ASSOLOMBARDA

Industria 4.0 per la ripartenza

Focus Additive Manufacturing

L'esperienza di **Ferdinando Auricchio, Prof. Ordinario e coordinatore di 3D@UniPV**

Area Industria Energia e Innovazione 15/06/2020

Introduzione

- ❑ ***Assolombarda***

- ❑ ***Industria Energia e Innovazione***
  - *Awareness 4.0 – videopillole*
  - *Industria 4.0: elemento necessario per la ripartenza – ciclo di webinar*

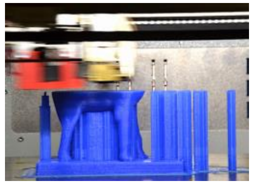
- ❑ ***Focus Additive Manufacturing. L'esperienza di Ferdinando Auricchio, Prof. Ordinario e coordinatore di 3D@UniPV***

Timeline

Ministero della Salute

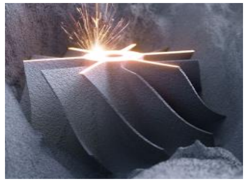
“Pancreas Project” funded by Italian Minister of Health

2013



PROTOLAB: First Prototyping Lab

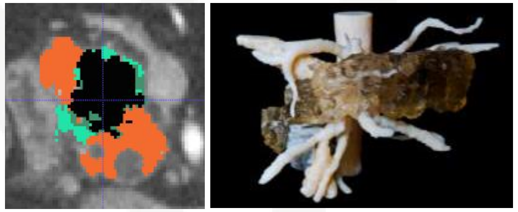
2016



3DMetal@UniPV

2018

2011



Master Thesis of Eng. S. Marconi: Virtual Reconstruction of Pancreatic Tumors

2015

A Strategic Theme for UniPV

2016

UNIVERSITIAMO by UNIPV

Crowdfunding Campaign

2018

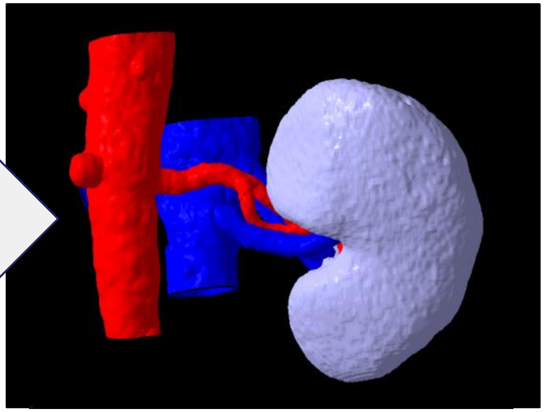
3D4MED

3D4MED: How?

A **new instrument** for surgical planning, training and simulation.

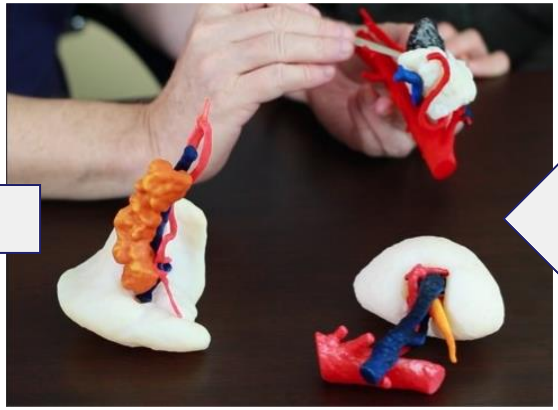
MDTC Scan

Image Segmentation

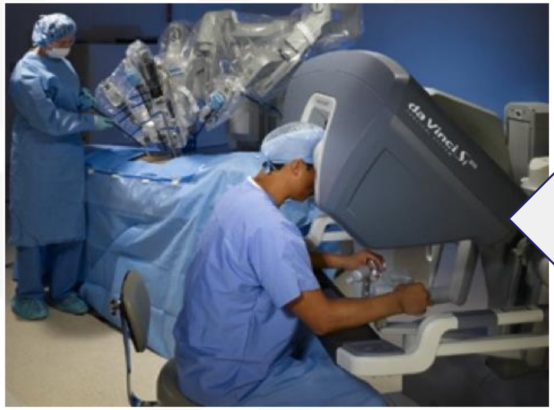


3D Virtual Model

3D Printed Model



Surgical Planning,
Simulation & Training



Minimally Invasive
Robotic Surgery

3D4MED: Why?

The 3D printed model **helps the surgeon** in:

Intra – operative navigation

Surgical planning

Communication with patients

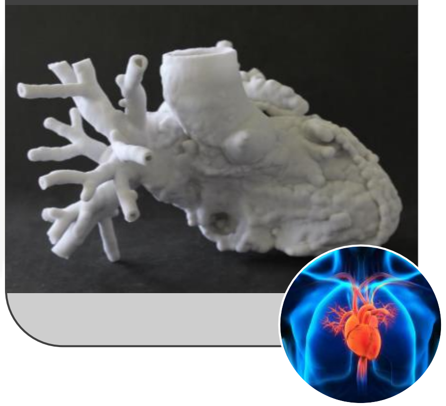
Surgical training and simulation

3D4MED: To Whom?

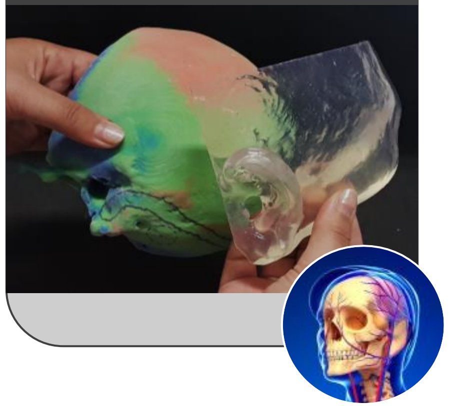
Our 3D printed models are made for **any medical specialty**. We have several years' experience in the following areas, to date:

Abdominal Surgery

Vascular Surgery



Otolaryngology



Orthopedics

Abdominal Surgery	> **45** clinical cases	Orthopedics	> **10** clinical cases
Otolaryngology	> **15** clinical cases	Vascular Surgery	> **35** clinical cases

... but it is possible to reproduce **many others anatomical structures**!

3D4MED: the Lab

3D4MED is the **first Clinical 3D Printing Lab** in Italy and one of the first worldwide.

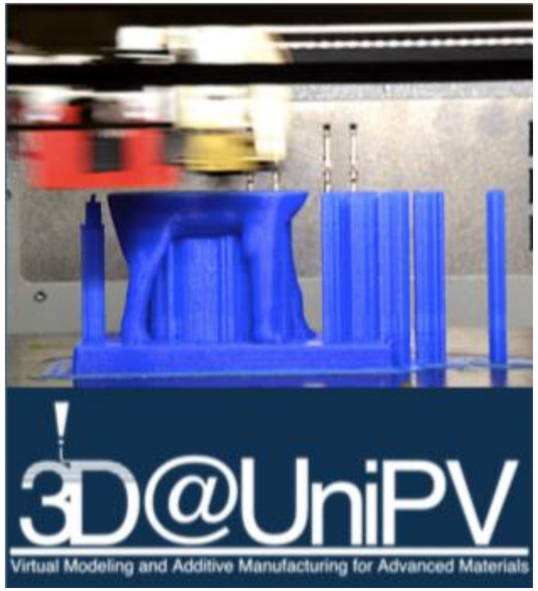
It is located at the **DEA building** of **IRCCS Policlinico San Matteo** of Pavia and it has a strategic position to improve its **visibility** (to disseminate the new proposed service) and **centrality** (to facilitate the collaboration between surgeons and engineers).

DEA Building
0 floor – tower B

3D4MED Lab

UniPV Strategic Theme

Virtual Modeling and Additive Manufacturing for Advanced Materials

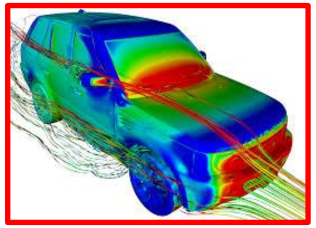


Web http://www.unipv.it/3d

3D@UniPV: university strategic theme

Modeling & Simulation

1



In collaboration with:
Prof. Anselmi-Tamburini (UniPV)

In collaboration with:
Prof. Denicolai
Prof. Hagen
(UniPV)

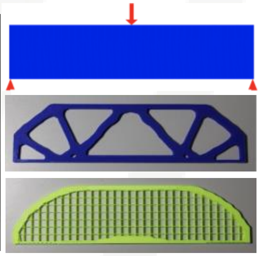
5

Socio-Economic Impact

5 PILLARS

2

New Materials



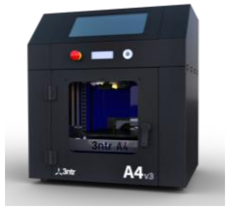
Many fields of applications from medical to mechanical and civil engineering app.

