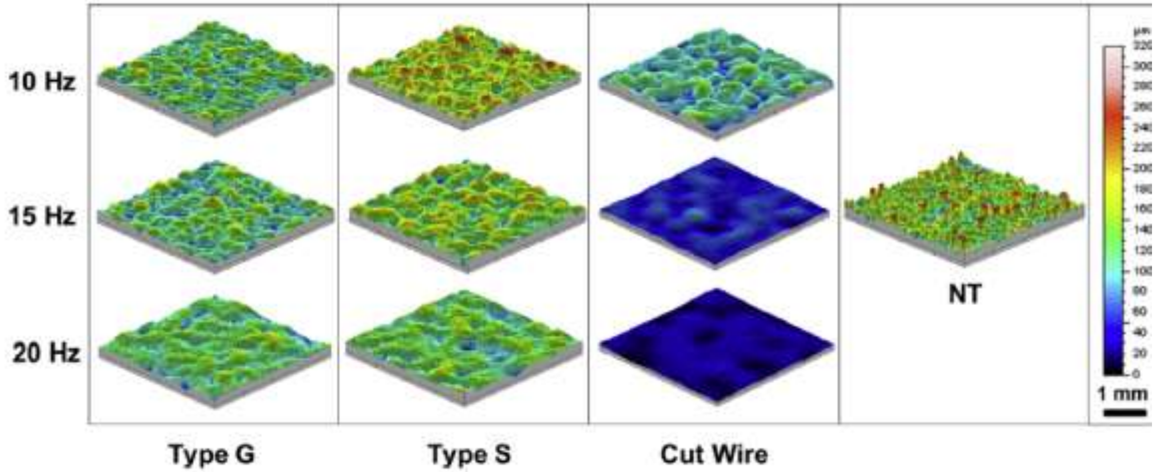
RESEARCH METAL

SLM

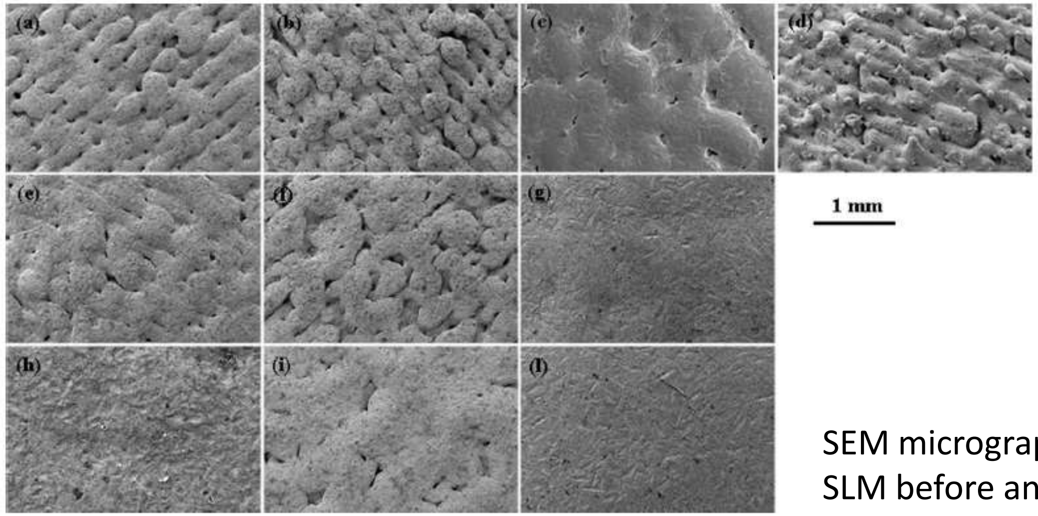
Surface finishing

Abrasive Fluidized Bed





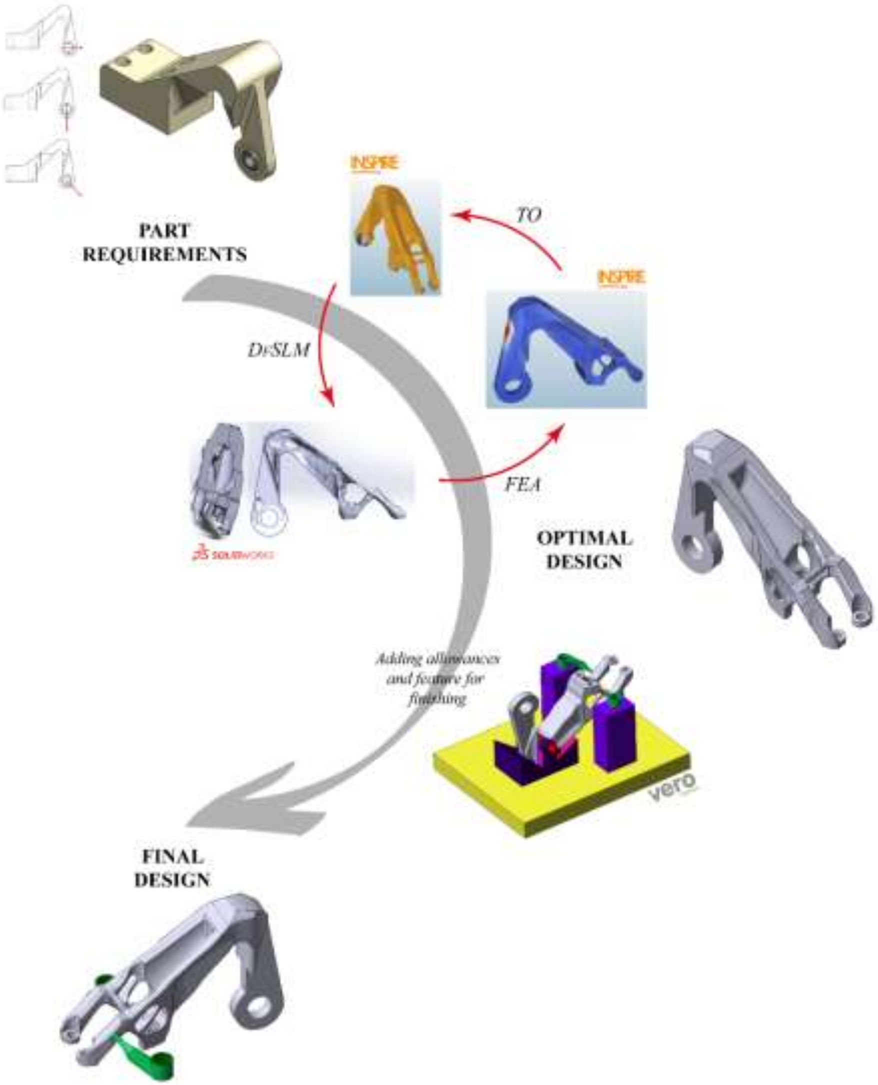
3D morphological maps of the AlSi10Mg substrates manufactured by SLM before and after AFB finishing.



SEM micrographs of the AlSi10Mg substrates manufactured by SLM before and after AFB finishing

Design for Additive Manufacturing (DFAM)

DFAM methodology is enhanced encompassing also the post-processing and finishing phases. In details, the requirements for the finishing phase (metal allowances, sacrificial features for clamping, …) should be considered in the design of the part in order to fully exploit the AM potential



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fabbrica intelligente

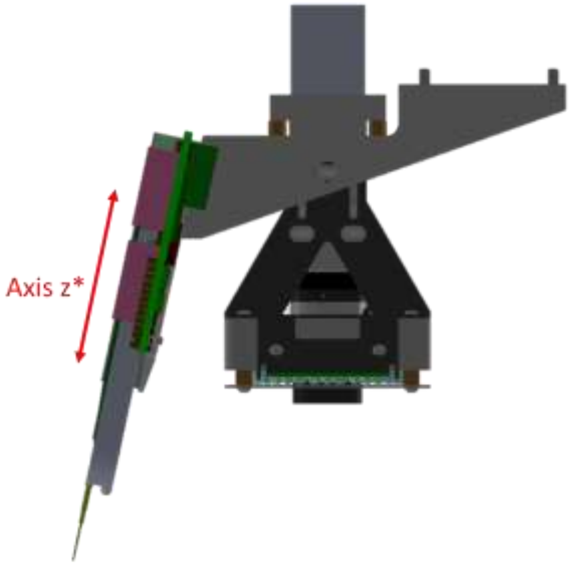
Project 4 "High Perfomance Manufacturing"

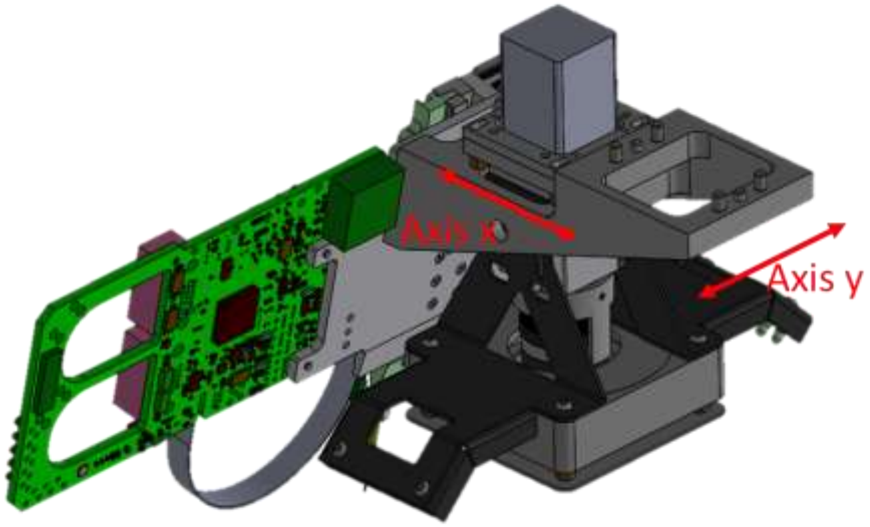
Smart Factory Cluster

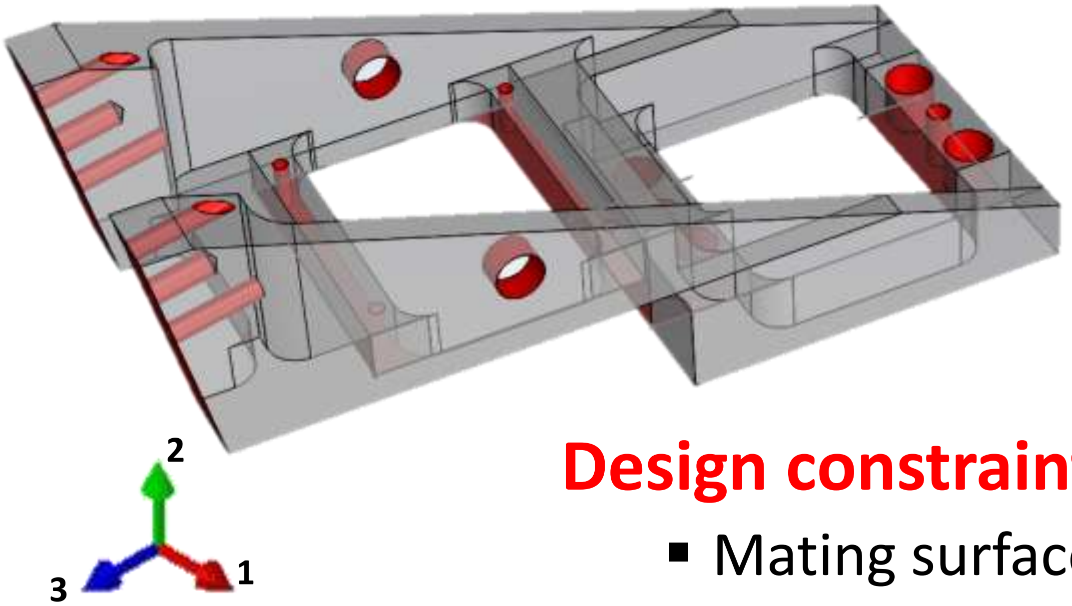
RESEARCH METAL

SLM

Topology Optimization







Design constraints

- Mating surfaces
- Centering holes
- Fixturing holes

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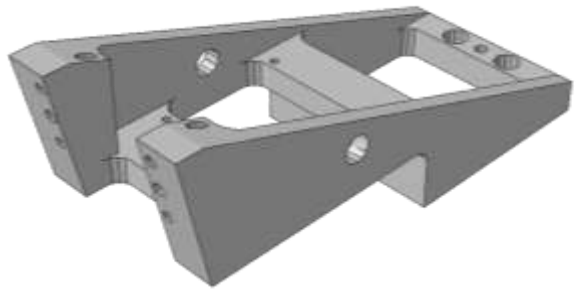
RESEARCH METAL

SLM

Topology Optimization



Original design

Initial weight = 200 g

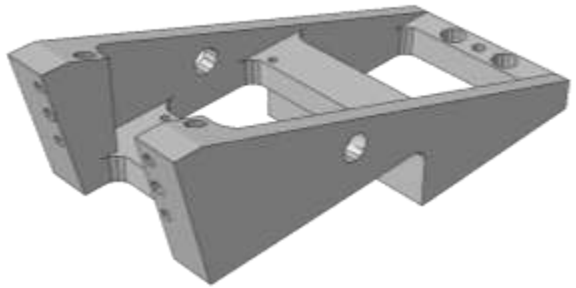
Result

–50% weight

Weight Reduction

SLM

Topology Optimization



Original design

Initial weight = 200 g

Result

+30% compliance

–10% weight

Maximization of compliance

SLM
Topology Optimization Approach

- Reduced manufacturing constraints
- Fabrication of the part with controlled density and complex surfaces
- The STL model resulting from topology optimization might be directly used for AM fabrication

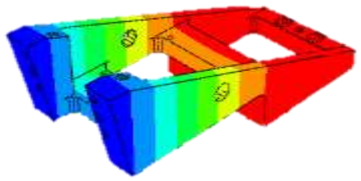
CAE Analysis
- Static analysis
- Dynamic analysis

Topology Optimization
- Identification of design goals
- Definition of constraints
- Selection of AM material and process
- Topology optimization

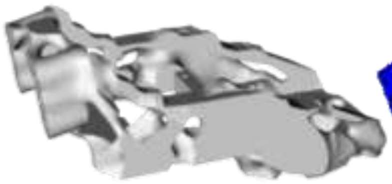
Post Processing
- CAD modelling and geometry optimization
- Validation through CAE analysis

Conceptual prototype
- Design evaluation

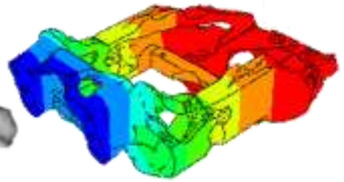
Manufacturing
- Additional material as allowance for finishing
- Fabrication of the part



Weight = 200 g
Max displacement = 31 µm

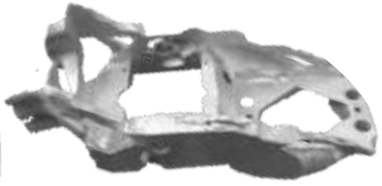


Material AlSi10Mg



Weight = 184 g (-10%)
Max displacement = 18 µm

Material ABS
FDM

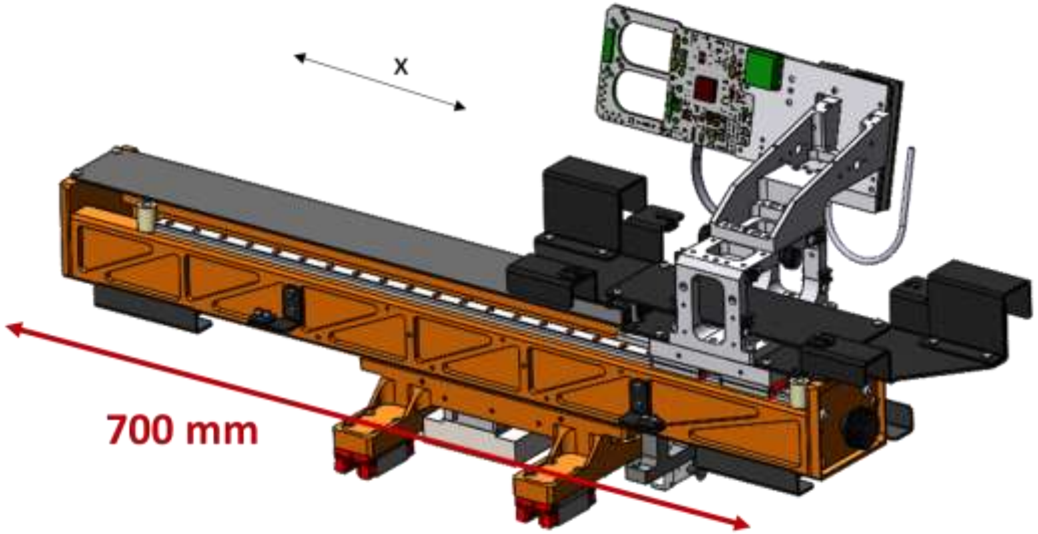


Material AlSi10Mg
SLM

SLM

Topology Optimization

18 componenti



Originale

1 componente
Peso -15%

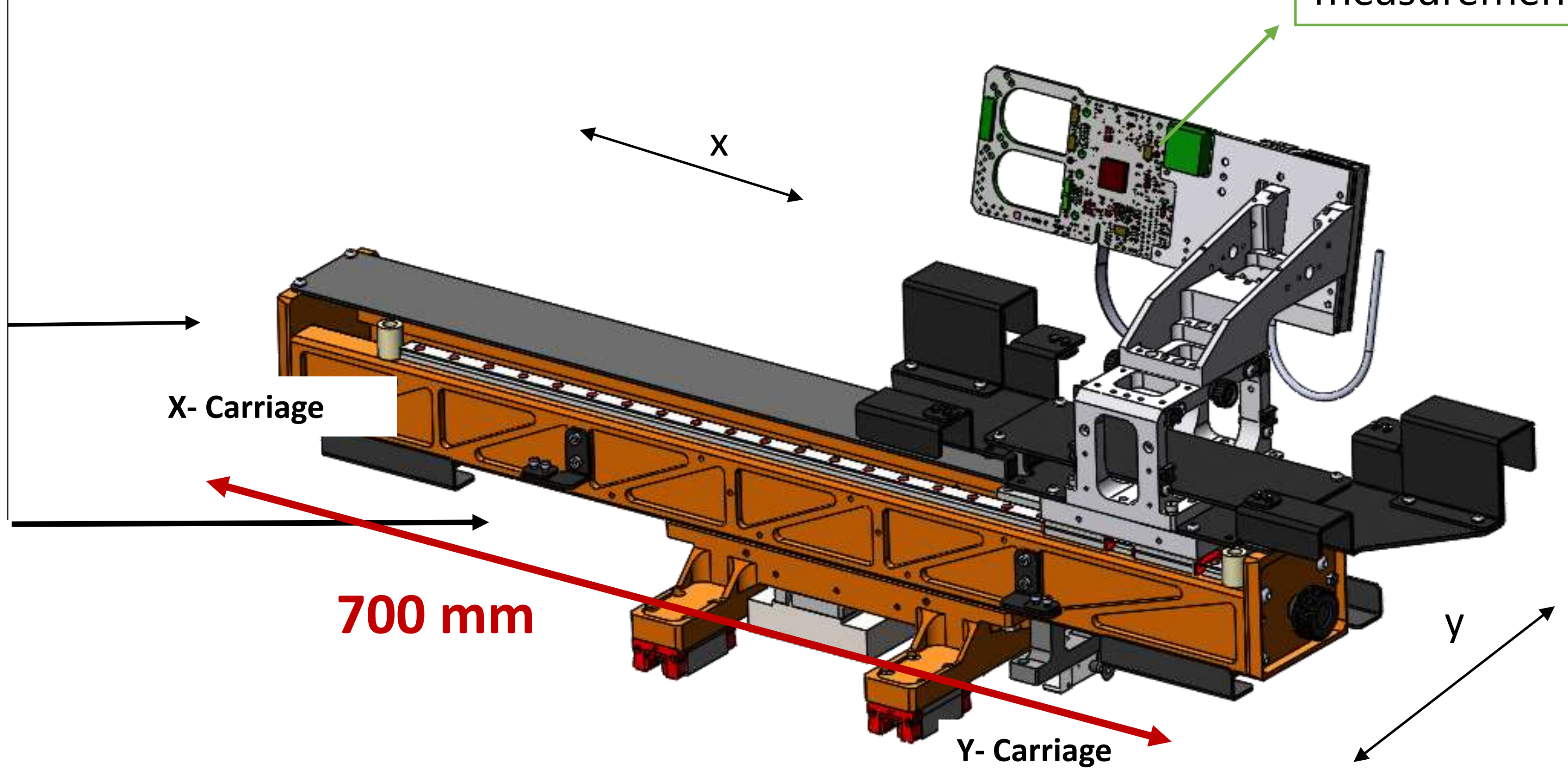
Ottimizzato

CASE STUDY

STRUCTURE

Two fixed parts connected to each other, Y- carriage and X-carriage

A moving part, on which the measurement system is placed



High Stiffness systems

CASE STUDY

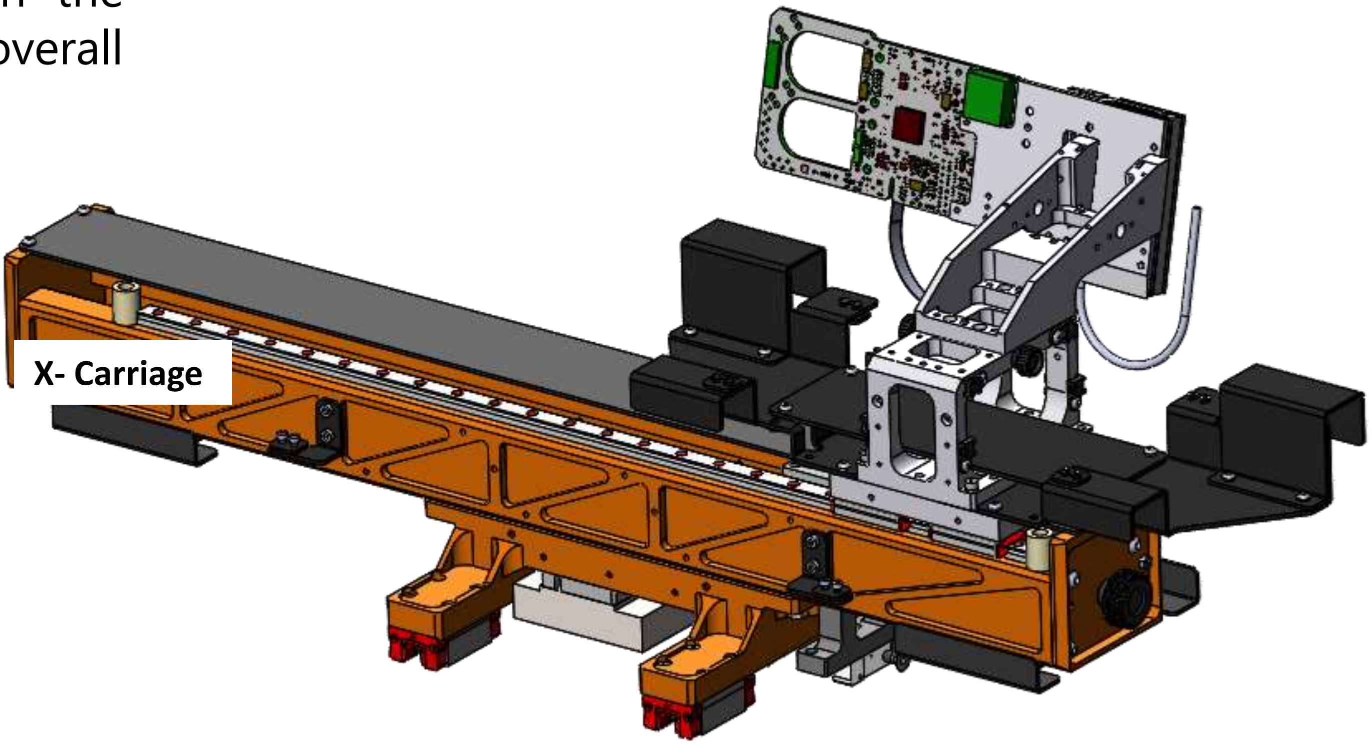
Basic structure of the coordinate measuring system

TARGET

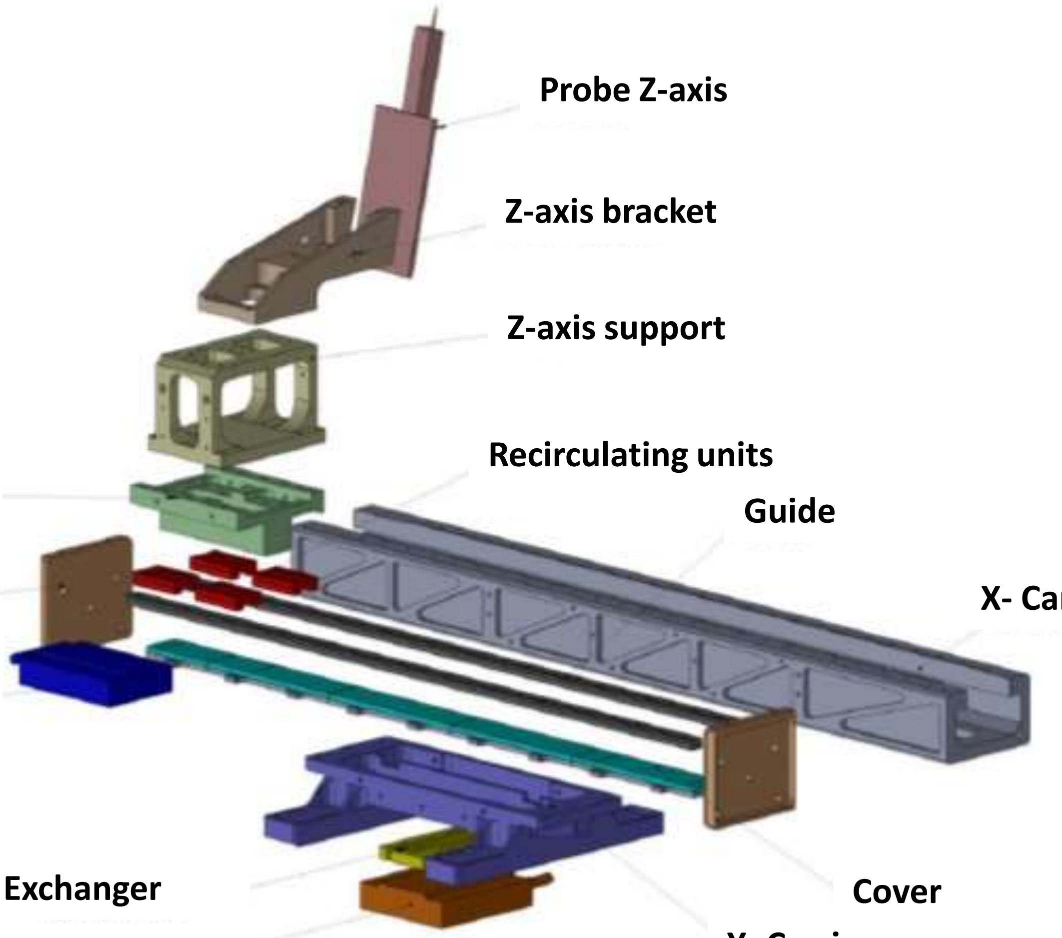
Redesign the carriage in order to lighten the structure overall, trying to keep the overall rigidity unaltered.

CONSTRAINTS

- Maximum envelope equal to original
- Freezing the areas of coupling to other systems
- Using similar material, to highlight the potentiality of good design
- Maximum displacement for each axis that have not exceed 25 μm



CASE STUDY



Design for Assembly:
Y - carriage
X - carriage
Side covers

Parts	Weight [g]
X - carriage	3113
Y - carriage	1062
Side covers	146
Total	**4321**

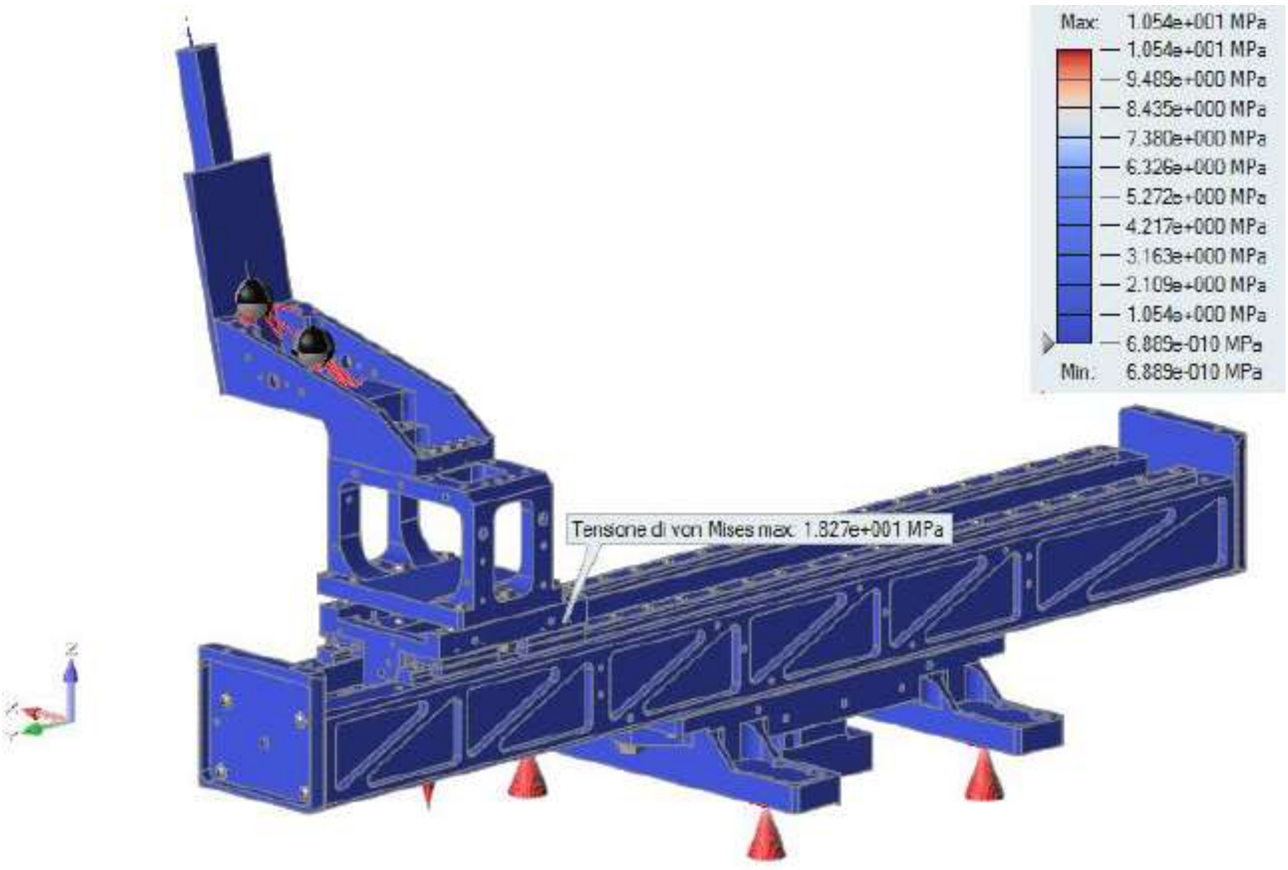
Overall dimensions of the structure :
88 x 690 x 54 mm^3

CASE STUDY

FEM ANALYSIS

ORIGINAL COMPONENT

Von Mises



Material: Al7075-T6

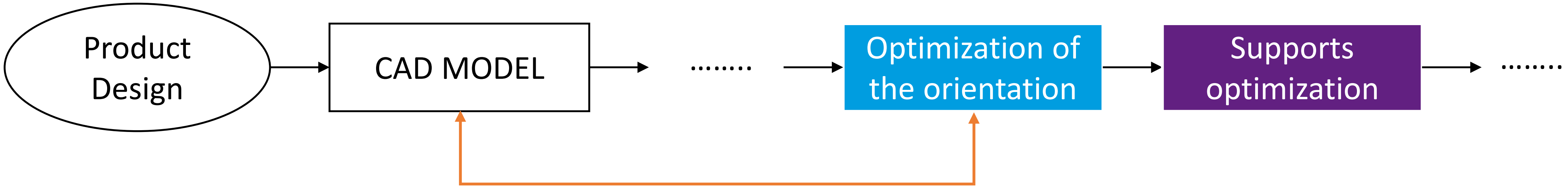
- Maximum equivalent stress on the component is far below the limit of the material
- Maximum displacement around 25 µm

Maximum displacement [µm]	FS min	Von Mises max [Mpa]	Weight [g]
26	43	18	4321

CASE STUDY

DESIGN FOR L-PBF

PRELIMINARY STEP



THEY ARE DEPENDENT PHASES

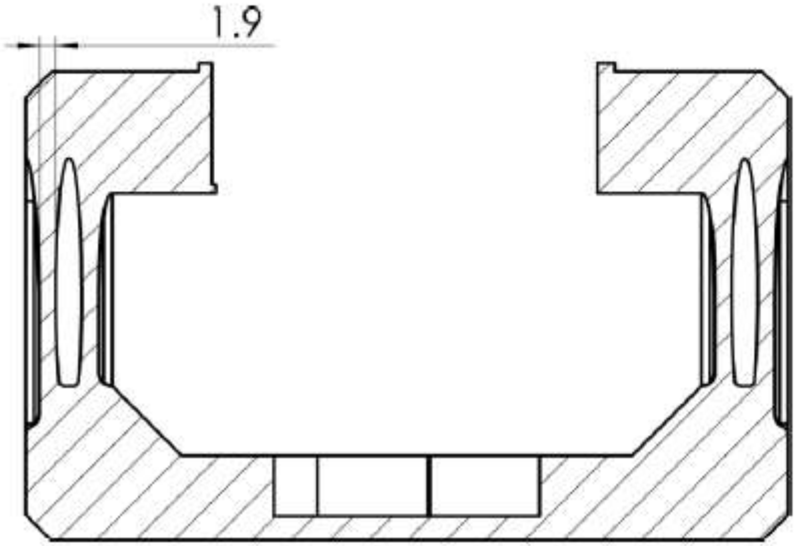
After modeling, the component should be modified according to the chosen orientation

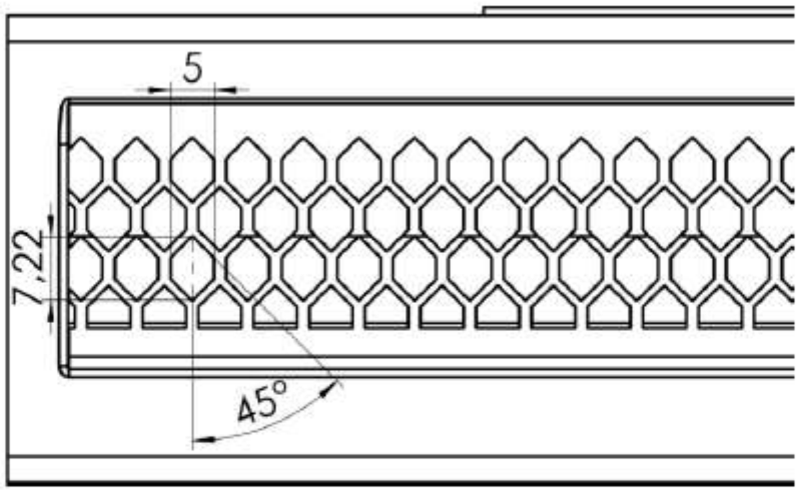
- Lower cost,
- less deformation,
- control surface roughness,
- etc.