4

Applications

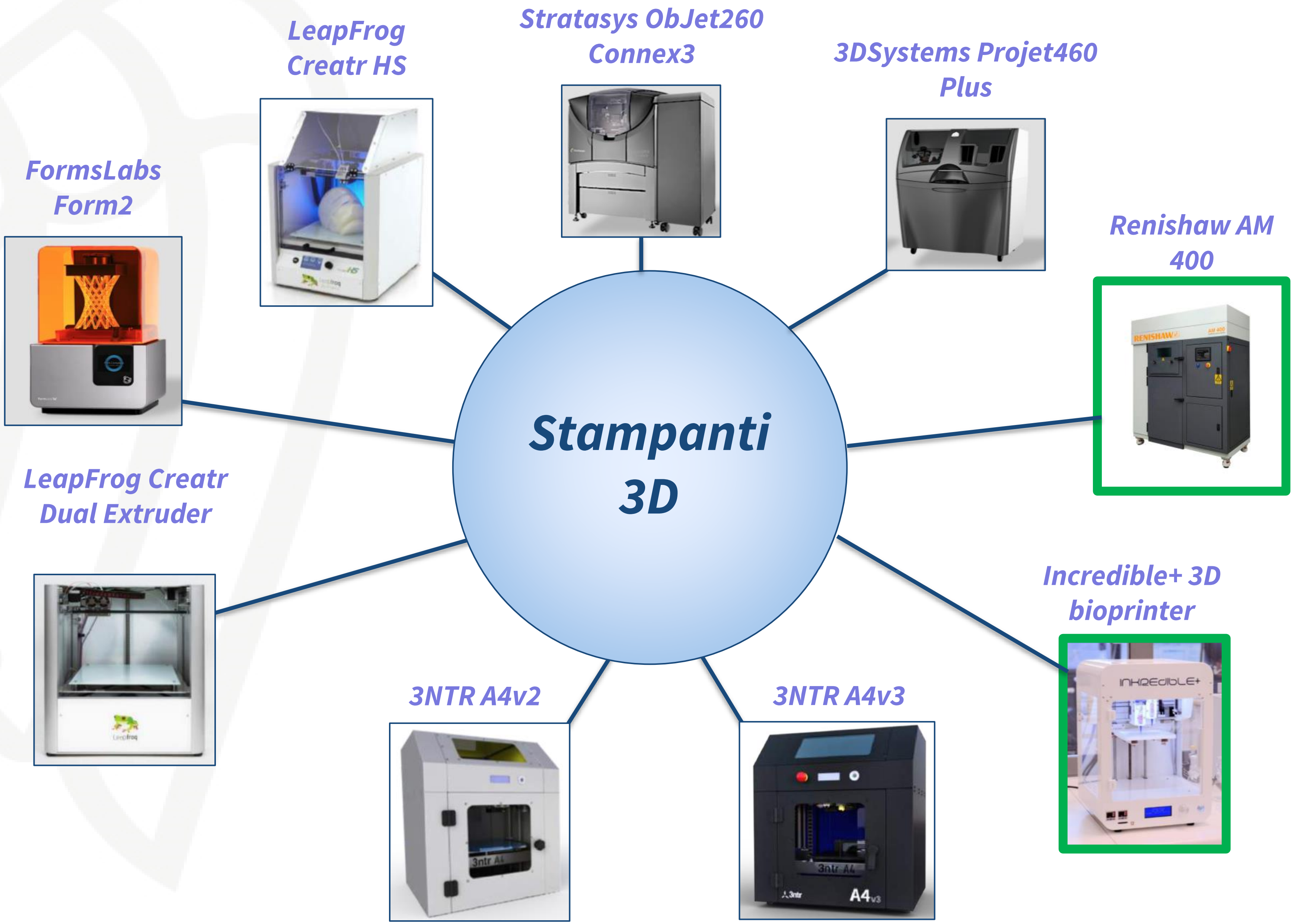
3

Manufacturing

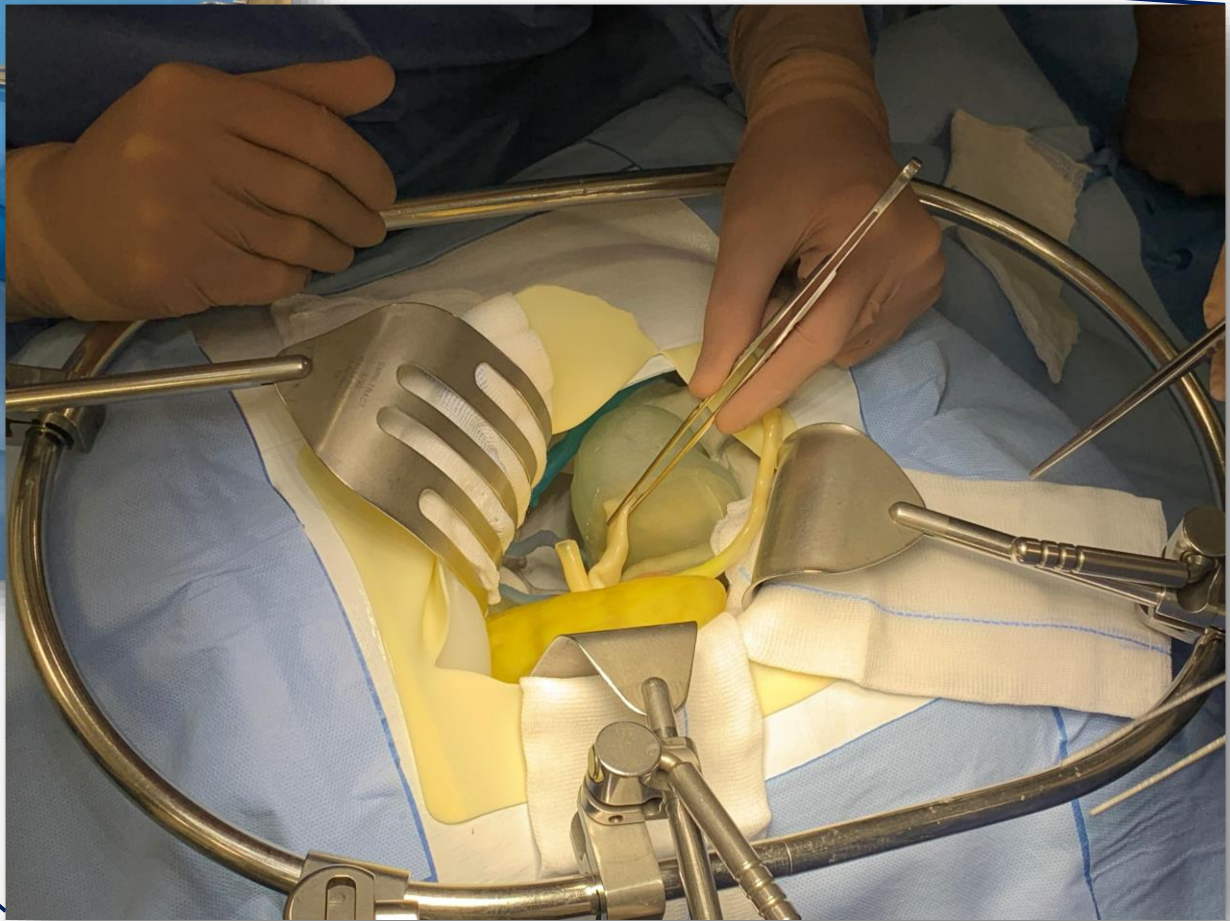


Collaboration with many companies:
7 printers (4 technologies)
1 SLM metal printer