CASE STUDY

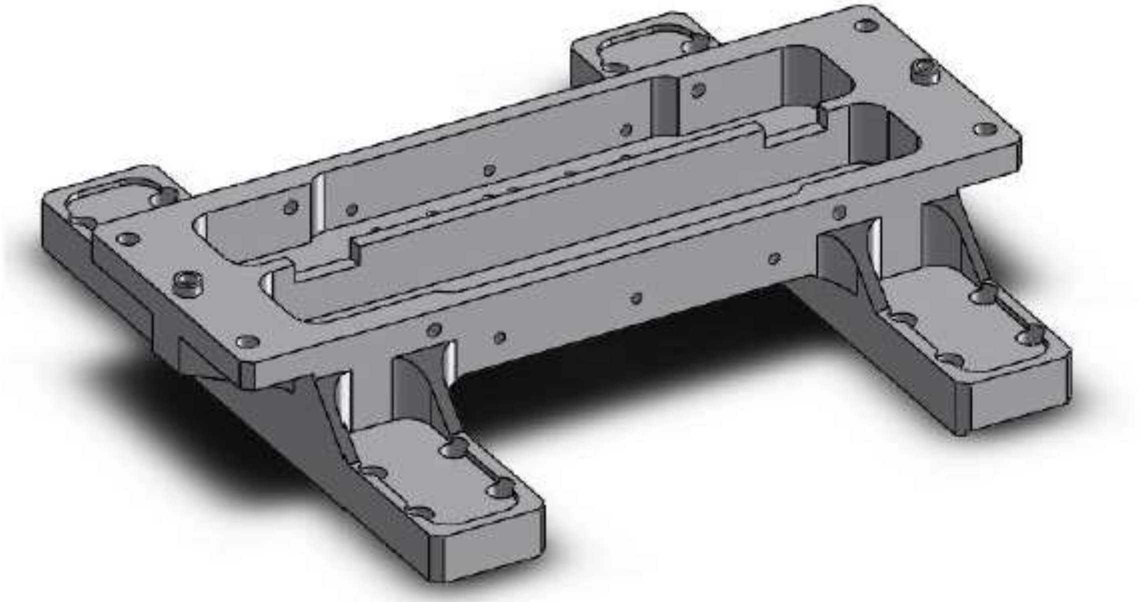
DESIGN FOR L-PBF

X - CARRIAGE

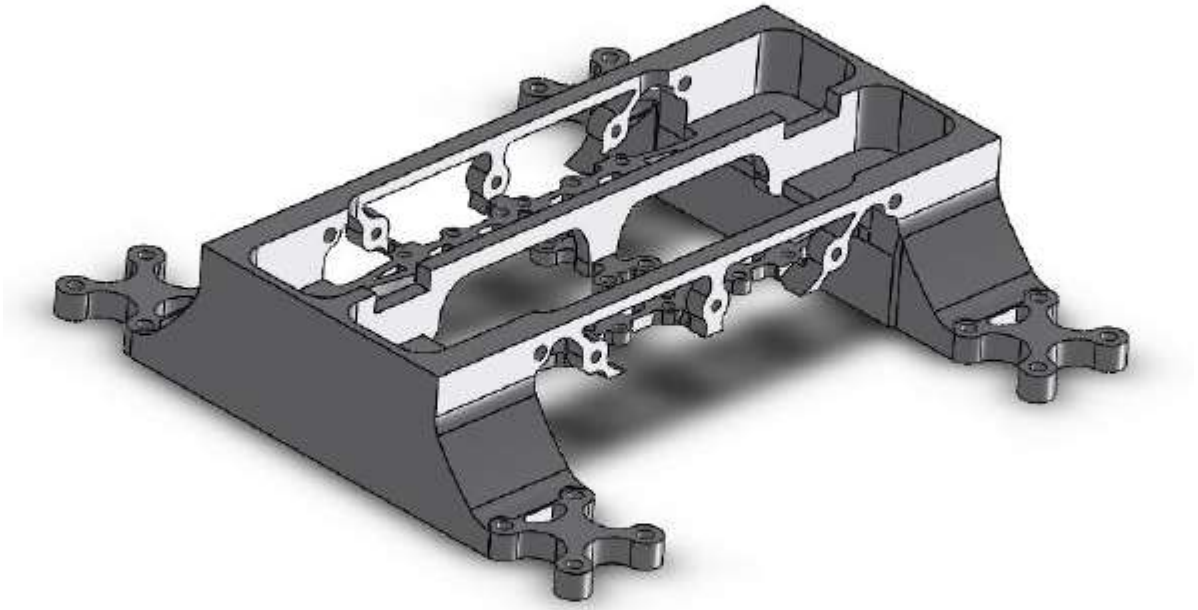




Y - CARRIAGE

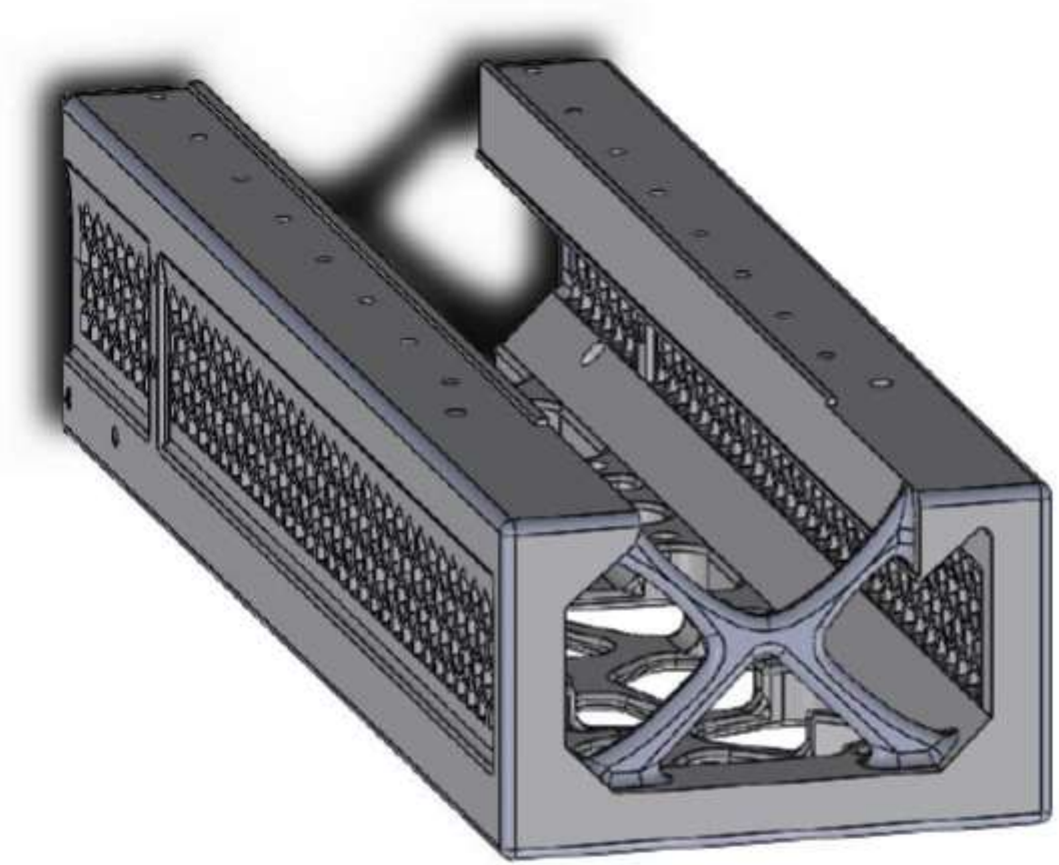


Original



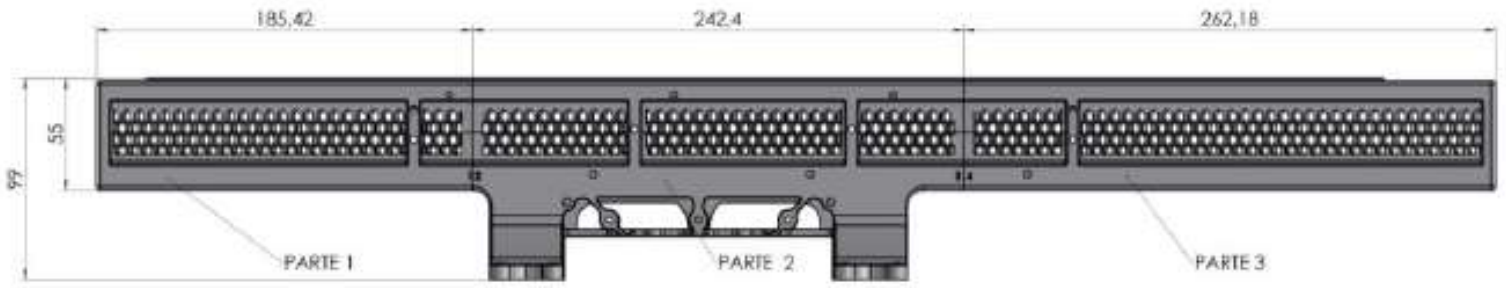
New design (AM)

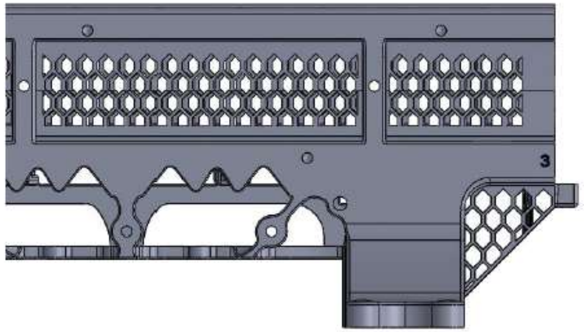
Side cover

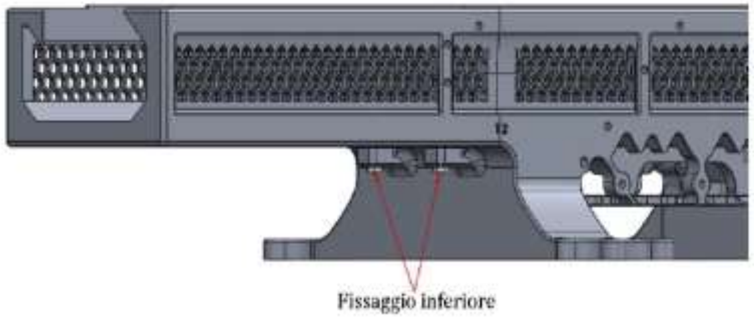


CASE STUDY

DESIGN FOR L-PBF







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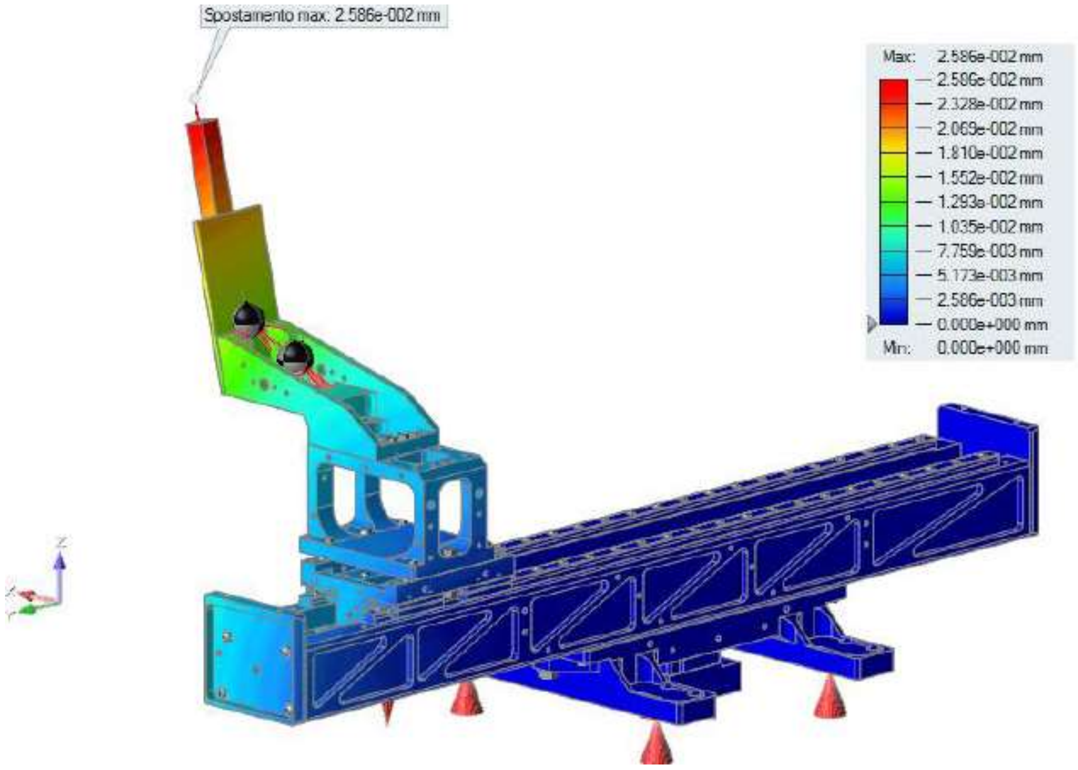
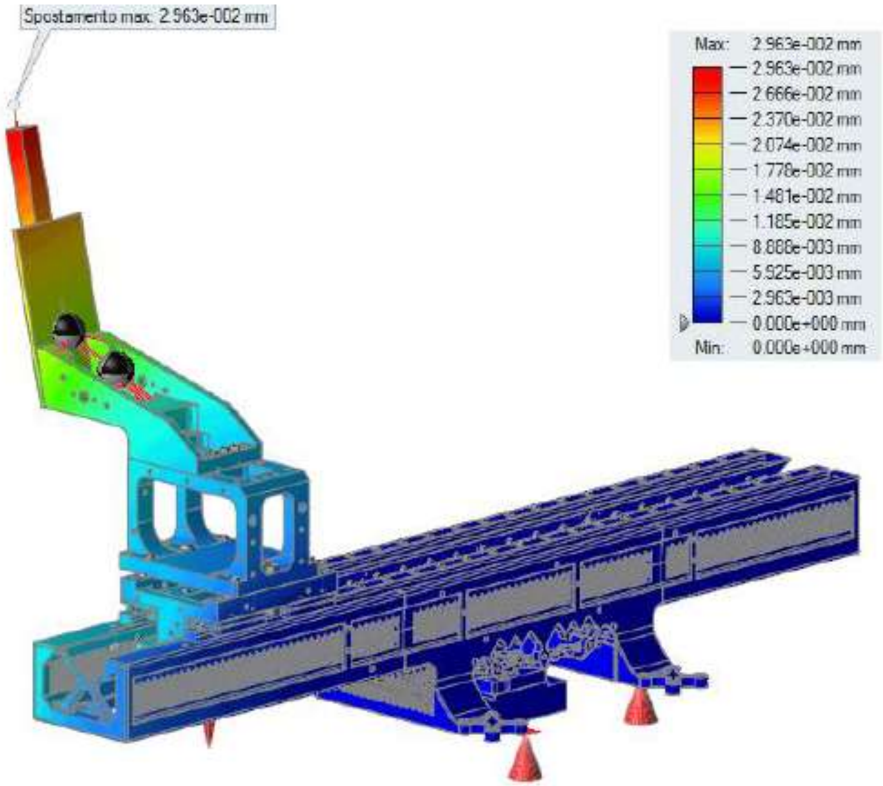
CASE STUDY

DESIGN FOR L-PBF





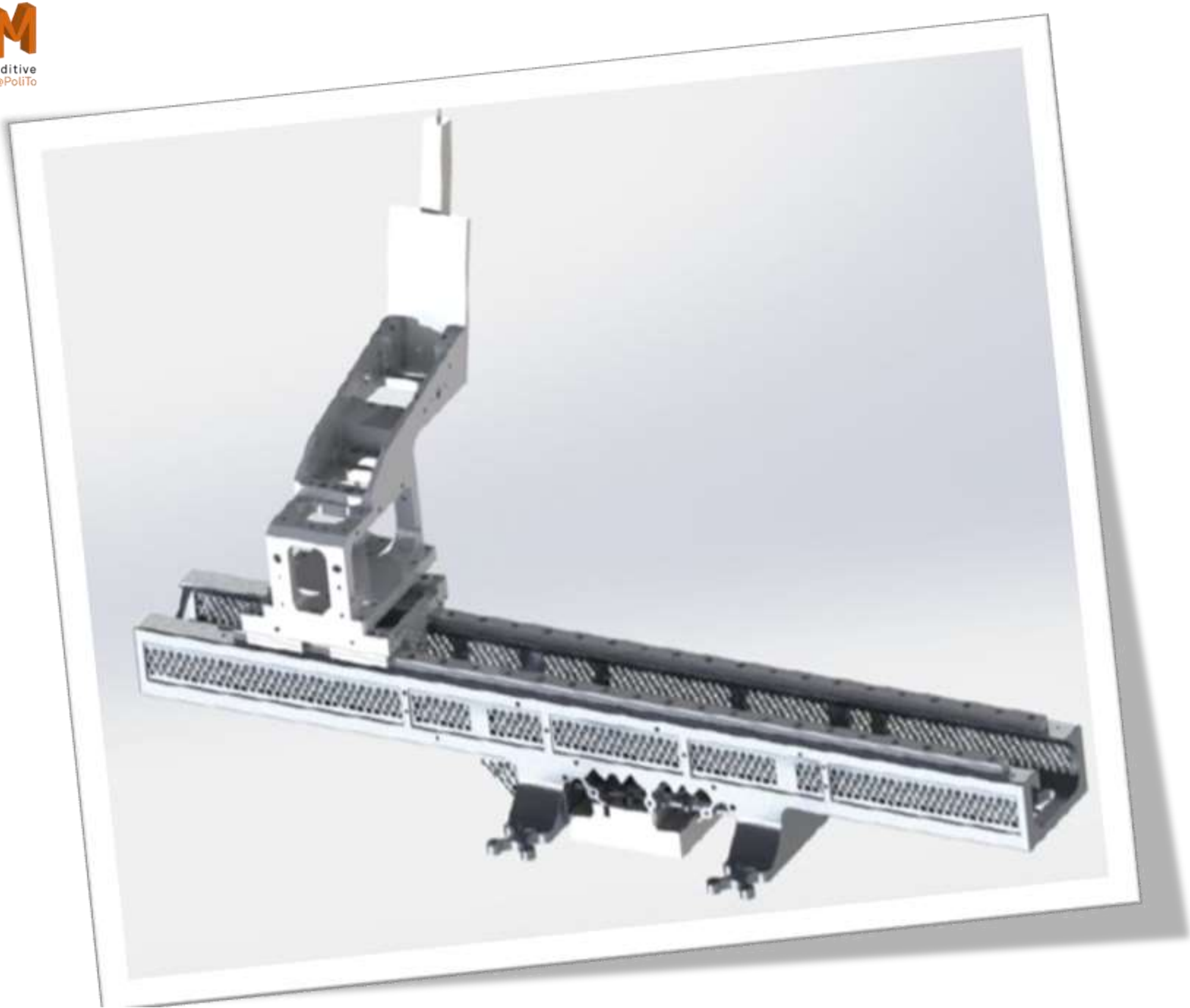
Material: Al7075-T6

Weight 4321 g

-32%

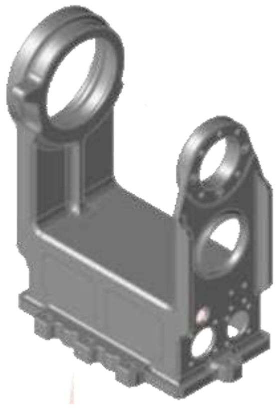
Material: AlSi10Mg

Weight 2947 g



SLM

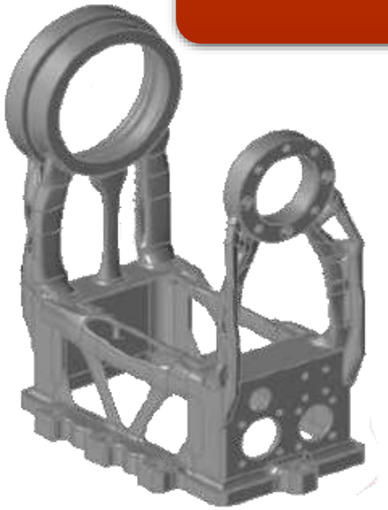
Topology Optimization



Original design

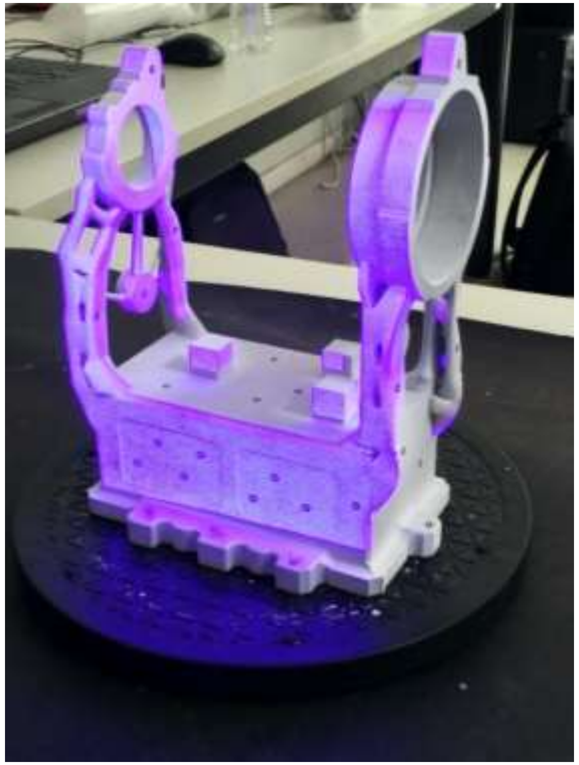
Result

–27 % weight

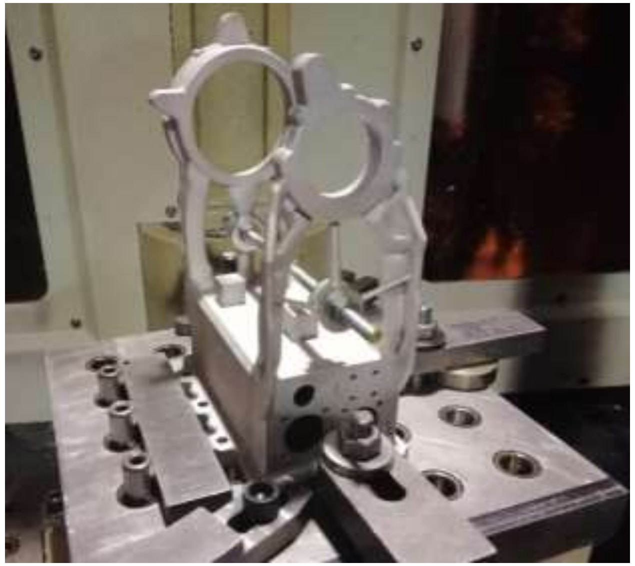


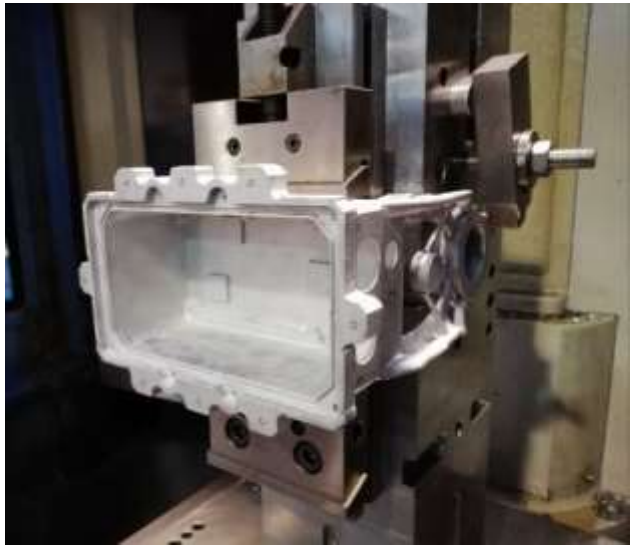
SLM

Topology Optimization



3D scanner



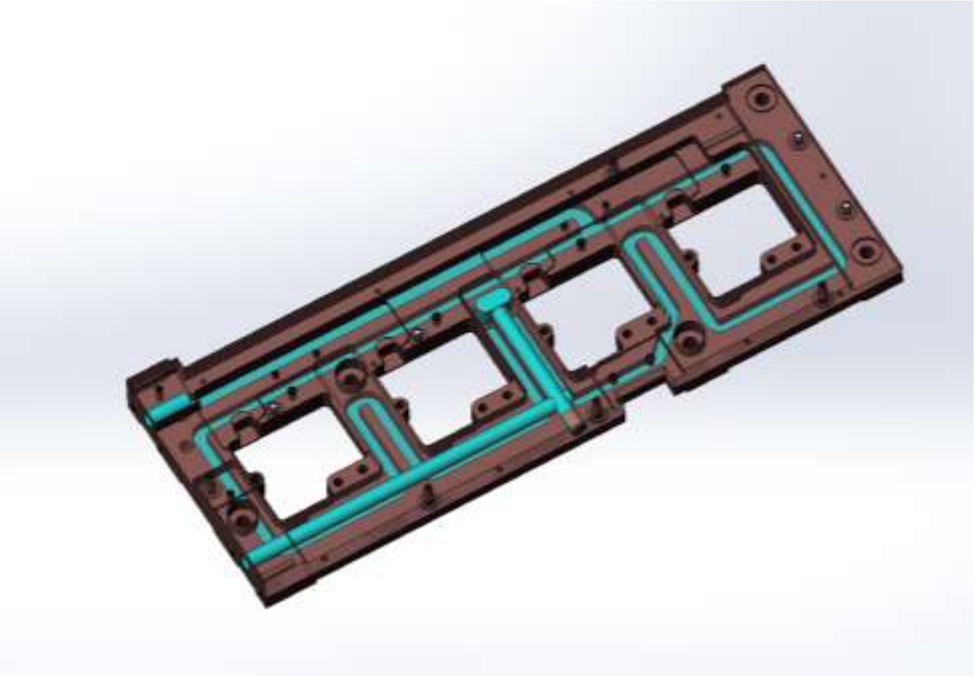


Conventional machining

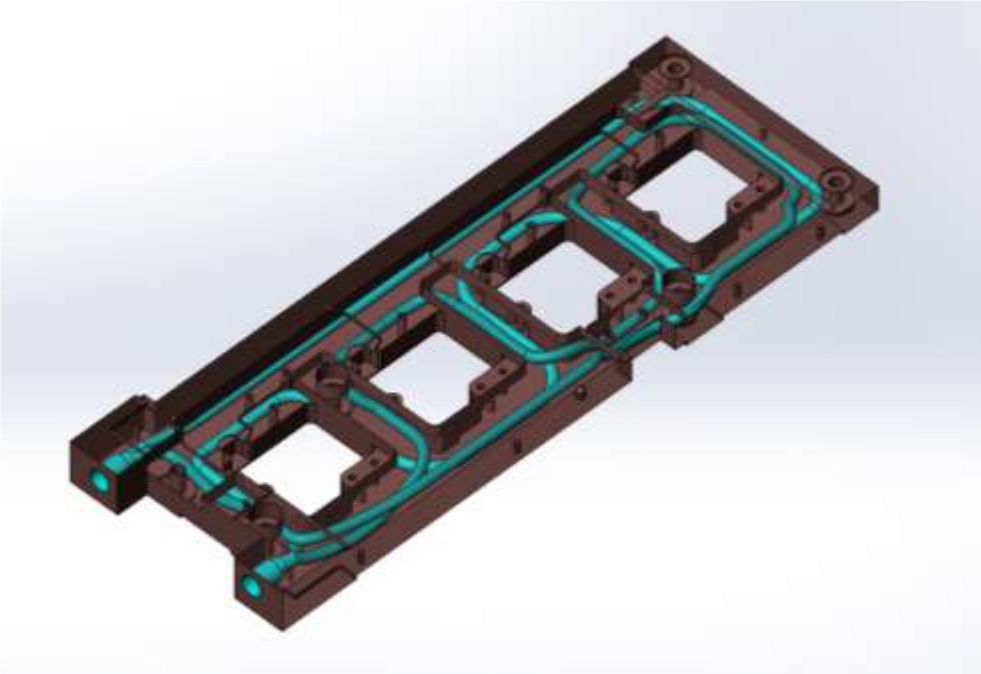
Final component

SLM

Topology Optimization



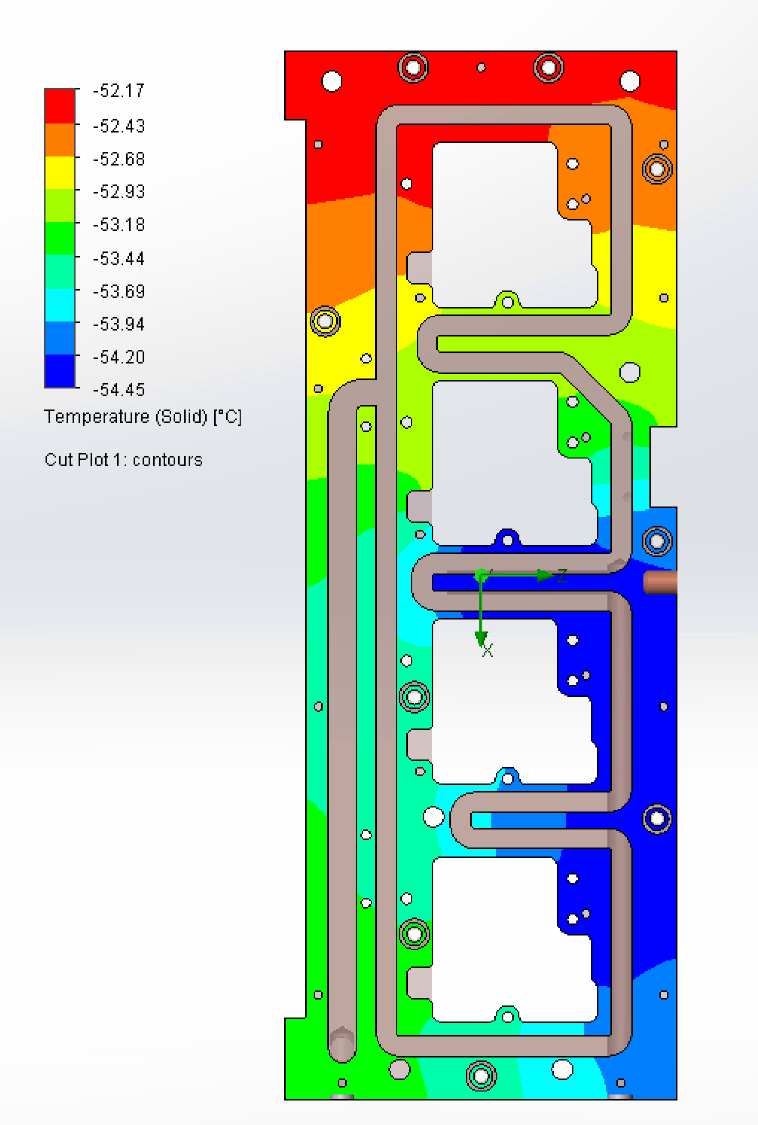
Componente Originale



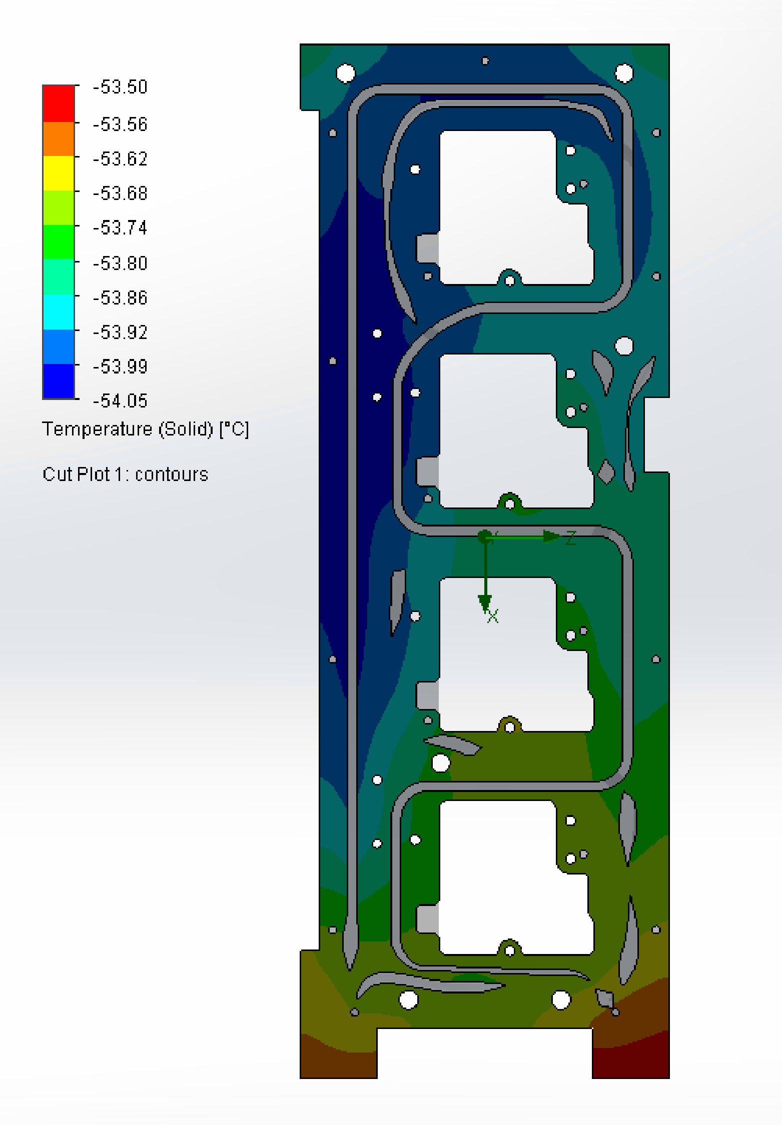
Canali di raffreddamento conformali

SLM

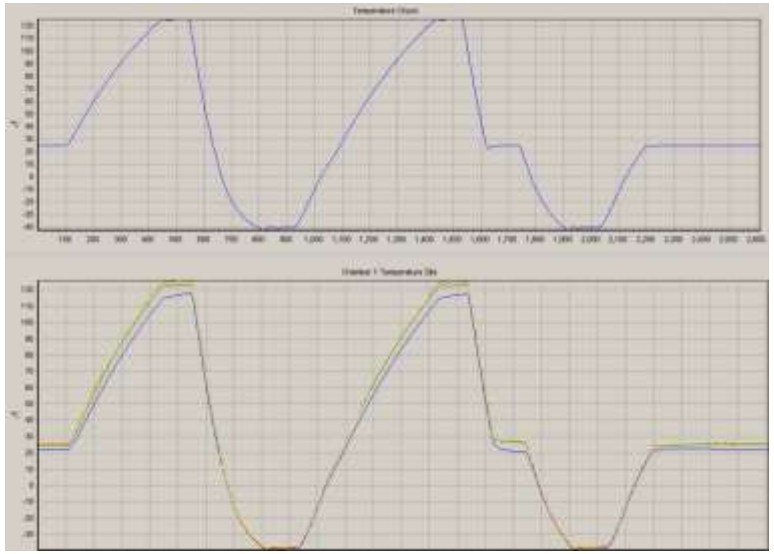
RESEARCH METAL

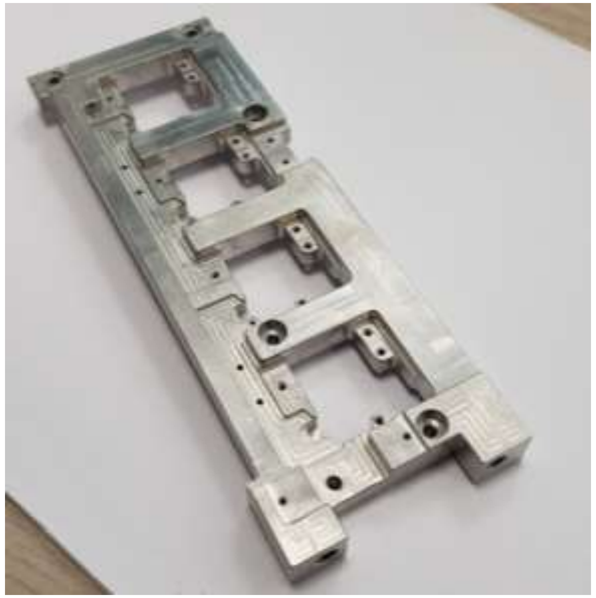


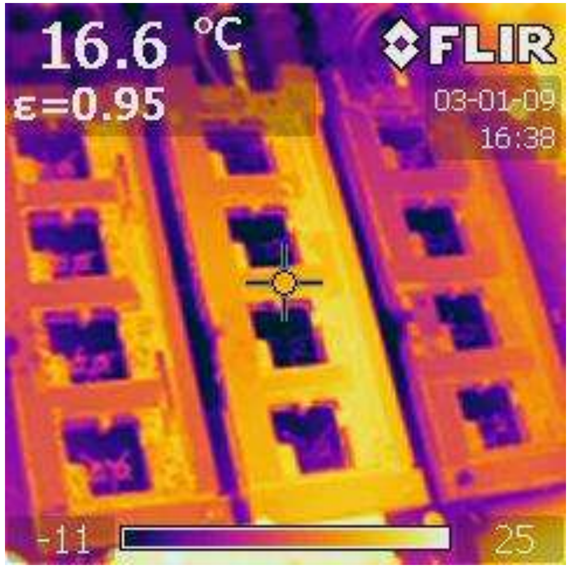
Riduzione dello spread termico
76%



SLM







		Copper (conventional)	Copper (3D printing)	Aluminium (3D printing)
	T max dispersion	2,5 °C	0,7 °C	1,5 °C
	Heating time	490 s	500 s	415 s
	N. components	13	1	
Cost [€]	Semifinished		1525	475
	Rework		300 (est.)	300 (est.)
	Total	798	1825	775

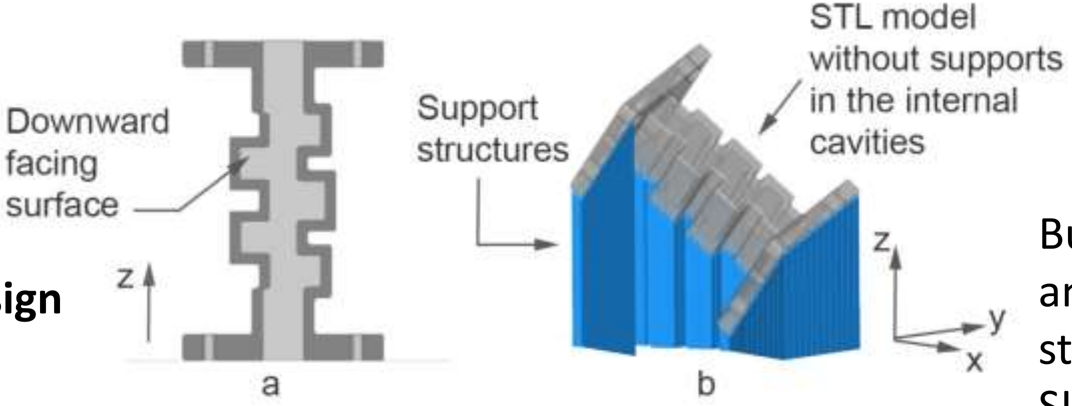
RESEARCH METAL

SLM

Design, building orientation & support structures' optimization

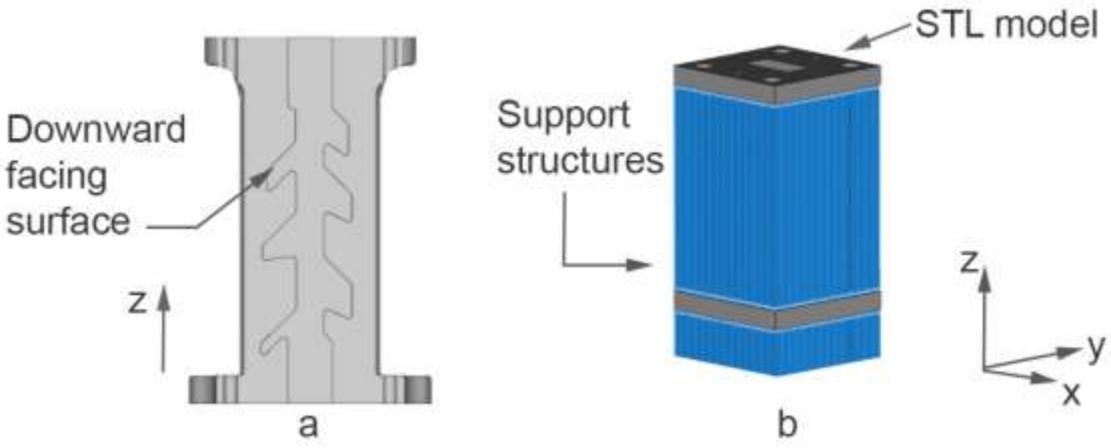
KU/K BAND WAVEGUIDE FILTERS

Fifth-order Ku/K-band low-pass filter: **typical design**



Building orientation and support structures for the SLM process.

Sixth-order Ku/K-band low-pass filter: **design, building orientation and support structures for the SLM process**.