Available 3D printers

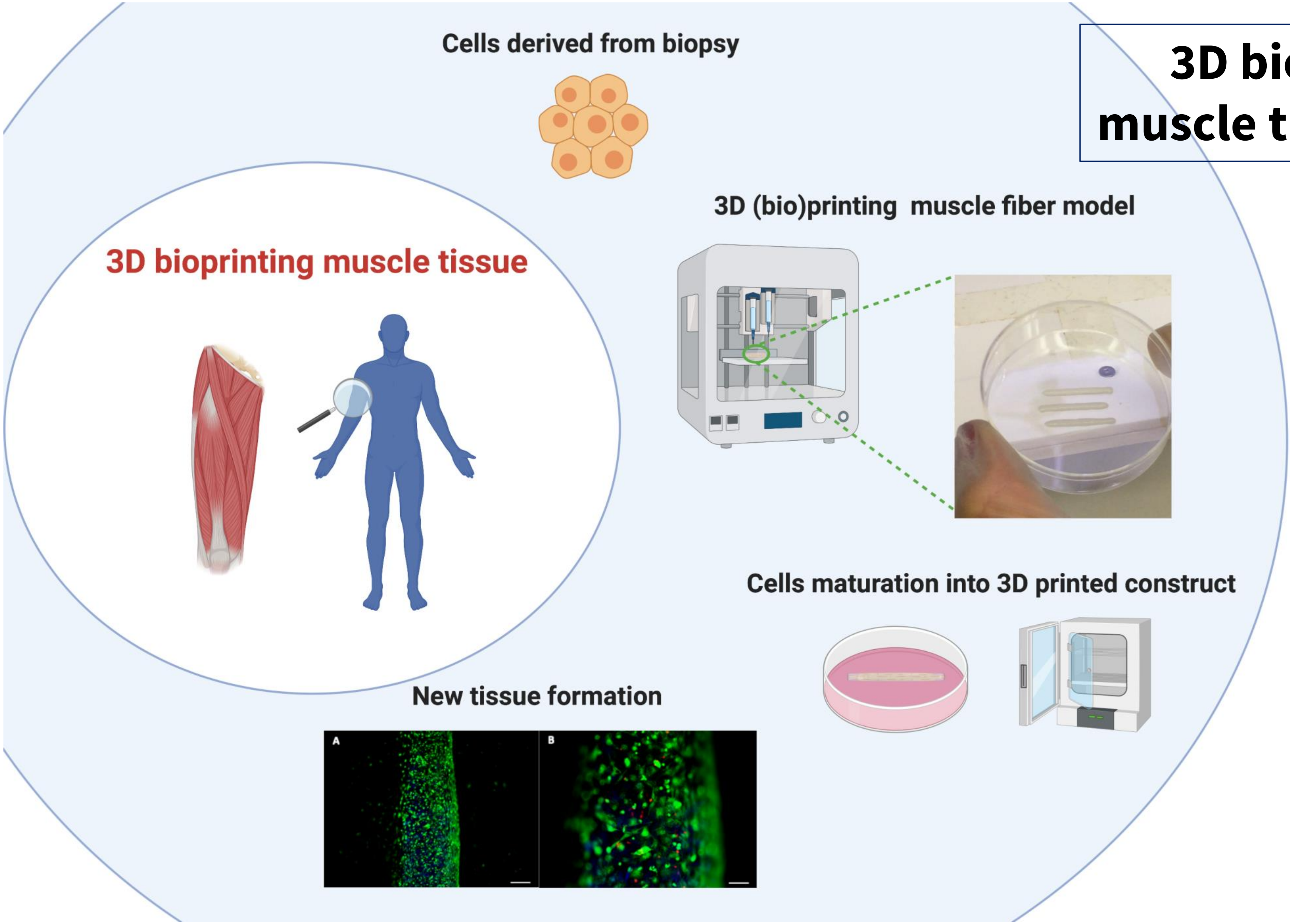


3D printed patient-specific phantoms for living donor kidney transplantation



- Realistic simulation of the intra-operative conditions
- Effective training for novice surgeons

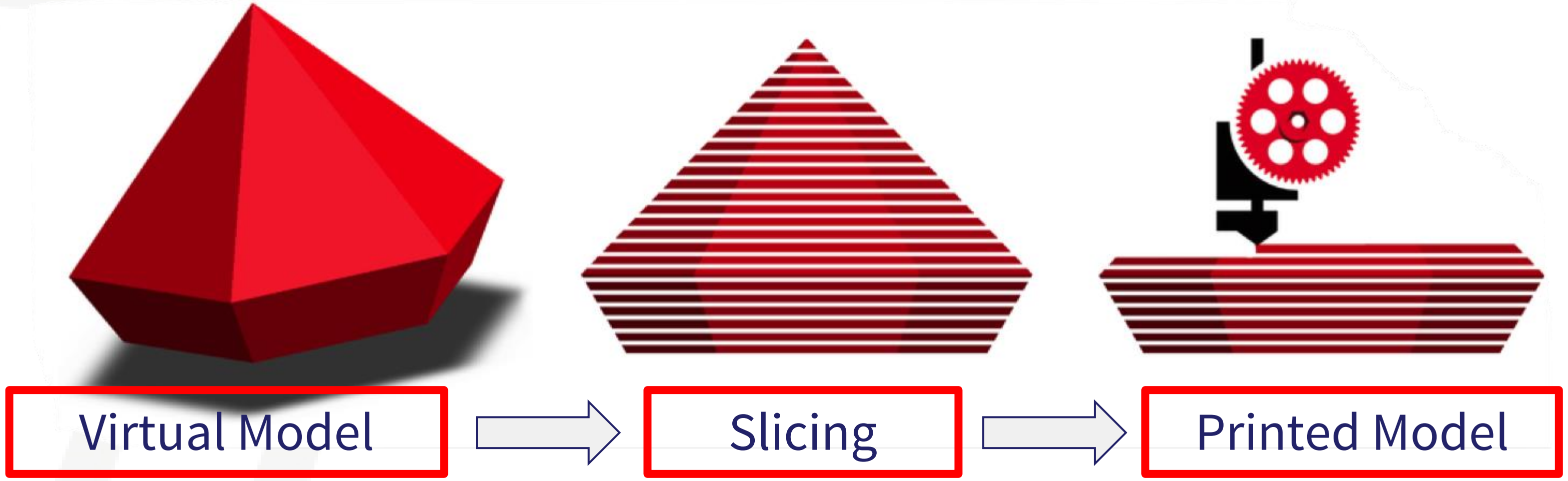
3D bio-printing for muscle tissue generation

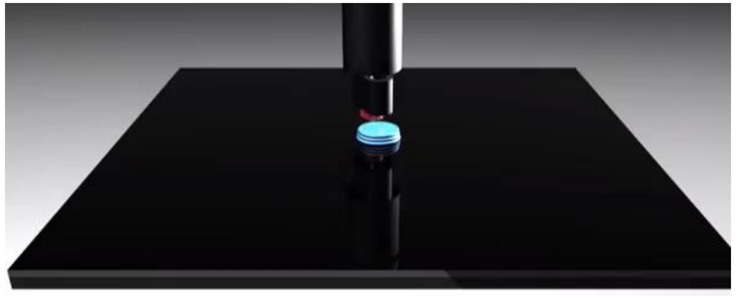



PERCHÉ UN'IMPRESA DOVREBBE ESSERE INTERESSATA AL TEMA DELL'ADDITIVE MANUFACTURING?

3D printing: general principles

- **3D printing** also known in general as **additive manufacturing**
- in contrast with more traditional subtractive manufacturing such as machining / milling

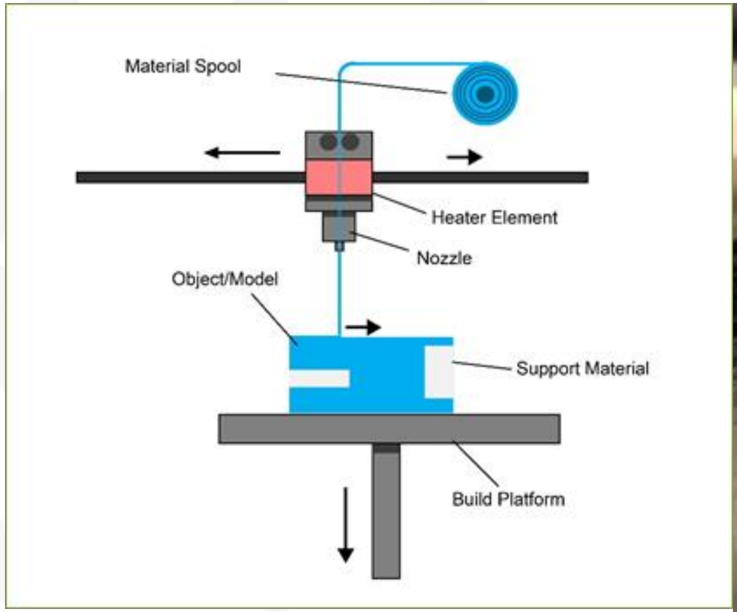


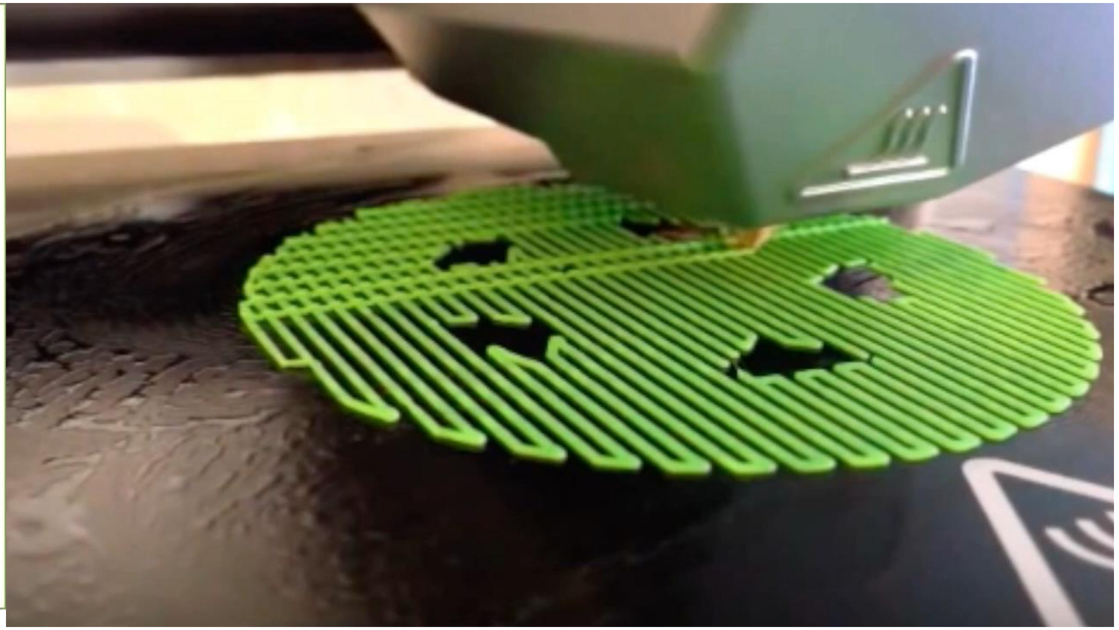


FDM *(Fused Deposition Modeling)* uses a thermo-plastic filament, pushed through a heating chamber and extruded through a small nozzle