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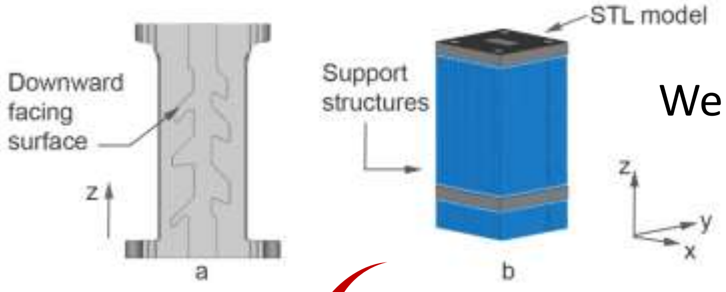
RESEARCH METAL

SLM

Design, building orientation & support structures' optimization

KU/K BAND WAVEGUIDE FILTERS

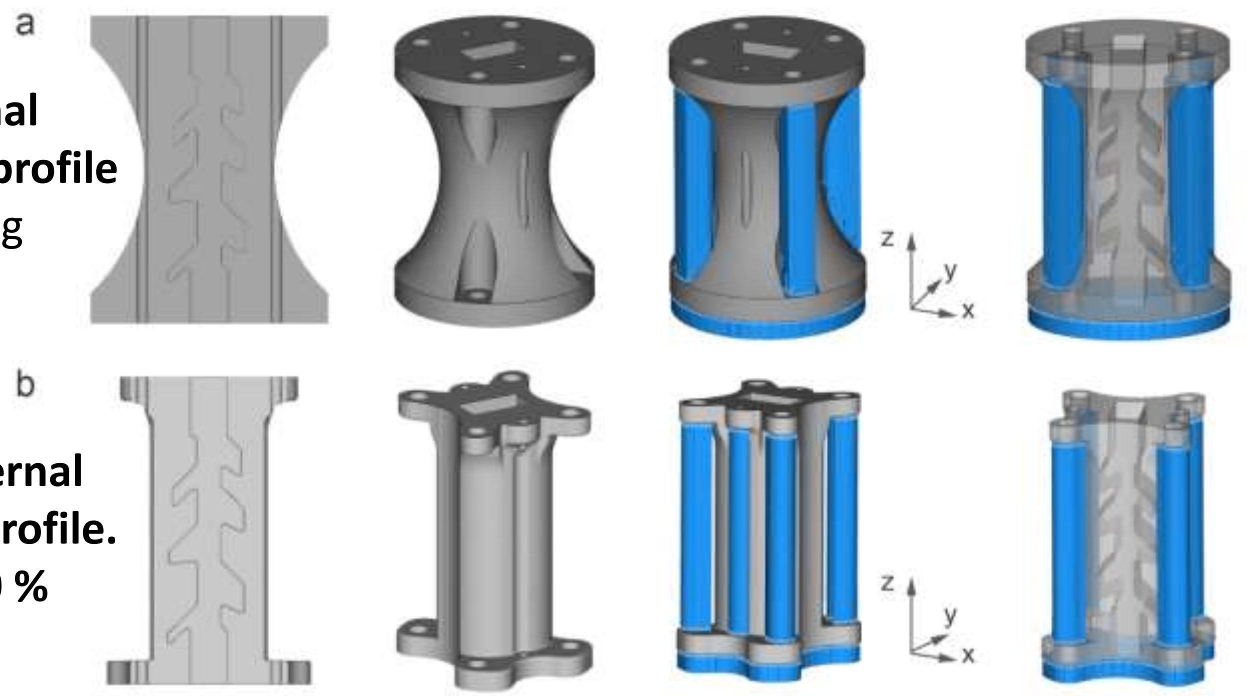


Weight: 27 g

In order to reduce the support structures also for the external profile

First external optimized profile
Weight: 76 g

Second external optimized profile.
Weight: **- 50 %**



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SLM

Design for AM of a non-assembly robotic mechanism

Lattice structures
Non-assembly mechanisms

Hydraulic Manifolds for HyQ (Hydraulically Actuated Quadruped Robot)

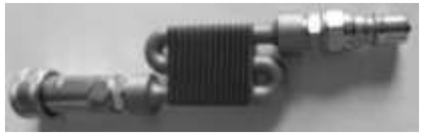

Photo courtesy Oak Ridge National Laboratory's Manufacturing Demonstration Facility

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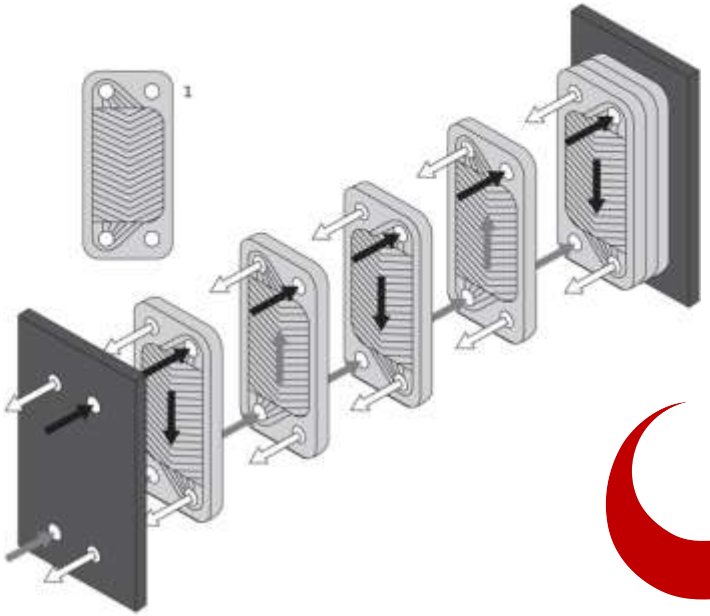
RESEARCH METAL

SLM

Design for AM of a heat exchangers

Traditional design process



New concept

New design structures to increase compactness and effectiveness

- *Compact design → no assembly*
- *Scalable design*
- *Maximum heat transfer*

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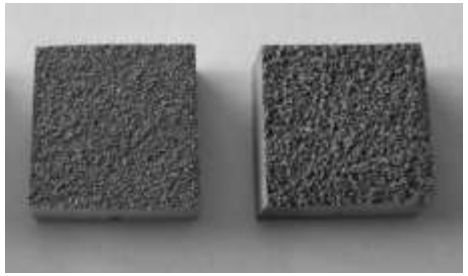
RESEARCH METAL

SLM

Design for Additive Manufacturing of a heat exchangers

From single module to scale up

AlSi10Mg



Microstructured Roughness

High R_a → increase efficiency

160 mm x 160 mm x 170 mm

For each layer 6320 ellyptical fins

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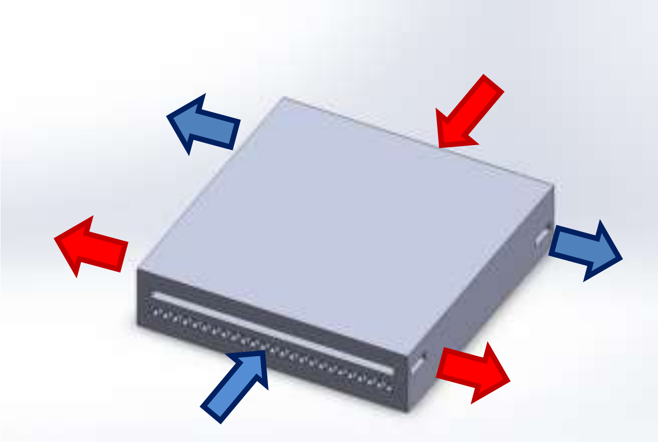
ASTRA

RESEARCH METAL

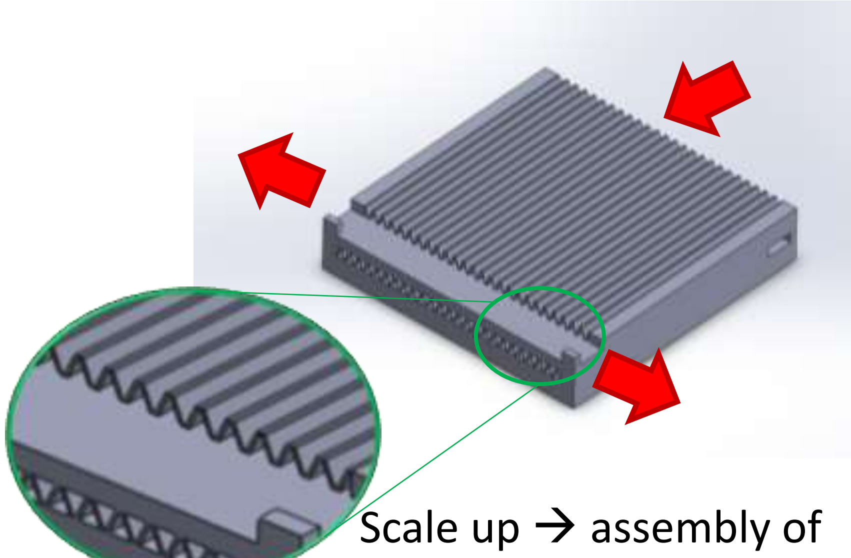
SLM

Design for Additive Manufacturing of a heat exchangers

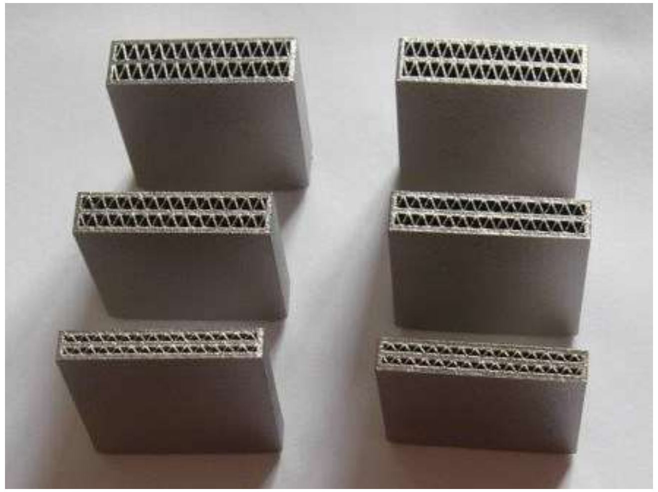


Complex shapes and hollow structures to work

- at high T (800 °C) and
- in a corrosive gas environment (H_2)



Scale up → assembly of modules with different heights



In718

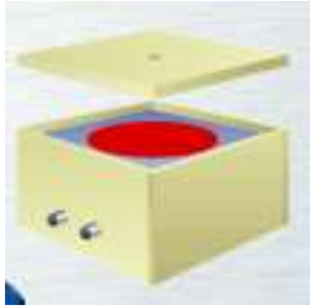
The corrugated structure acts as support for the overlying layer helping the SLM sintering

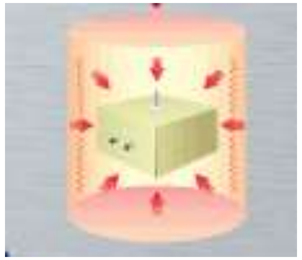
EU Project
FPVII - Integrated High-Temperature Electrolysis and Methanation for Effective Power to Gas Conversion

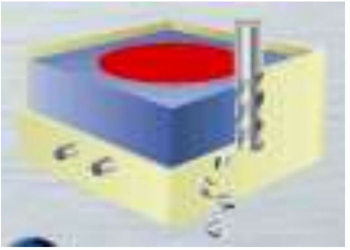
New processes of NNS

Main steps:

- Definition of line-guides for component design
- Development of simulation models
- Development of moulds and tools for production
- Optimization of HIP conditions
- Optimization of strategies for mould removal
- Optimization of thermal treatment of the final component.







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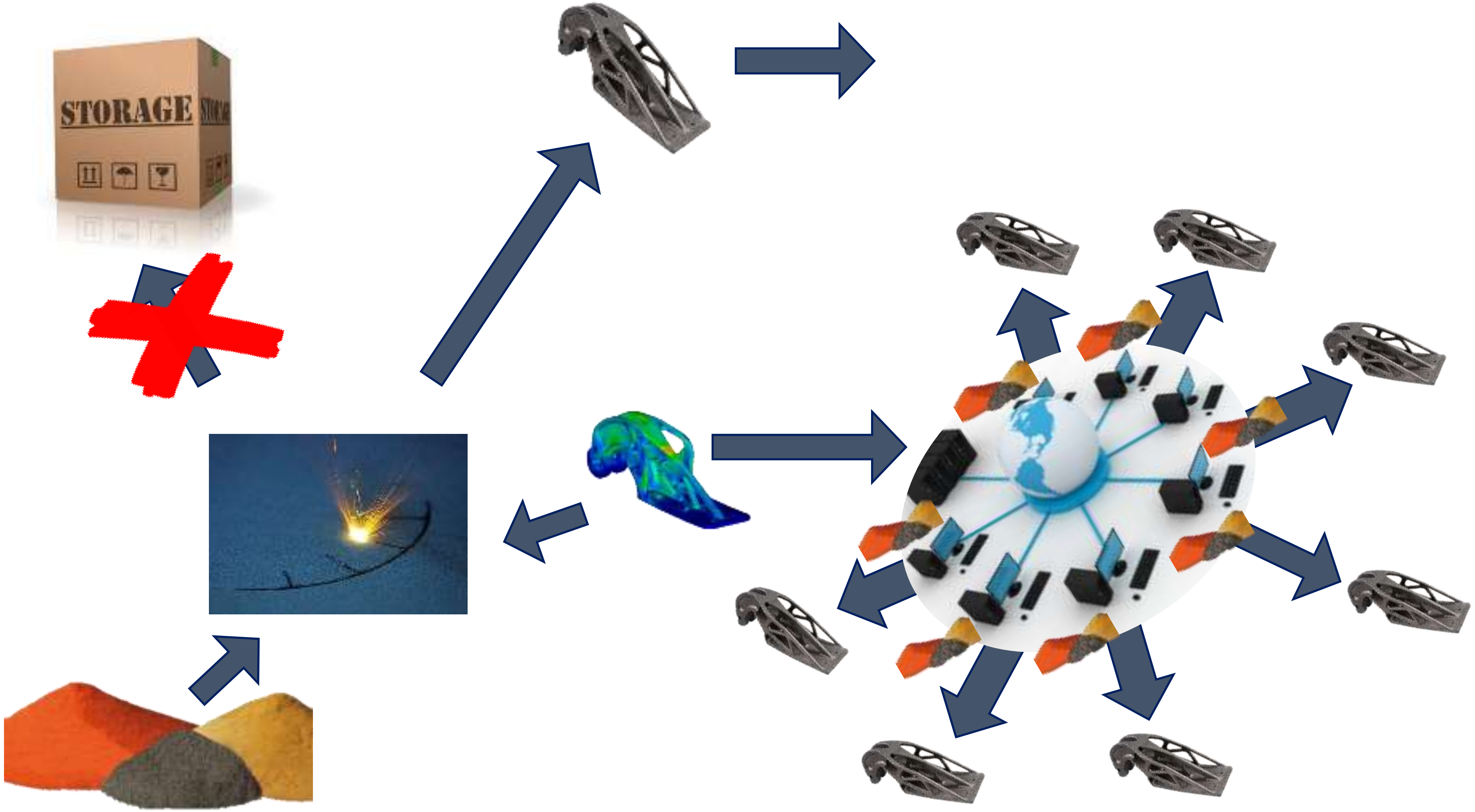
RESEARCH | METAL

Spare Parts



Integration with MES and other information systems

- AM quite different from a traditional manufacturing s systems
- supplies, steps, etc
- Closer to semiconductor manufacturing
- Integration with commerical MES not trivial
- Need adaptation of MES to support it
- Essential to move to mass production
- Activities ongoing with a major MES provider

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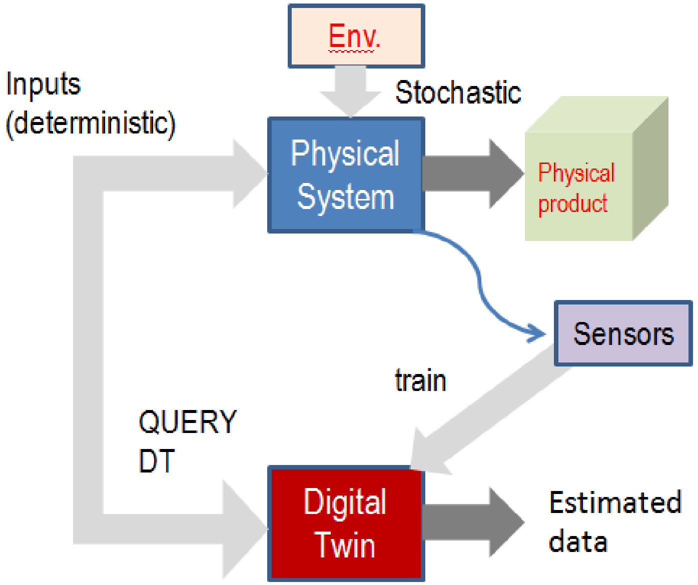
RESEARCH METAL

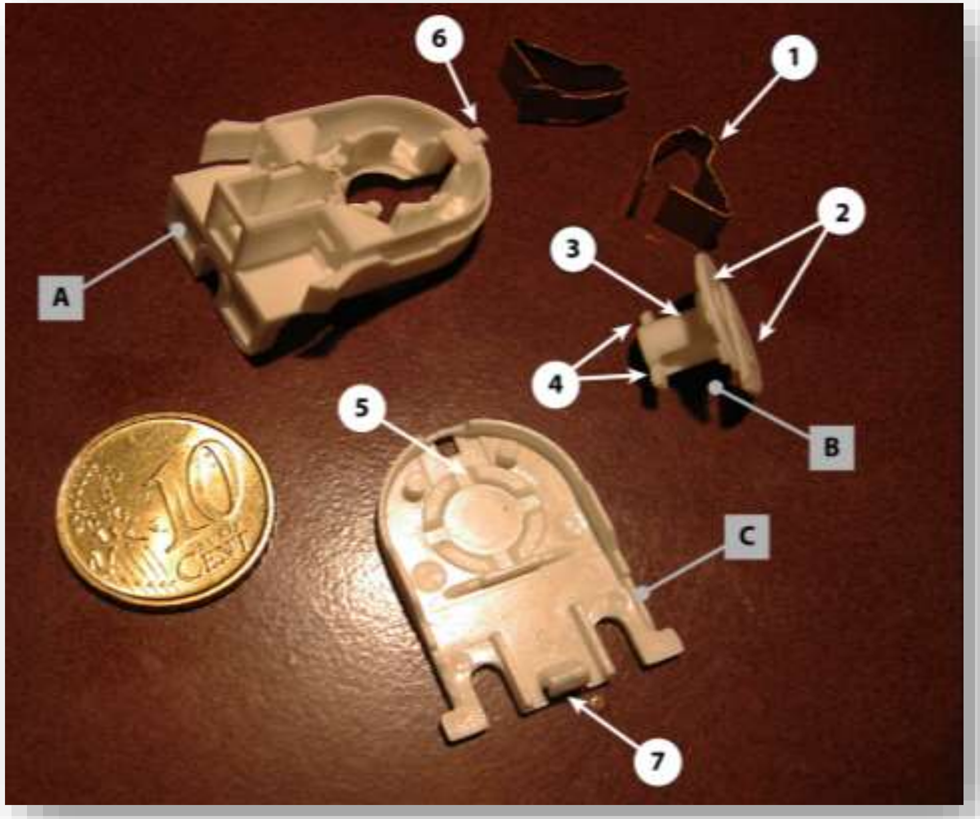
ICT support for process optimization

1. Optimization of semi-manual phases of the process
   - Optimization of support structures at design time
2. Construction of Digital Twins (DT) for AM production
   - Based on invasive or non-invasive sensors
   - Include non-deterministic environmental disturbances
   - Train the DT
   - Includes big-data management, AI techniques for clustering and inference.

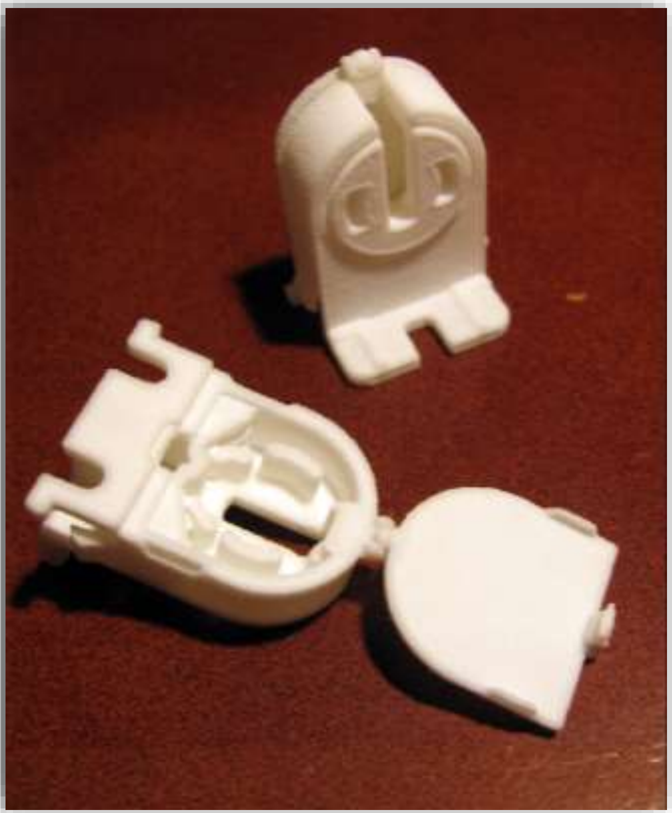
Activities planned in the near future



Case study of a polymeric component

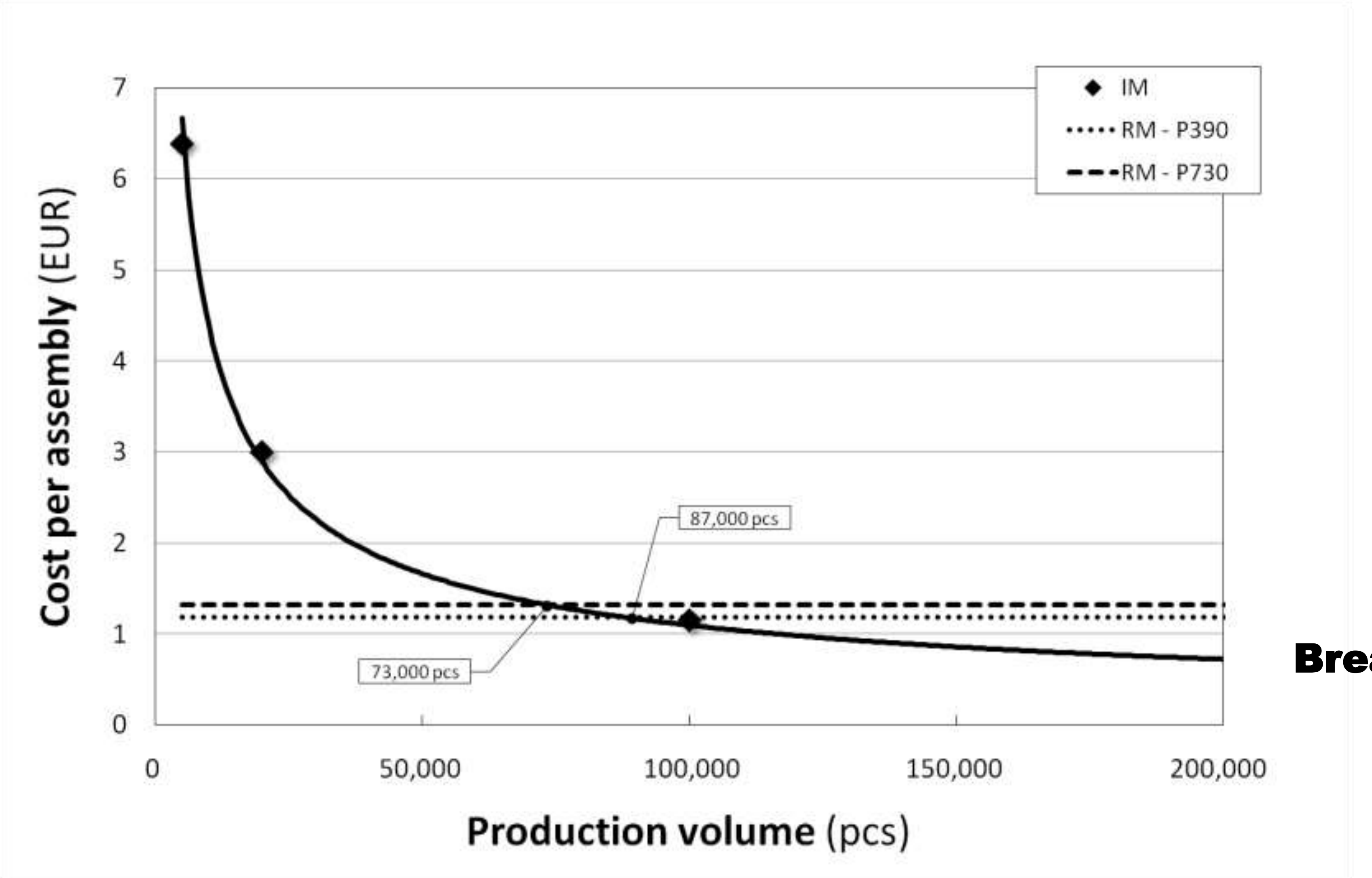


Injection Moulding (IM)



Additive Manufacturing (AM)

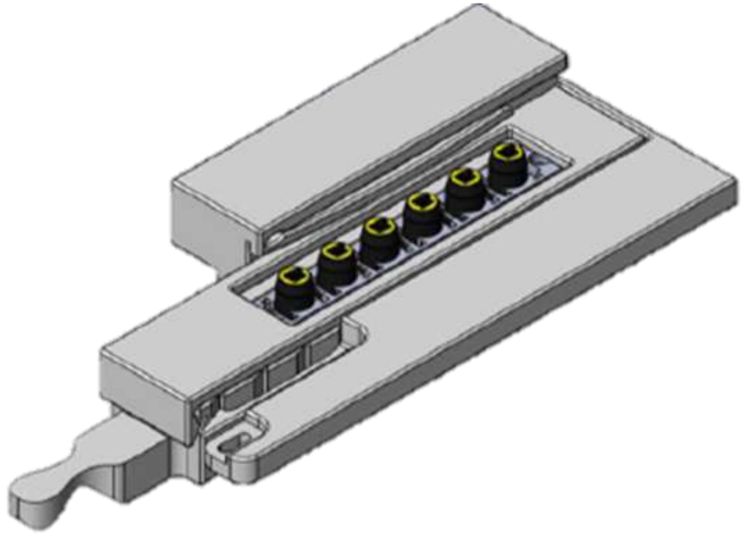
Case study of a polymeric component



Break-even analysis

Originale

14 componenti

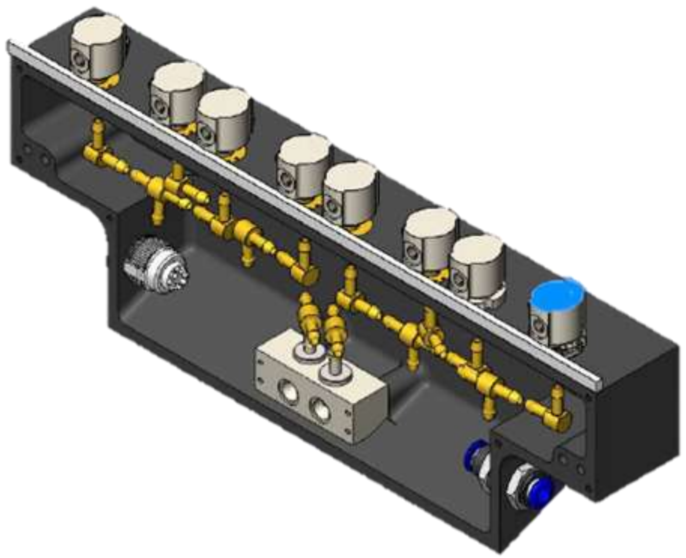


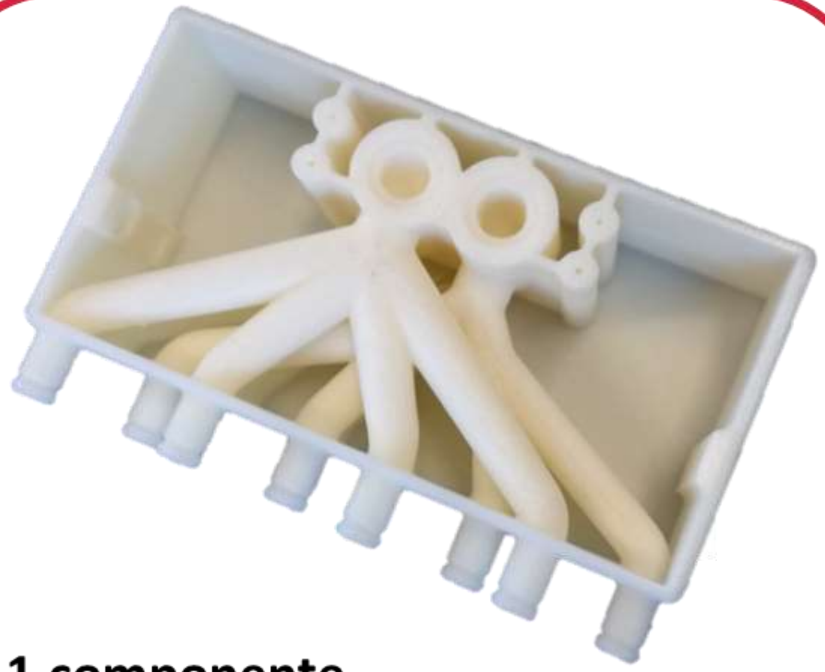
1 componente

Ottimizzato

Originale

32 componenti



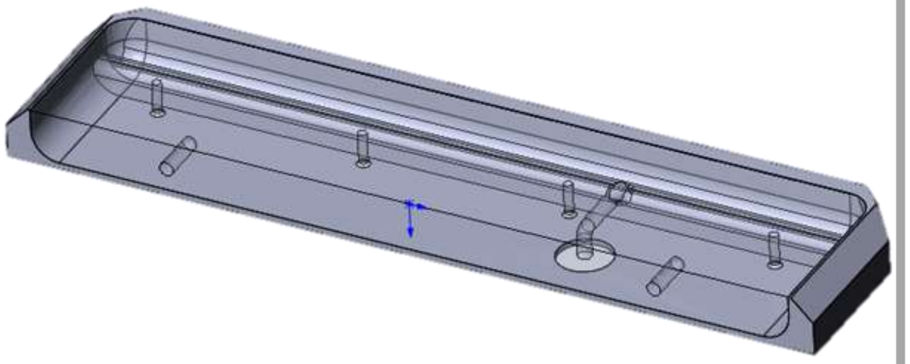


1 componente

Ottimizzato

Originale

3 componenti



1 componente

Ottimizzato

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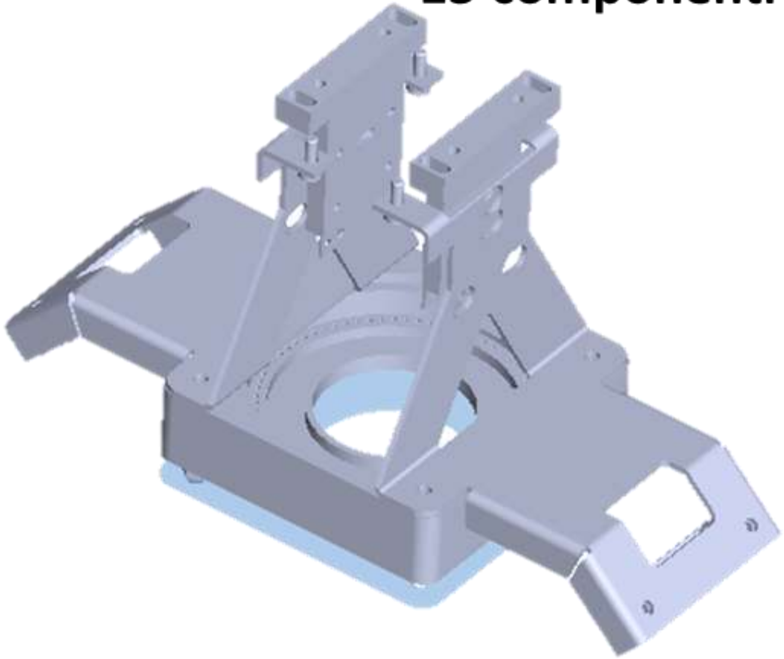
Originale

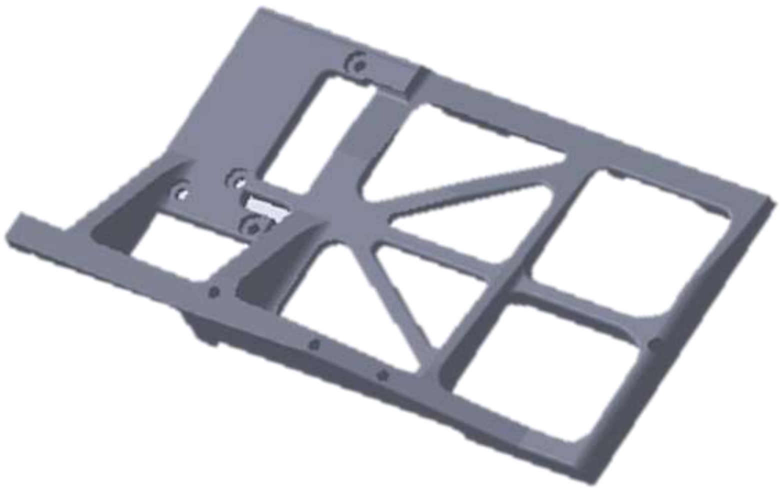
13 componenti

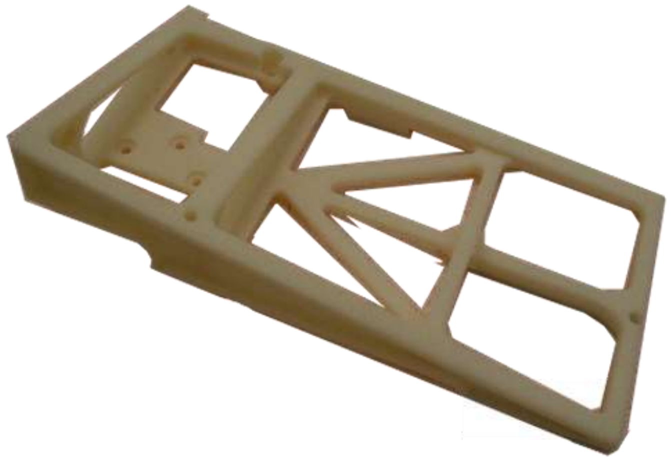


1 componente

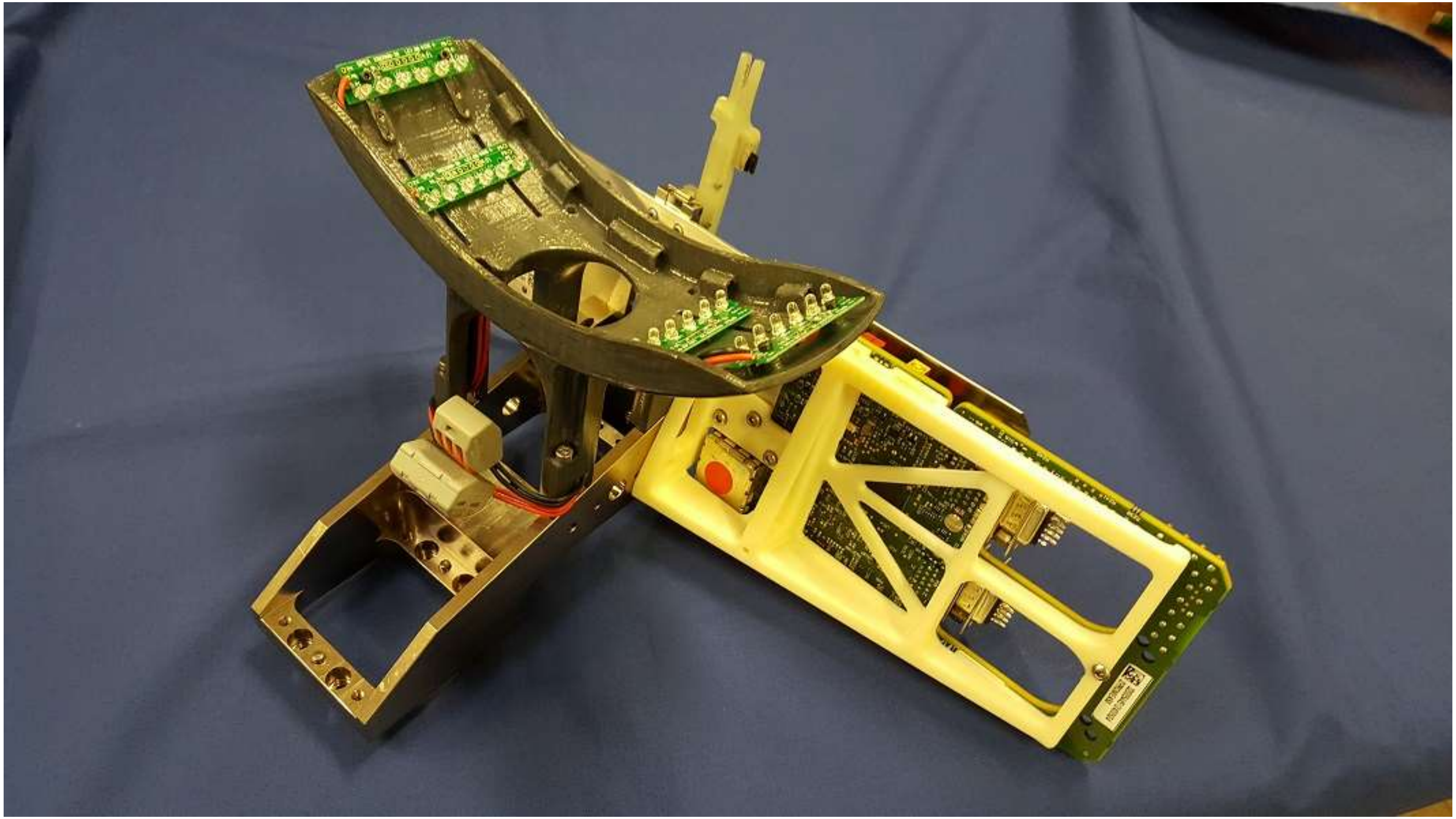
Ottimizzato

Originale





Ottimizzato



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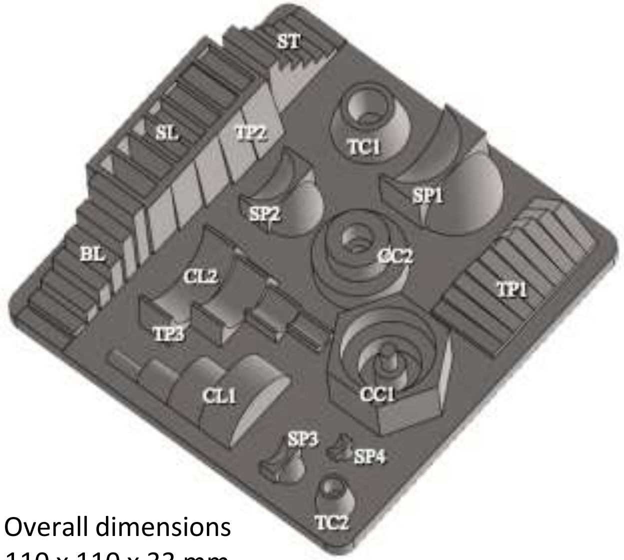
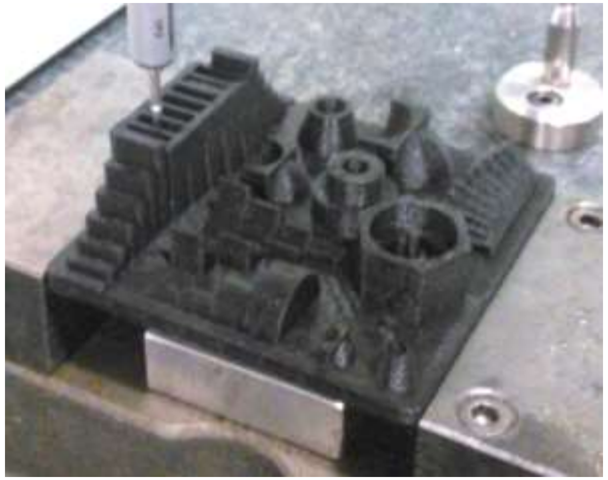
RESEARCH POLYMER