- Material: **thermoplastic filaments** (PLA, ABS, HIPS,TPU, TPE, PETG,Nylon, reinforced materials)
- Curing: **temperature gradient**

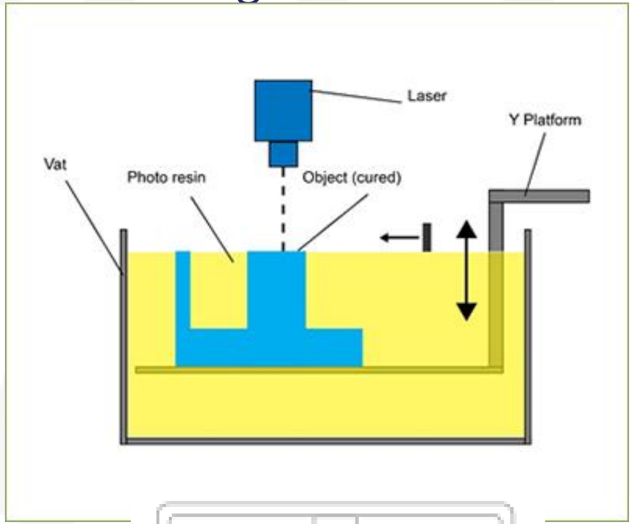
- **Inexpensive** process
- **Low resolution** with respect to other processes

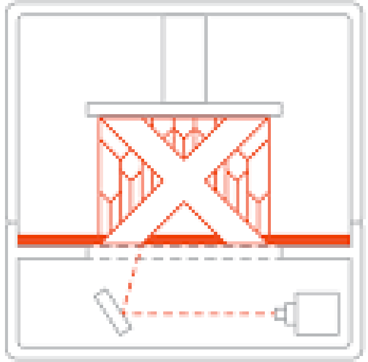




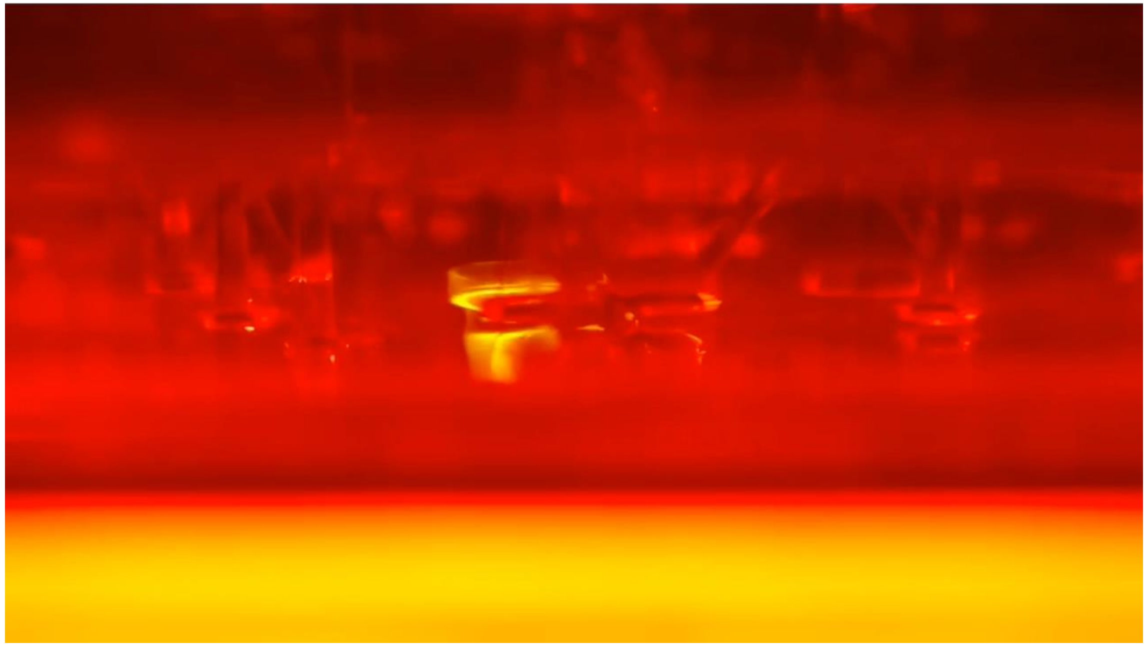
Vat – Polymerization or **SLA** (*stereolithography*) uses a container with liquid photopolymer, cured through UV laser

- Material: **photo-polymeric resins**
- Curing: **UV laser**



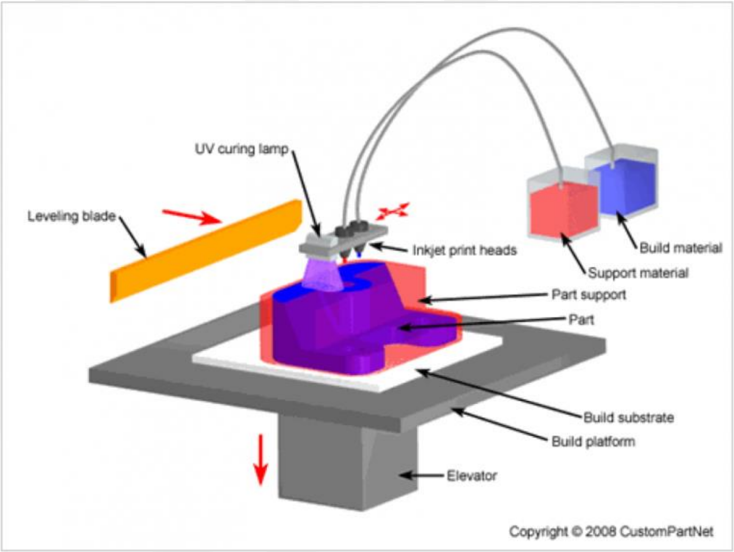


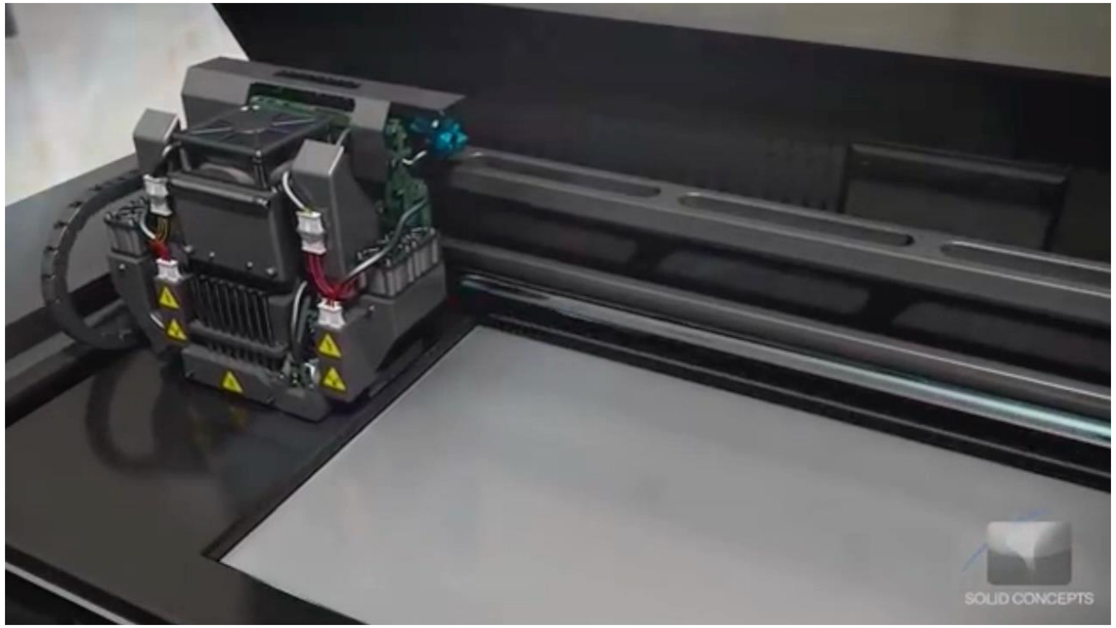
- **Quite expensive** process
- **High accuracy** and good finish
- Only one material at a time



Material Jetting uses photopolymers that are dropped through small nozzles

- Material: **photo-polymeric resins**
- Curing: **UV lamp**
- **Highly expensive**
- **Multiple** materials & colours with **high accuracy**