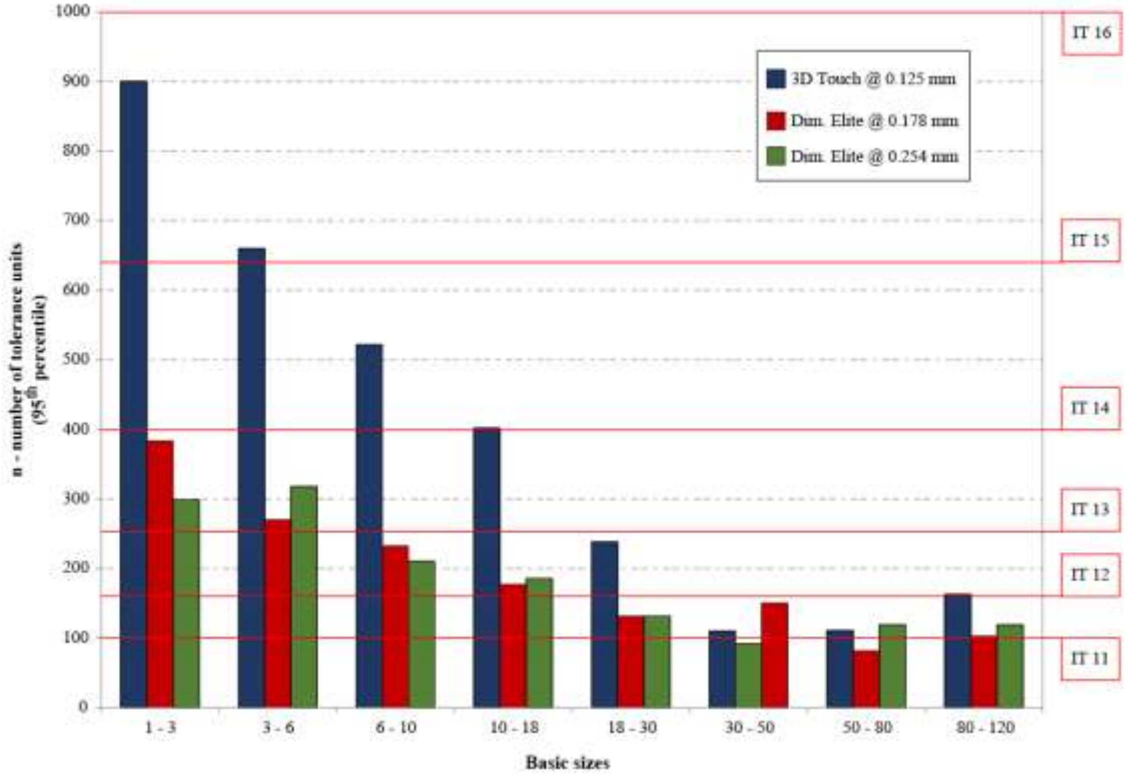
Dimensional characterization of AM systems



Overall dimensions
110 x 110 x 33 mm



Inspection by CMM



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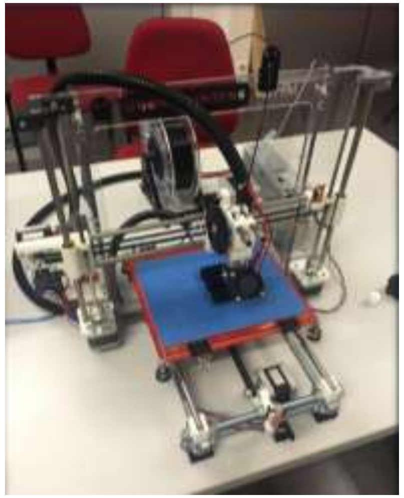
Characterization of 3D printers

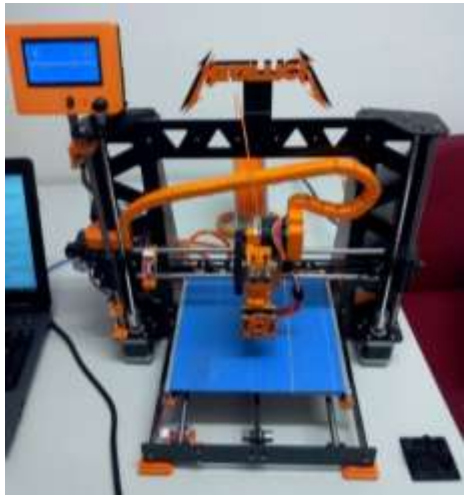
in COMAU within the Specializing Master in Industrial Automation

Fluo

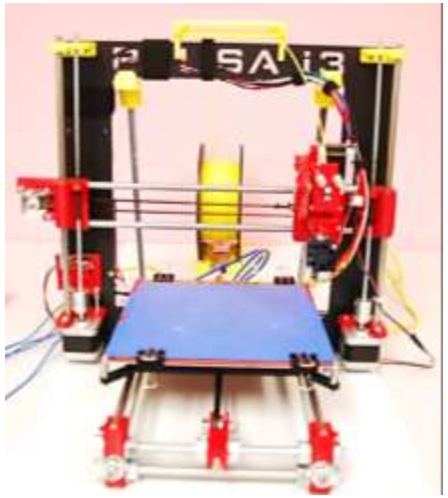
Ghost

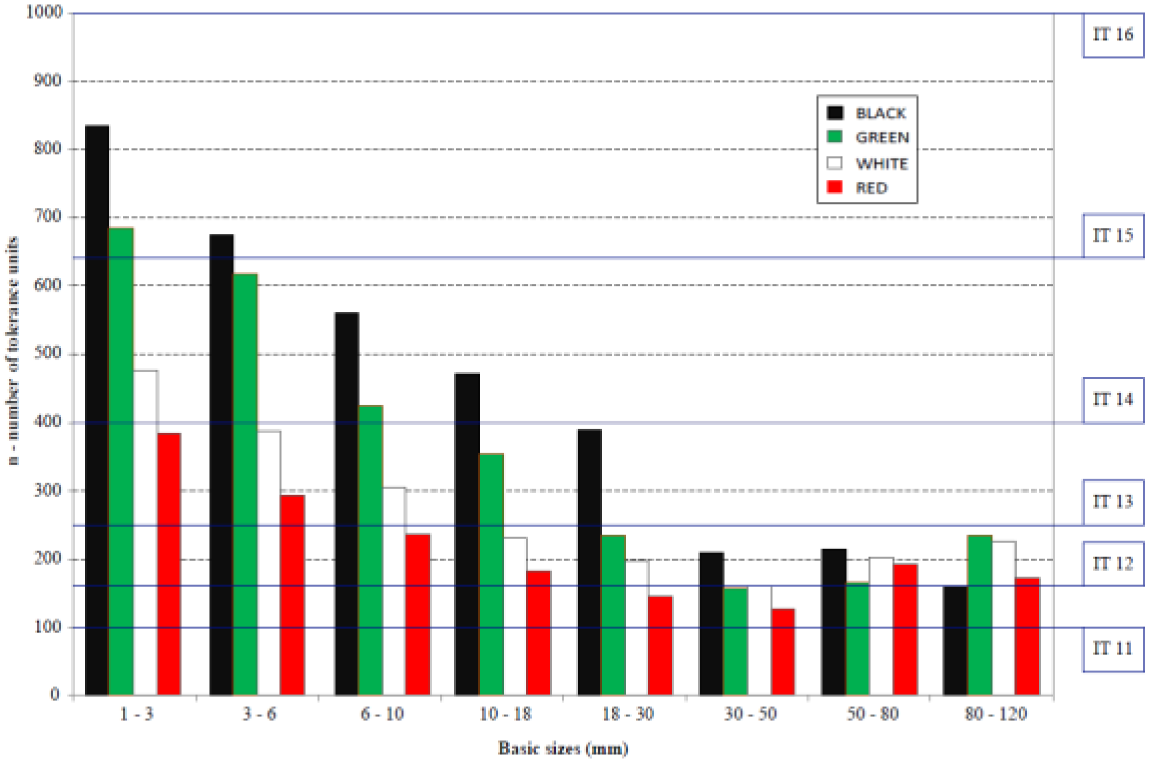


Metallica



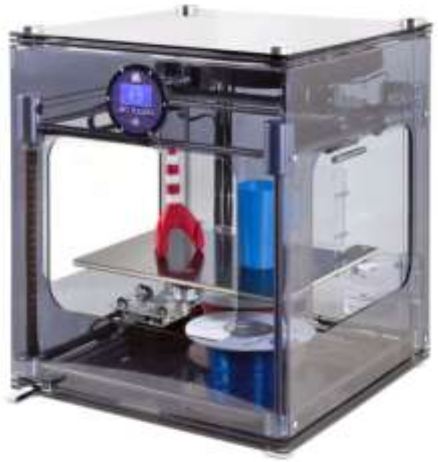
Print-Doh



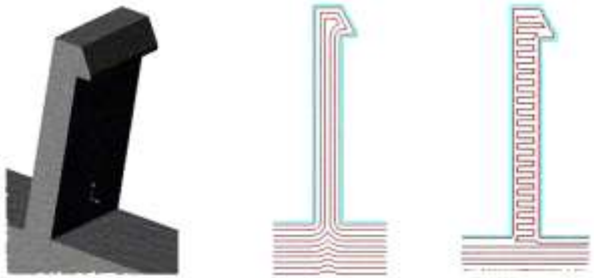


Performances of AM polymeric parts with fillers

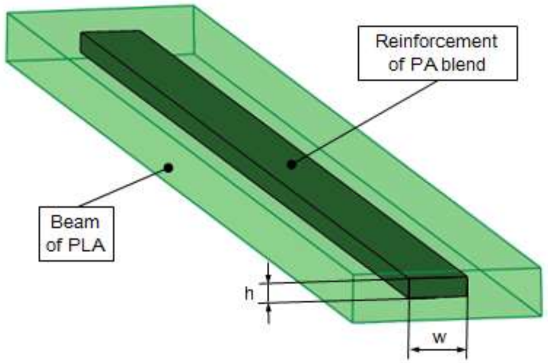
(Graphene, Carbon fibres, ...)

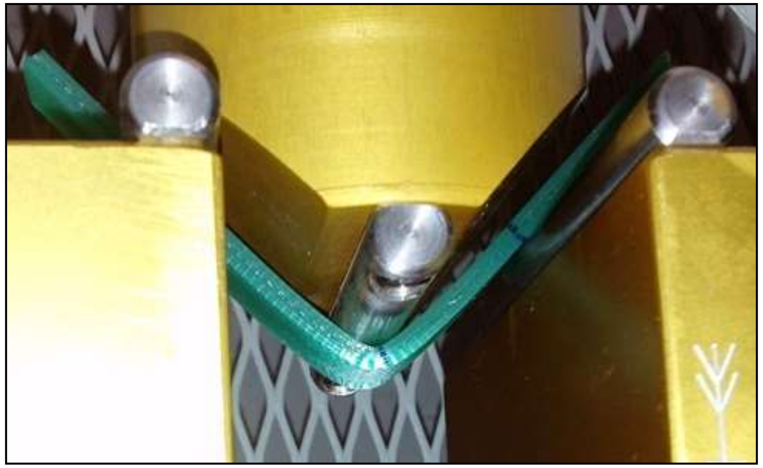


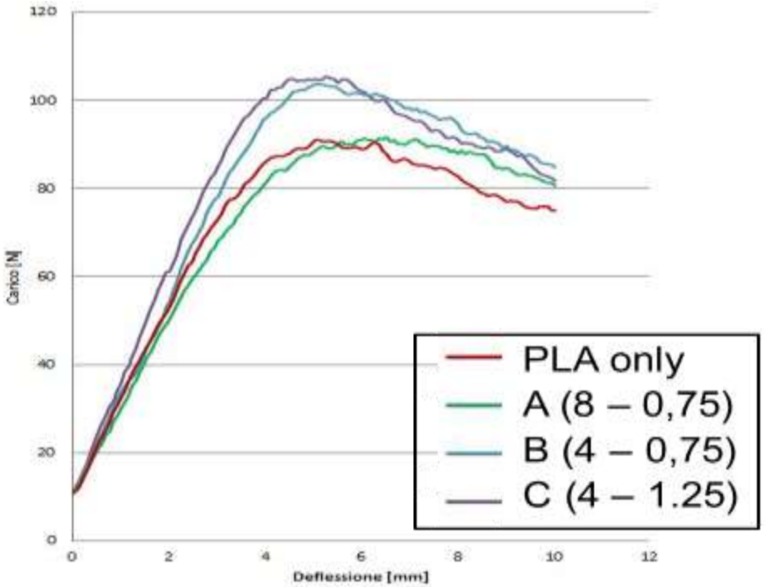
FDM machine with 3 extruder heads



Different strategies for deposition of the graphite filled filament



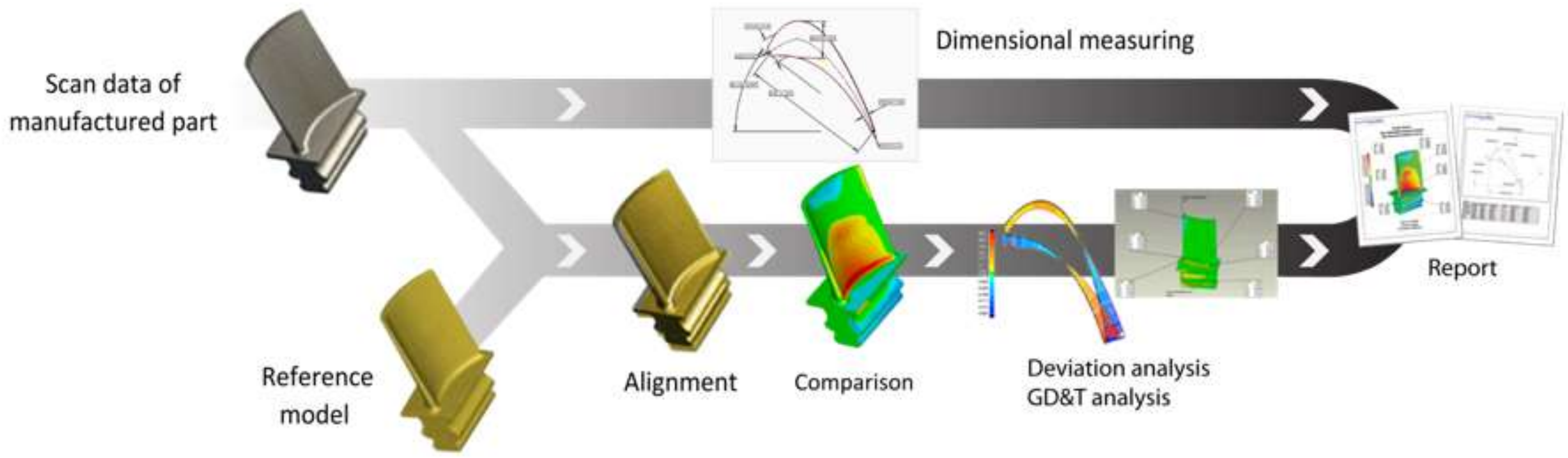




Additive Manufacturing improves the economic and environmental sustainability:

- Less consumption of raw materials;
- Optimized product efficiency;
- Light-weight components;
- Reduced need for tools and dies;
- Reduced investments and less stocks;
- *Supply chain* efficiency and new models of retail (Simplified chains and reduced delivery times)

REVERSE ENGINEERING

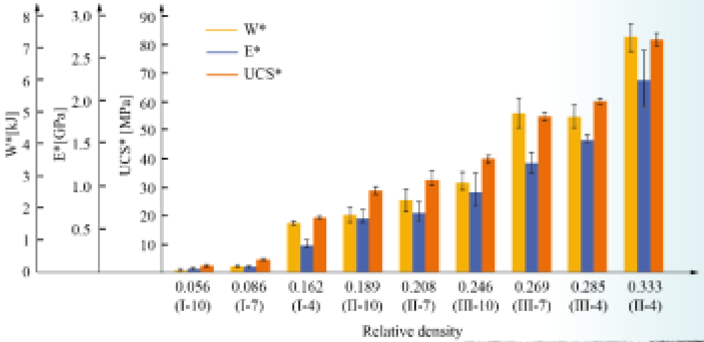


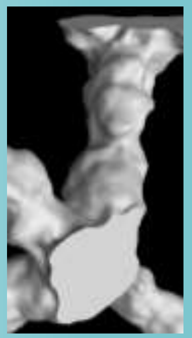
Computer Aided Inspection (CAI) and Reverse Engineering (RE)

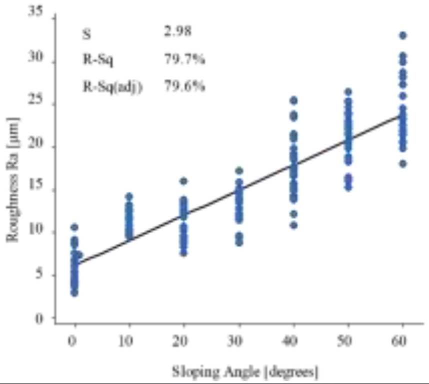
When a part exists but not the drawing the CAD model can be generated using data from 3D-digitising (non-contact scanner system) and the RE methodology

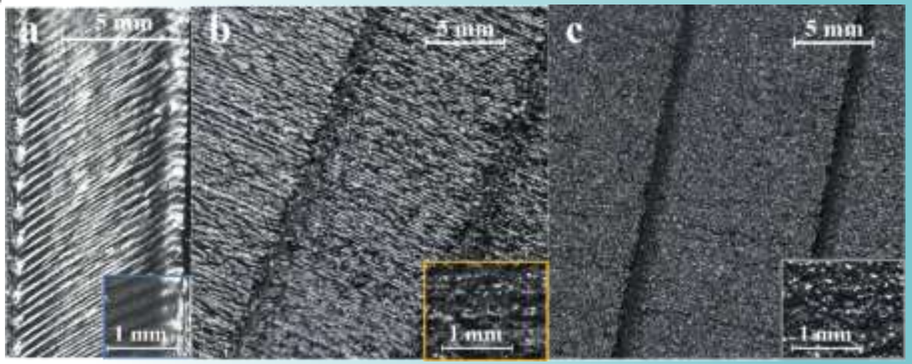
CT-SCAN

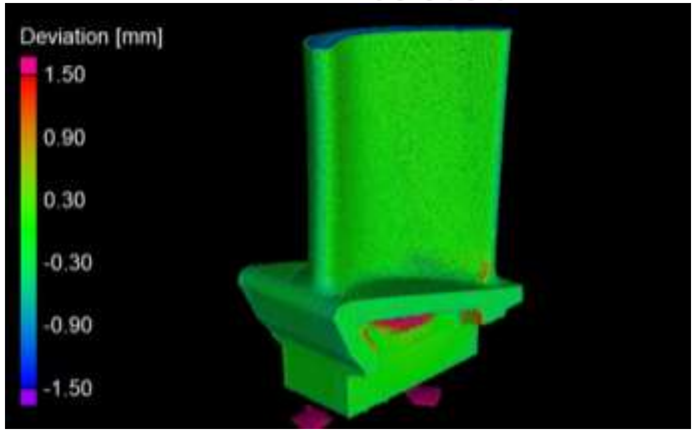
- Process development, dimensional and mechanical characterisation of **metallic alloys** processed by **Electron beam Melting** (both bulk and lattice material)

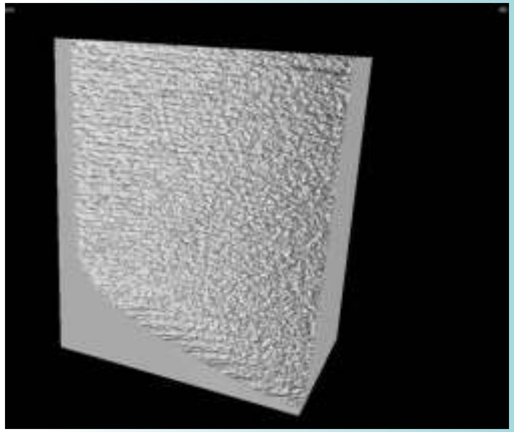


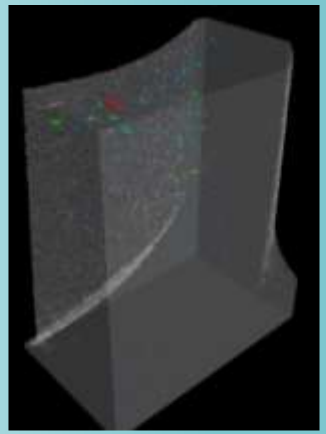












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Research with the involvement of companies such as FCA, GE Avio, Prima Industrie,...