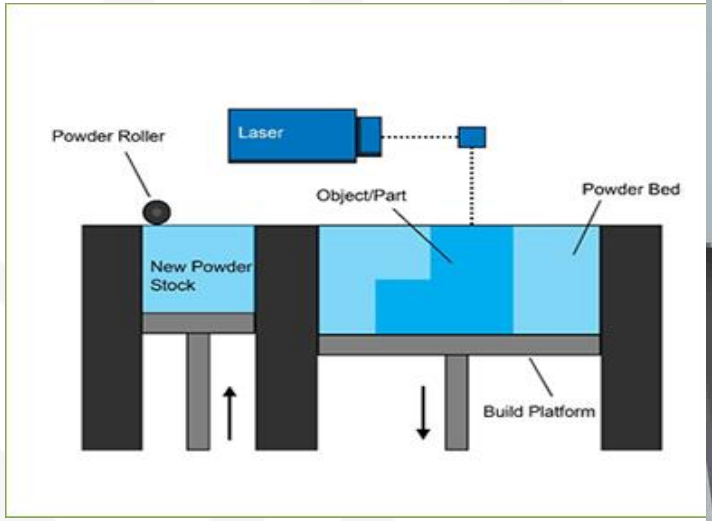


3DP technologies

Power bed fusion uses a laser source to melt powder on a printing plate

- Material: **metal alloys** (Ni, Co, Fe, Al, Steel)
- Curing: **CO_2 laser**

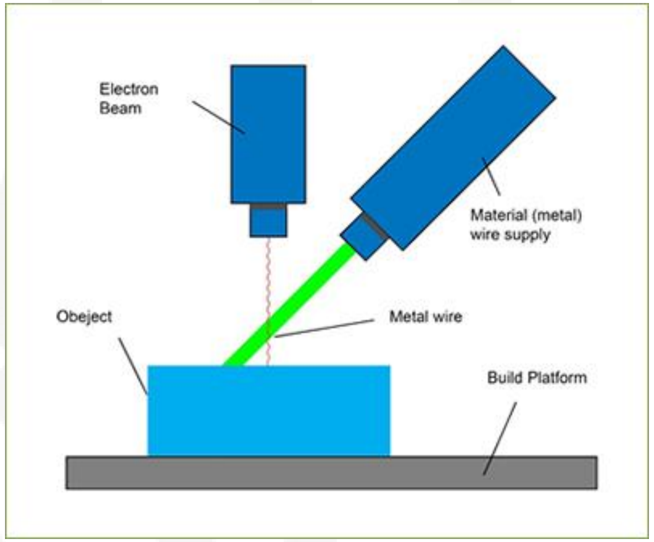
- **Expensive** process
- **Higher precision** but **lower speed** than other metal technologies
- Post-processing required



Directed energy deposition uses an electron beam source to melt powder while it is deployed

- Material: **metal alloys** (Ni, Co, Fe, Al, Steel)
- Curing: **high power electron laser beam**

- **Expensive** process
- **Lower precision** but **higher speed** than other metal technologies
- Post-processing required

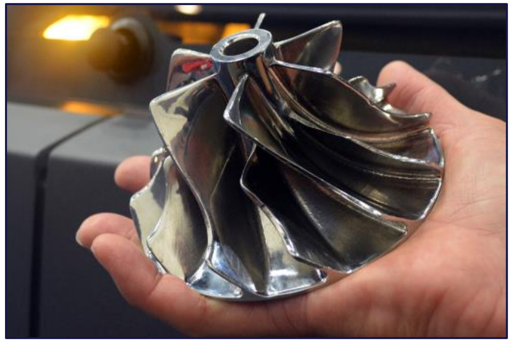


3D printing: some key-words !!

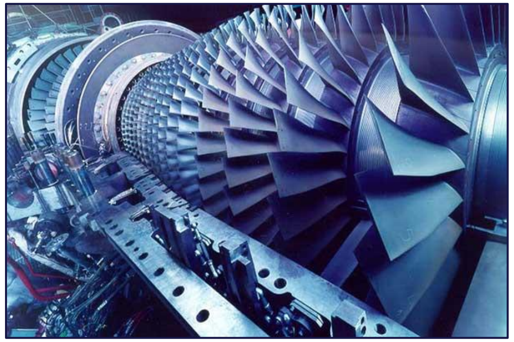
- ❖ **DEMOCRATIC TECHNOLOGY**
  - ✓ democratization of manufacturing & production
- ❖ **NATIVE DIGITAL TECHNOLOGY**
  - ✓ Technology which was born digital
- ❖ **HIGHLY MATERIAL DEPENDENT**
  - ✓ 3DP includes many different technologies due to a broad range of materials

Prototyping vs production

3D Printing technologies → **Prototyping**



Standard technologies → **Production**



Prototyping vs production

3D Printing technologies ⇨ Prototyping

3D Printing technologies ⇨ Production

ALLOYS PROPERTIES

Aluminum AlSi12

Mechanical Properties

PARAMETER	TRADITIONAL PART	3D PRINTED PART	3D PRINTED AFTER HEAT TREATMENT
Yield Strength	131 MPa	270 MPa	180 MPa
Ultimate Tensile Strength	290 MPa	480 MPa	240 MPa
Elongation at break	3,5 %	5,5 %	20 %
Hardness	80 HB	137 HB	90 HB

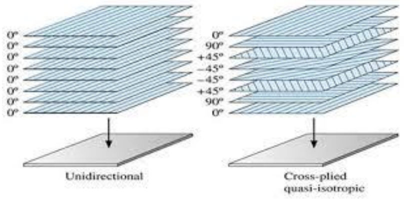
Data from: MatWeb MATERIAL PROPERTY DATA, 3D SYSTEMS

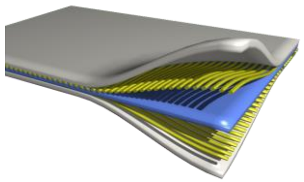
Architectured materials

MATERIALS vs STRUCTURE

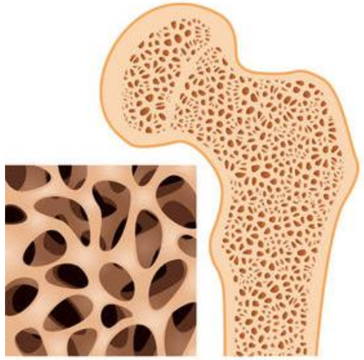
MATERIALS and STRUCTURES

Laminates / Composites





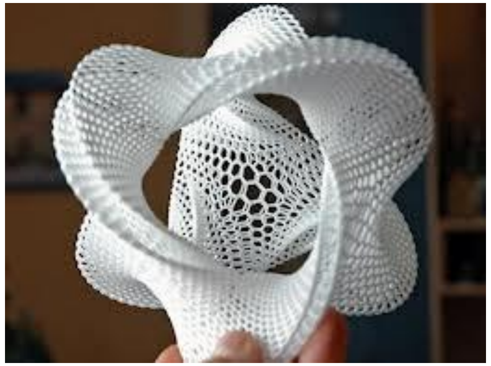
- **Inspiration by nature**: relatively small number of natural materials vs large quantity of available structures, showing wide range of properties



Architectured materials: combinations of two or more materials, or one material and space (pores), designed to display attributes not offered by one material alone

4D printing

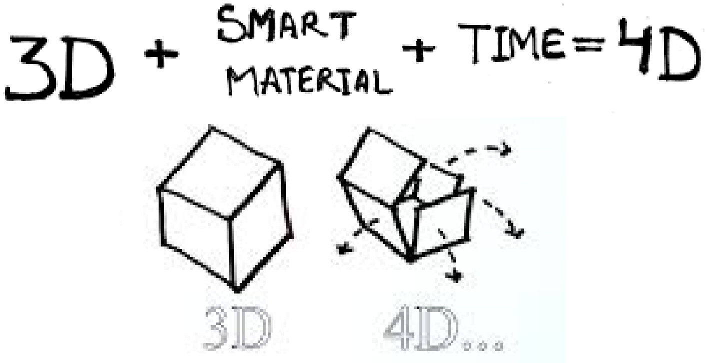
From 3D printing ...



3D PRINTING or ADDITIVE MANUFACTURING: allows the creation of 3D objects with complex shapes

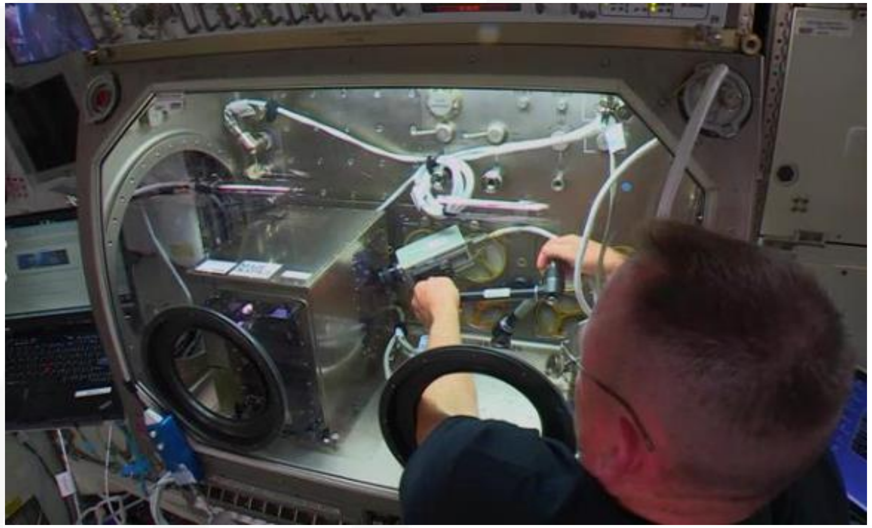
... to 4D printing

4D PRINTING: adding a new capability (transformation) to **multi-material** 3D printing

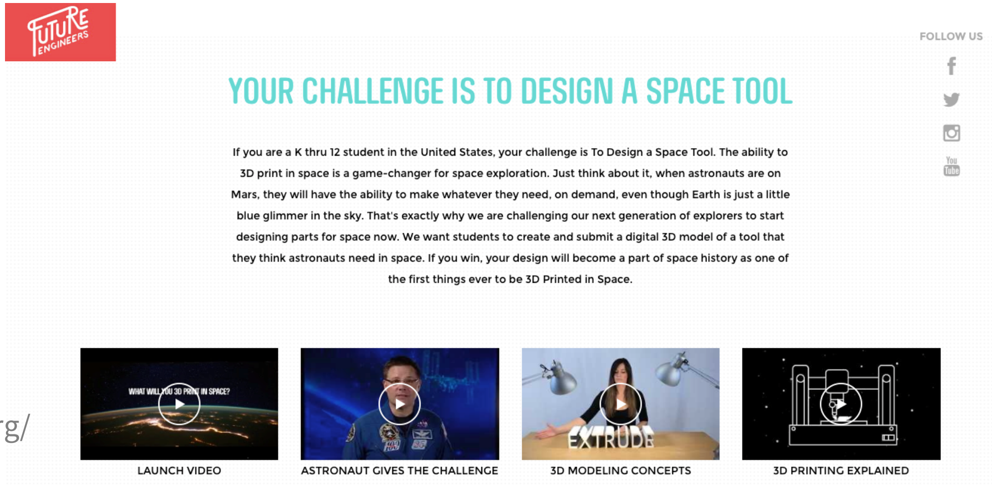


Stampa 3D a bordo della stazione orbitante

Portal: progetto realizzato da *Made In Space*, azienda americana nata con lo scopo di portare la manifattura additiva nello spazio: sperimentazione utile per verificare la possibilità di produrre pezzi di ricambio in orbita



http://corriereinnovazione.corriere.it/tech/2014/21-novembre-2014/stampante-3d-bordo-stazione-orbitante-230584475104.shtml



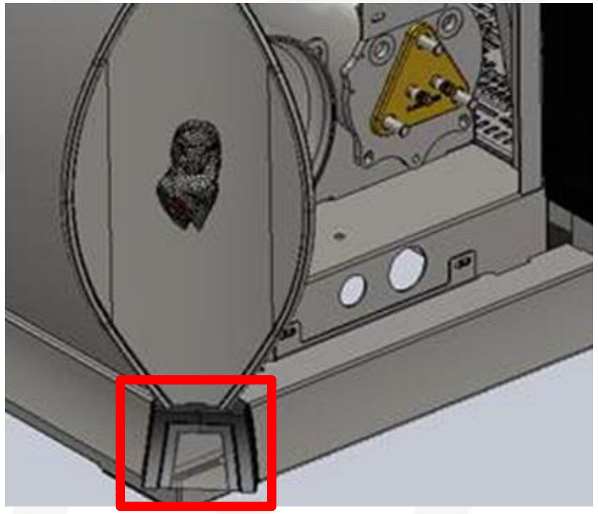
//www.futureengineers.org/

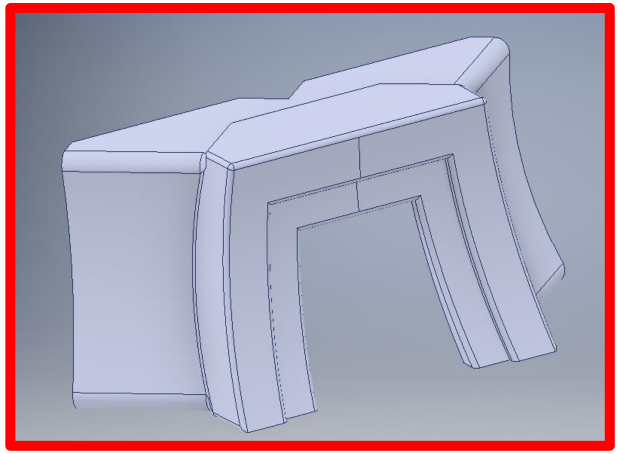
- Programma NASA utilizzato anche per promuovere i temi Stem (science, technology, engineering and math) nella scuola

INDUSTRIAL CASE STUDIES

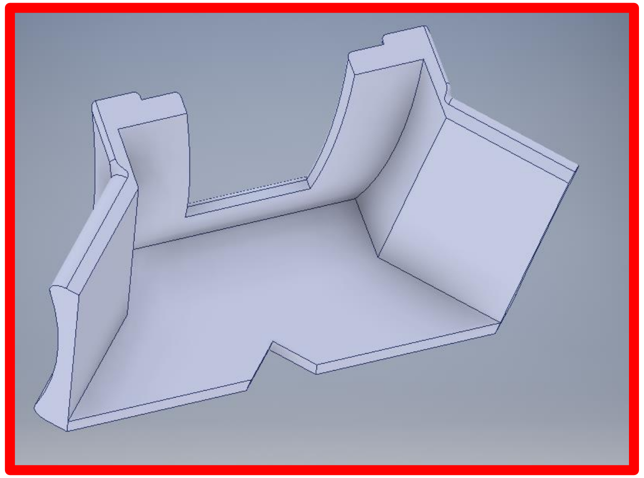
Coffee machine component - 1

Original prototype where redesigned and prepared for AM production

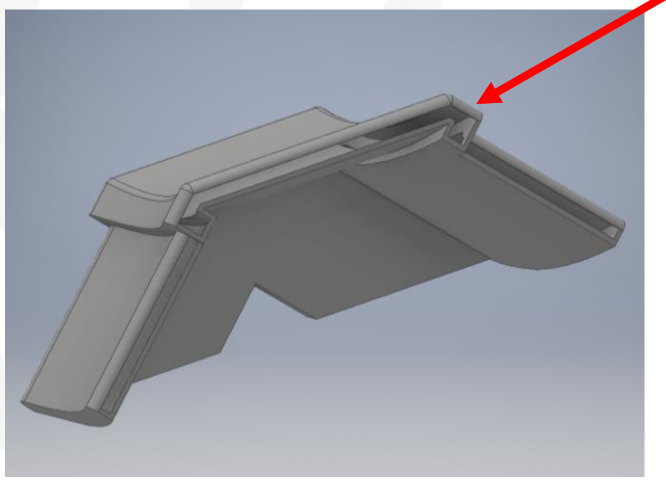




Original component in Stainless Steel

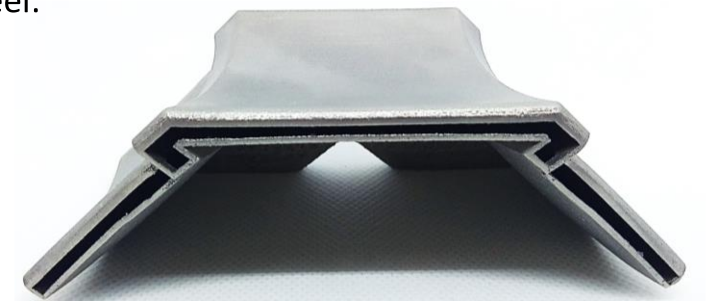


The component was **lightened** relying on exclusive features of **AM**



AM component in Stainless Steel:

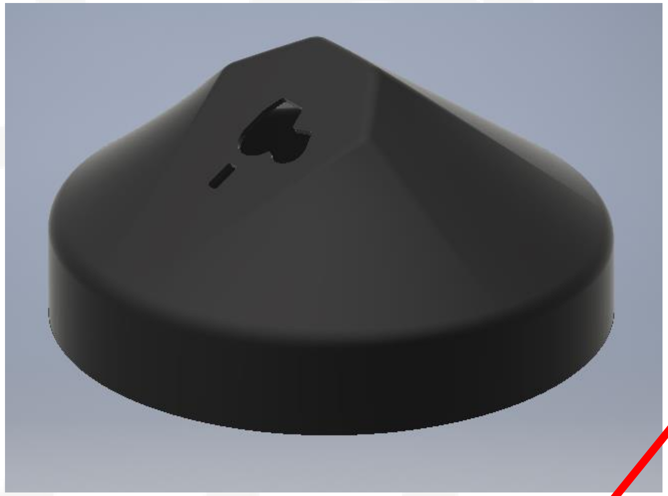
- **60% MASS REDUCTION**
- **Around 50% TIME SAVED**
- **Reduced number of post processing operations**

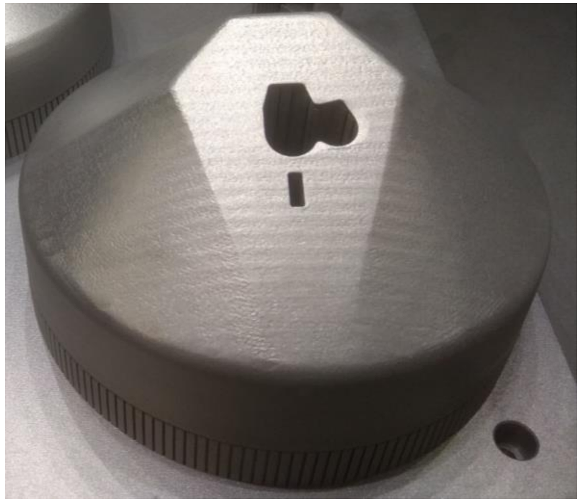


INDUSTRIAL CASE STUDIES

Coffee machine component - 2

Component designed and optimized for AM production





AM component in Stainless Steel:

- **thin skin**
- **supports** needed only **on the perimeter** of the component

AM component after **post processing operations** and after **installation on the machine**!!