RESEARCH

TECHNOLOGY TRANSFER

«Industry-funded academic inventions boost innovation»
Nature Comment,
Brian D. Wrigh et al.

INSTITUTIONAL

WITH THE INVOLVEMENT OF BUSINESSES

EDUCATION

THE DISSEMINATION OF KNOWLEDGE IS ONE OF THE MAJOR FOCUSES AND AN INTEGRAL PART OF THE CENTER IAM@POLITO

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RESEARCH

TECHNOLOGY TRANSFER

Research with the involvement of companies such as FCA, GE Avio, Prima Industrie,...

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Nature Comment,

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Institutional

With the involvement of Businesses

EDUCATION

The dissemination of knowledge is one of the major focuses and an integral part of the Center IAM@PoliTo

INSTITUTIONAL

Since 1994 Layer Manufacturing is taught at the Politecnico di Torino within the course of Computer-aided production (CAP) of the MSc. Course in Mechanical Engineering and MSc. Management Engineering, Manufacturing track

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Education 

INSTITUTIONAL

Master's Degree Programs in Mechanical Engineering / Materials
CAREER: ADDITIVE MANUFACTURING

Courses

- Progettazione per la fabbricazione additiva / Design for Additive Manufacturing (10 CFU)
- Tecniche di fabbricazione additiva / Technologies for Additive Manufacturing (10 CFU)
- Materiali per fabbricazione additiva / Materials for Additive Manufacturing (8 CFU)

Phd program Management, production and design
Phd program Materials science and technology

Courses

- Produzione additiva e reverse enginnering: innovazione, sviluppi e sostenibilità
- Additive Manufacturing Processes for Polymeric Materials
- Additive Manufacturing of metals by laser powder bed fusion: an integrated approach
- Directed energy deposition processes
- Additive Manufacturing: l'electron beam melting per la produzione di componenti metallici

POLITECNICO DI TORINO
REGIONE PIEMONTE

Specializing Master in ADDITIVE MANUFACTURING

3D-NT ADDITIVE TECHNOLOGIES
ATLA
COMPETENCE INDUSTRY MANUFACTURING 4.0
IRIS
LMA
MAGNA
MAV Tech
PRIMA INDUSTRIE
Skillab

Objective: create a new generation of high-level specialists in the Additive manufacturing process field.
Foreseen professional figures: Technical Leaders, Project Managers, Industrial Operational Leaders, Mechanical Designers, Software Designers and Spare Parts Managers.

These figures will integrate technical and managerial expertise for the use and management of Additive Manufacturing.

The Master Course offers the unique opportunity of being trained in an international environment with demonstrated mature working experience in advanced projects.

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Education 

WITH THE INVOLVEMENT OF BUSINESSES

Fondimpresa

Inside training on the ADDITIVE MANUFACTURING

Comutensili, FCA Fiat Chrysler Automobiles, APR, COMAU, PRIMA INDUSTRIE, Prima Electro, Ellena, 3D-NT Additive Technologies, Avio Aero A GE Aviation Business, SRSED, Skillab, IRIS

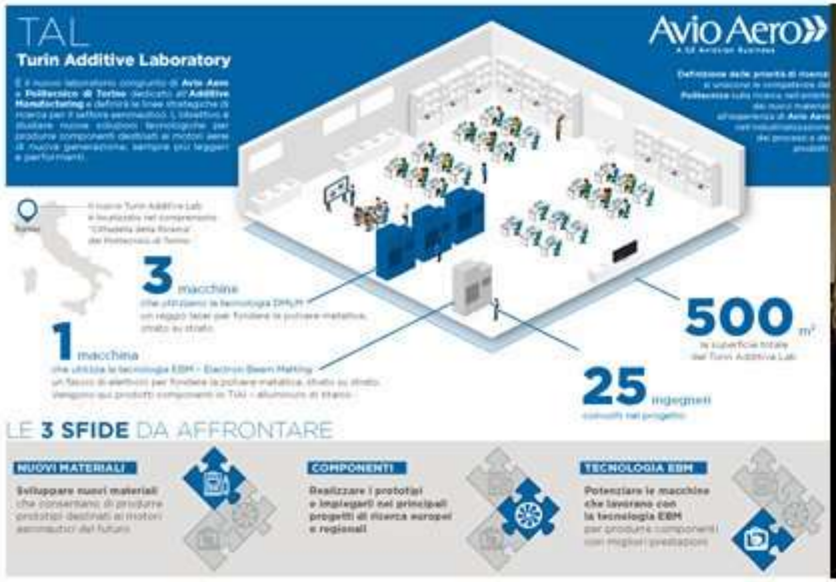
It promotes continuous training and redistributes to Companies the resources dedicated, by law, to training.

Technology transfer with the involvement of the digital innovation hub and Businesses:

- Business advice
- Access and use of infrastructure
- Business network projects
- Pilot line for business case

«Industry-funded academic inventions boost innovation»
Nature Comment,
Brian D. Wrigh et al.

The dissemination of knowledge is one of the major focuses and an integral part of the Center IAM@PoliTo

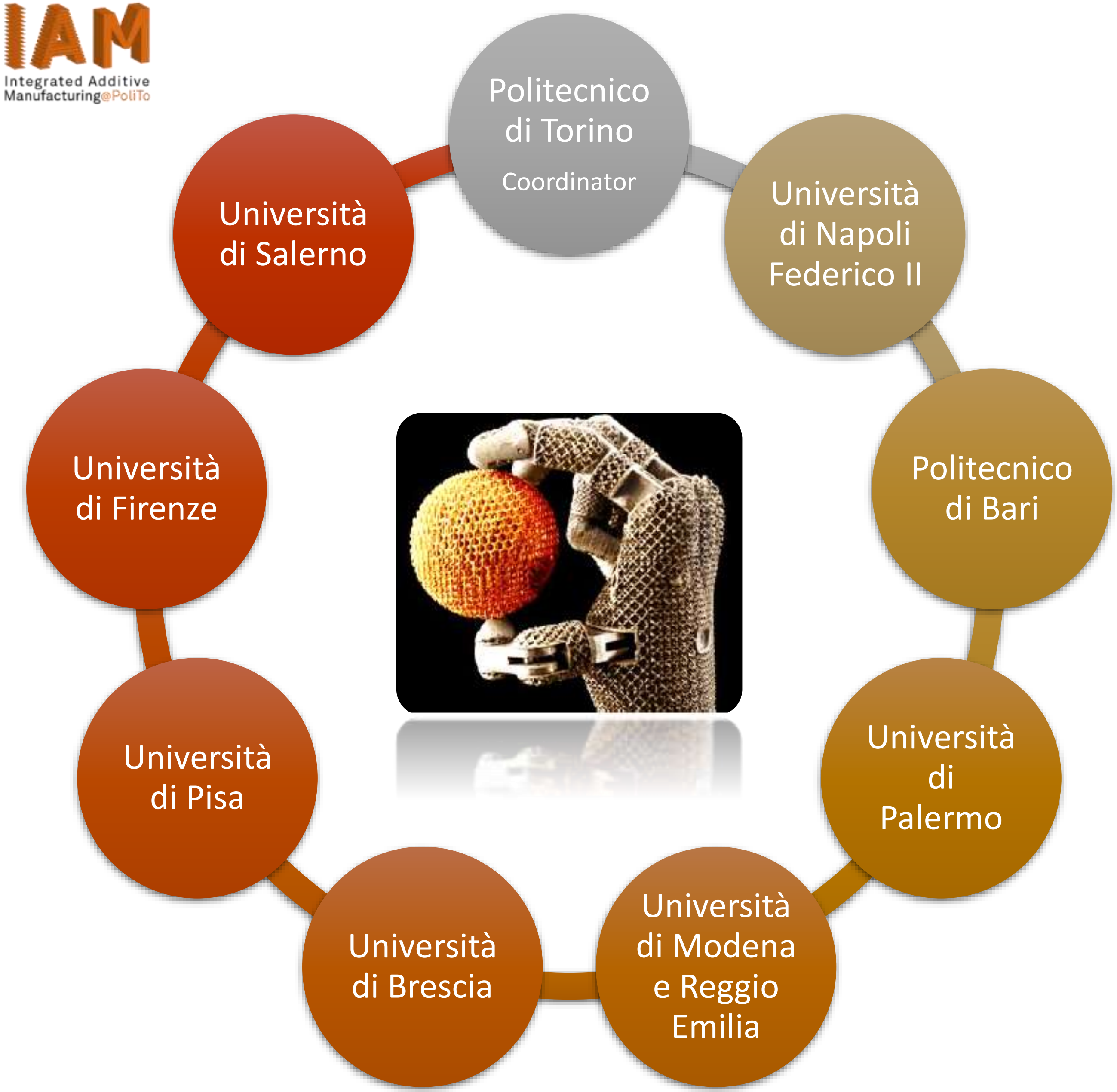


Turin Additive Lab - TAL

Together with the Politecnico di Torino, Avio Aero has created the TAL - Turin Additive Laboratory - a joint lab created to collaborate on strategic research topics for the aviation industry, such as identifying new materials for this production technology.

10% of the machine time of the EOSINT M400 (EOS GmbH) for research activities of the PoliTo

TECHNOLOGY TRANSFER



CENTRO INTERUNIVERSITARIO DI RICERCA PER L'ADDITIVE MANUFACTURING
CIRAM

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EVENTS

CARNEGIE MEETING G7
TORINO, 29 SEPTEMBER 2017

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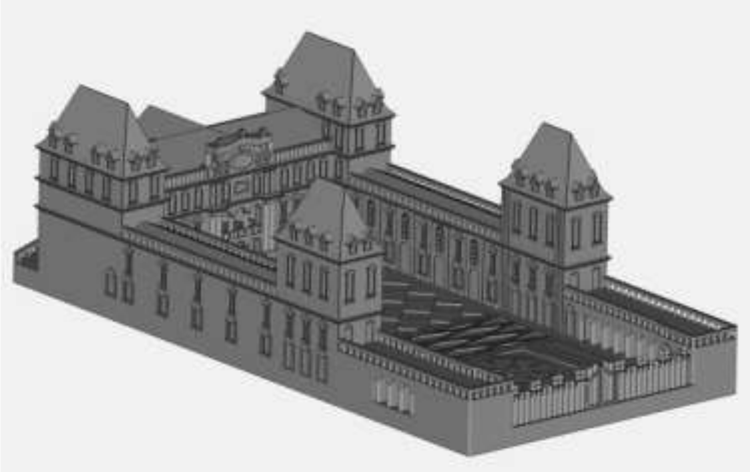
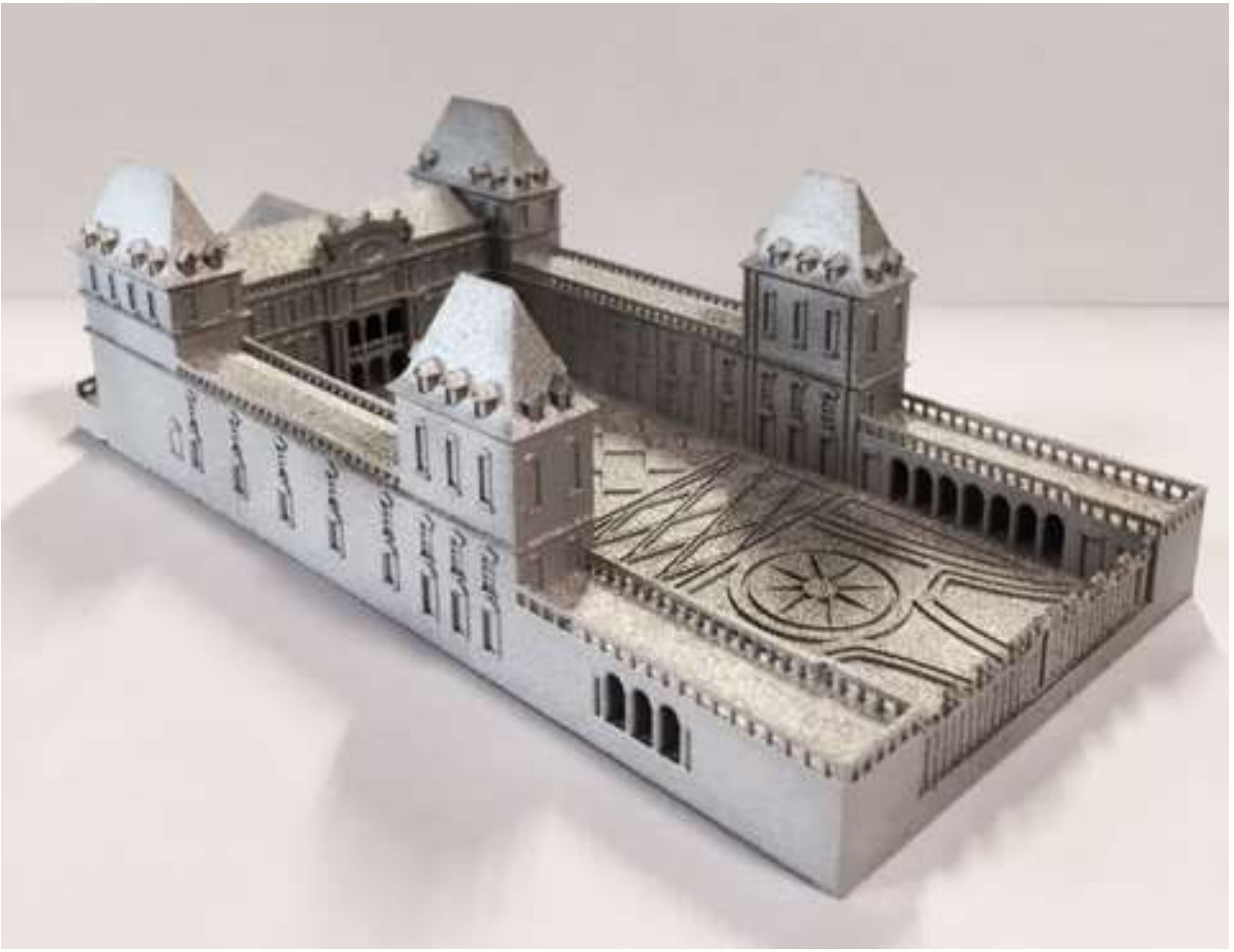
EVENTS

INAUGURAL LECTURE BY THE PRESIDENT OF THE REPUBLIC SERGIO MATTARELLA AT THE OPENING OF THE ACADEMIC YEAR 2017-2018 OF THE POLITECNICO DI TORINO
7 NOVEMBER 2017

Castle of Valentino produced by laser powder bed fusion technology
Machine: EOSINT M270 Dual Mode
Material: AlSi10Mg alloy
Realized by IIT@PoliTo & DIGEP





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EVENTS

ABS Prototype
Machine: Stratasys Dimension Elite
Realized by DIGEP

La Giornata dei Pionieri Dell'AM

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EVENTS

30 Anni di AM
Made in Italy

Torino 29 Maggio 2019

I Pionieri dell'AM presenti a Torino

I° Fila da sx: Carlo Grasso, Luigi Galantucci, Andrea Gatto, Rosolino Ippolito, Luca Iuliano, Giorgio Mondadori, Francesco Resecco.

II° fila da sx: Dante Pocci, Giorgio Buson, Vito Chinella to, Mario Salmon, Paolo Onesti, Enzo Dagnino, Rino Miglio, Sergio Pieri, Aldo Rotta

Projects

- **GREAT 2020** – GReen Engine for Air Traffic 2020 – Regional project (2009-2012)
- **ProTiAl** – Developing of a new concept for optimal Production and machining of aerospace components in TiAl (2009-2012)
- **AMAZE** – Additive Manufacturing Aiming Towards Zero Waste and Efficient Production of High-Tech Metal Products – UE Project, VII FP (2012-2015)
- **E-BRAKE** – Demonstration of breakthrough sub-systems enabling high overall pressure ratio engine – UE Project, VII FP (2012-2015)
- **TiAl Charger** – Titanium Aluminide Turbochargers – Improved Fuel Economy, Reduced Emissions – UE Capacities Project, VII FP (2012 – 2014)
- **HELMET** – Integrated High-Temperature Electrolysis and Methanation for Effective Power to Gas Conversion - New generation of high temperature electrolyser, UE Project, VII FP (2014-2016)
- **BOREALIS** – the 3A energy class Flexible Machine for the new Additive and Subtractive Manufacturing on next generation of complex 3D metal parts – UE Horizon2020 Project (2015-2018)
- **GETREADY** – HiGh spEed TuRbinE cAsing produced by powDer HIP technologY – UE JTI Cleansky (2014-2015)
- **GREAT 2020 phase 2** – GReen Engine for Air Traffic 2020 – Regional project (2009-2012).
- **Cluster Aerospazio** – Greening the propulsion – National project (2014-2017)
- **POP3D** – Progetto ASI – Validazione del livello di maturità tecnologica di un sistema di fabbricazione additiva polimerica in microgravità per utilizzo a bordo della Stazione Spaziale Internazionale (2014-2016)
- **STAMP -** Sviluppo Tecnologico dell'Additive Manufacturing in Piemonte (Technological Development of Additive Manufacturing in Piedmont), Regional project (2016-2019)
- **ECCO** - Energy Efficient Coil Coating Process, UE Horizon 2020 Project (2017-2019)
- **4D HYBRID** - Novel ALL-IN-ONE machines, robots and systems for affordable, worldwide and lifetime Distributed 3D hybrid manufacturing and repair operations, UE Horizon 2020 Project (2017-2019)
- **NEWTEAM** - Next gEneration loW pressure TurbinE Airfoils by aM, H2020 Clean Sky project (2018-2020)
- **HUC** - Development and validation of a powder HIP route for high temperature Astroloy to manufacture Ultrafan® IP Turbine Casings, H2020 Clean Sky project (2018-2021)
- **MANUELA** - Additive Manufacturing using Metal Pilot Line, UE Horizon 2020 Project (2018-2022)
- MAMMA - Multiple Advanced Materials Manufactured by Additive technologies, PRIN Project (2019-2022)

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