Time for producing the component:

- **Original: 8 weeks** for the final component
- **AM: 1 week** for the final component

Coffee machine component - 4

Material: Stainless Steel.

GOAL - 1: to increase internal temperature

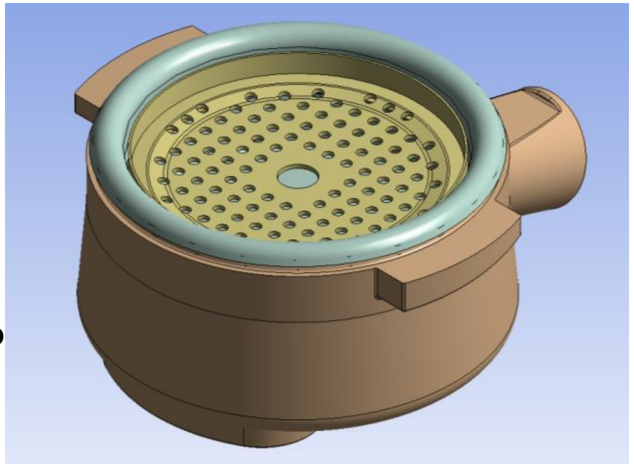
GOAL – 2: to reduce the external temperature in order to avoid accidents for the barman

Original component

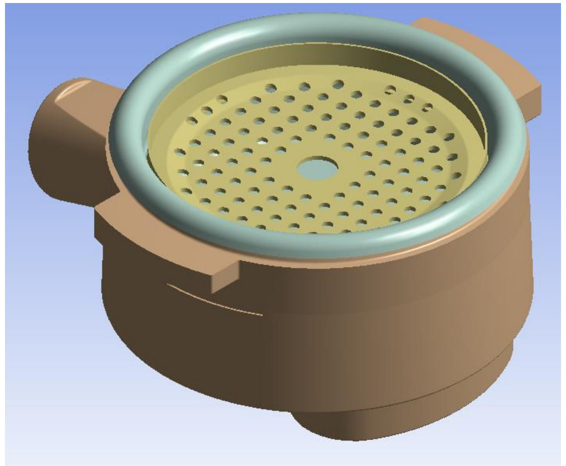
How to achieve the GOALS?:

- With **thermal shape optimization** we have developed TWO SOLUTIONS

ANSYS



GOAL - 1: internally warmer



GOAL - 2: externally colder

How to validate the design?

INDUSTRIAL CASE STUDIES

Coffee machine component - 4

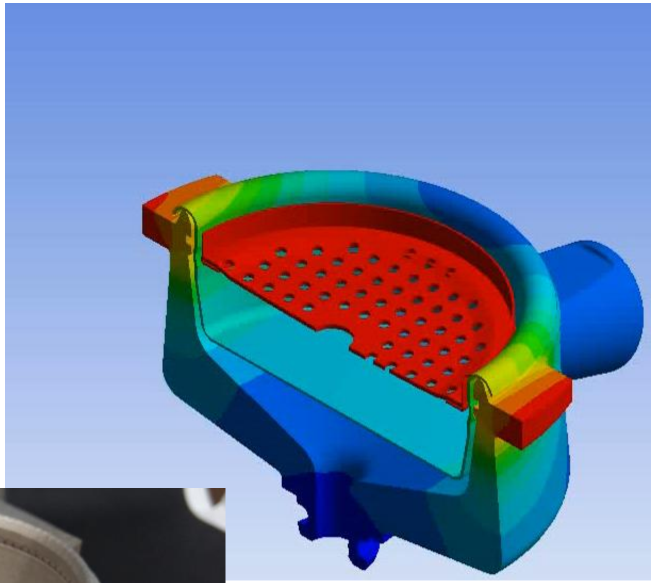
Material: Stainless Steel.

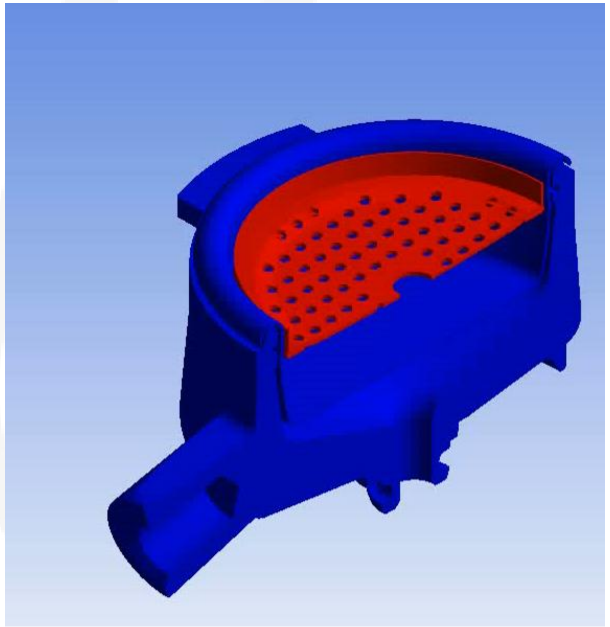
GOAL - 1: to increase internal temperature

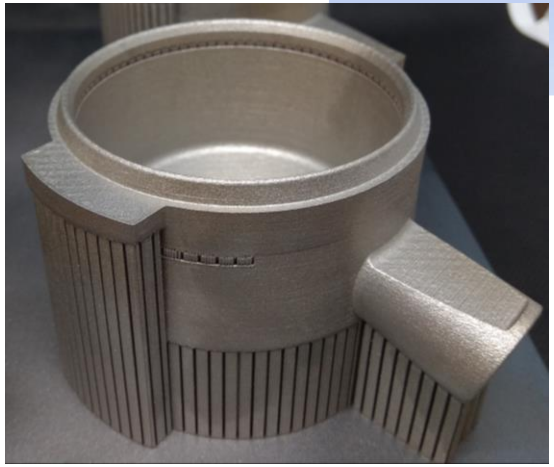
GOAL – 2: to reduce the external temperature in order to avoid accidents for the barman

How to define optimized design?

By non-linear transient thermal simulation with FEM







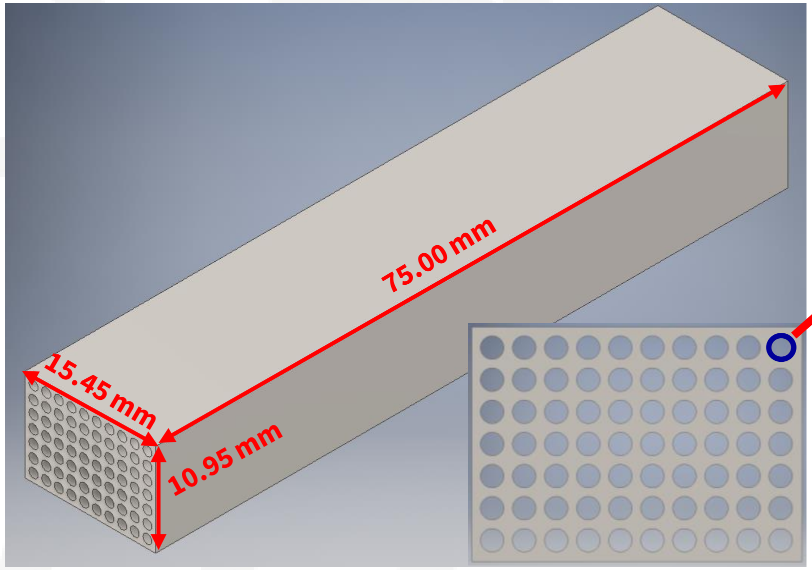
AM component in Stainless Steel:

- **able to respect the GOALS**

INDUSTRIAL CASE STUDIES

Optic fiber conveyor for nuclear applications

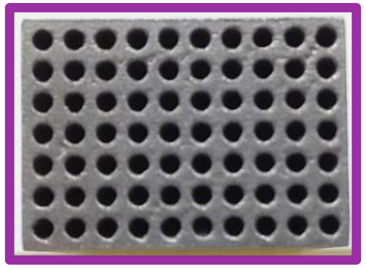
Simple geometry component almost impossible to realize with classical milling operations



Dimensional requirements:

- Min diameter: 1.10mm
- Max diameter: 1.15 mm

1st experimental result:

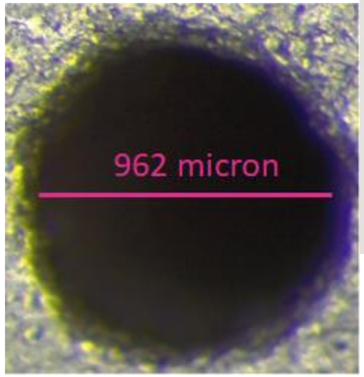


How to reduce the dimensional error?:

- With numerical simulations we can predict part distortions and compensate CAD geometry

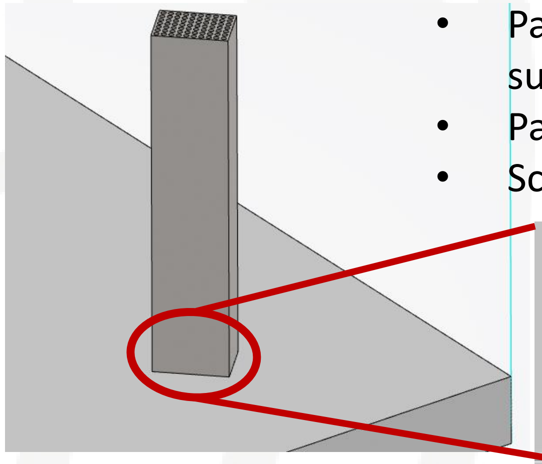
+ ABAQUS

DASSAULT SYSTEMES

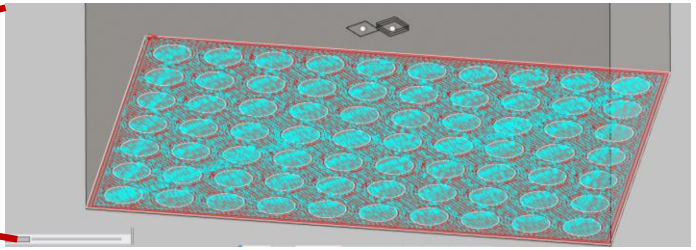


Optic fiber conveyor for nuclear applications

Simple geometry component almost impossible to realize with classical drilling operations

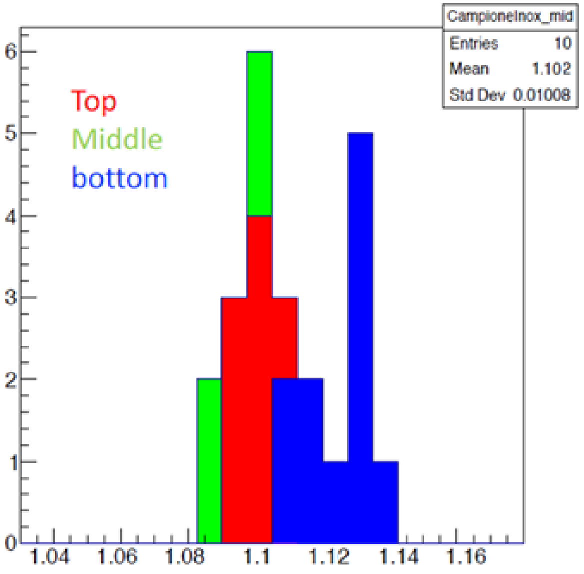


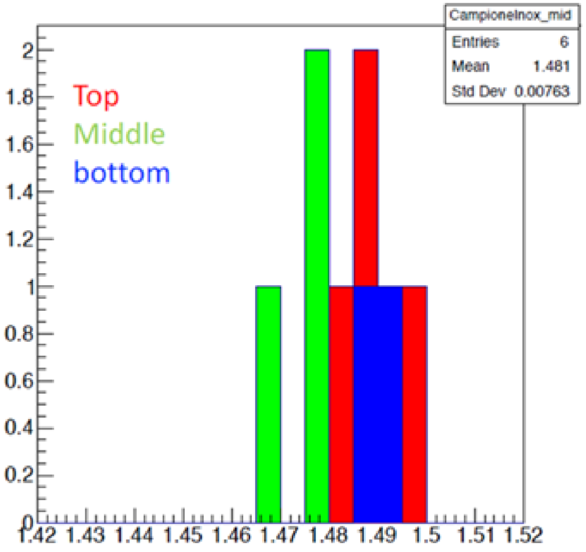
- Part orientation on build tray and supports generation were needed
- Parameter definition
- Scan path and supports generation



New dimensions:

- Medium diameter: **1.102mm** OK
- Distance between holes: **1.481 mm** OK





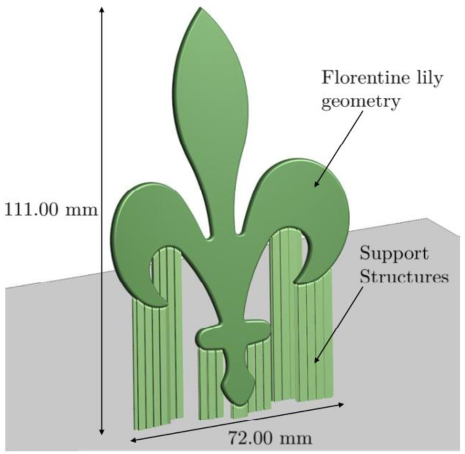
What about COSTS & PRODUCTION TIME?:

The only alternative method to produce the component is EDM:

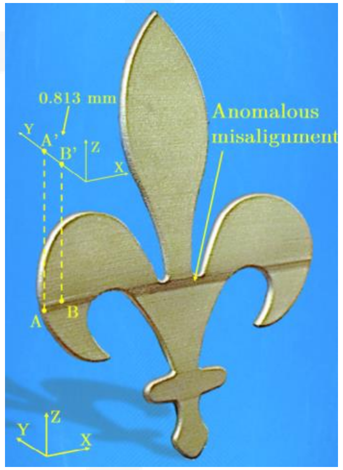
- **AM is 8 times FASTER** than EDM
- **AM is 10 times CHEAPER** than EDM

INDUSTRIAL CASE STUDIES

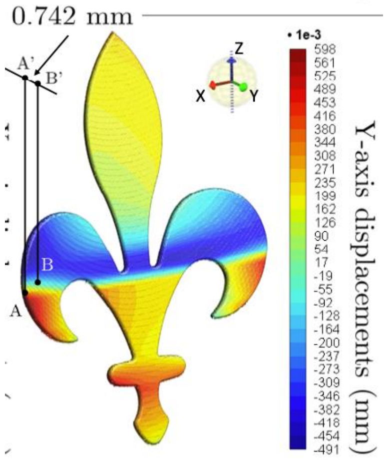
Florentine lily geometry: decorative element for coffee machines



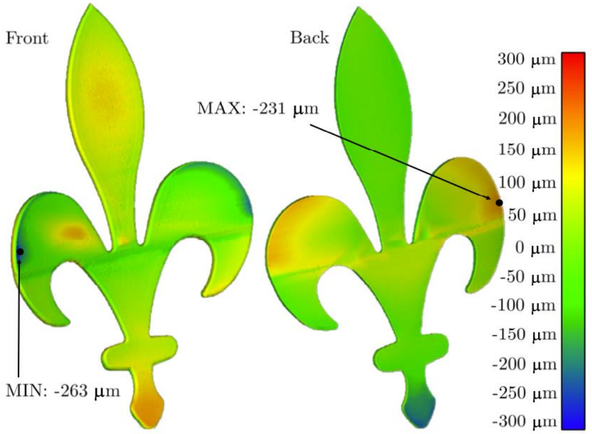
Original geometry and support structures



Printed original component

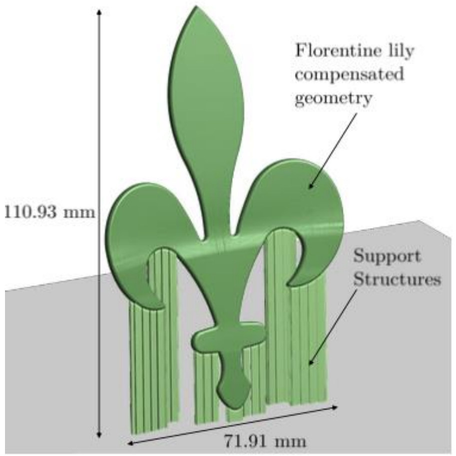


simulation results in terms of displacements

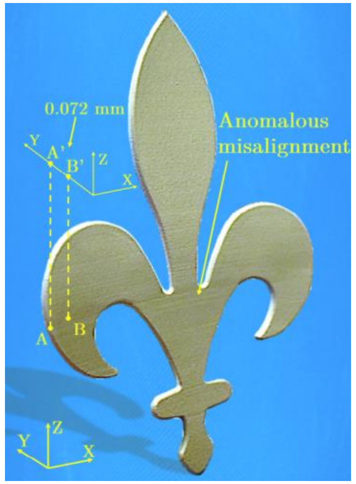


Relative displacements between numerical model and micro-CT

Idea: use numerical simulation to compensate original geometry



Compensated geometry

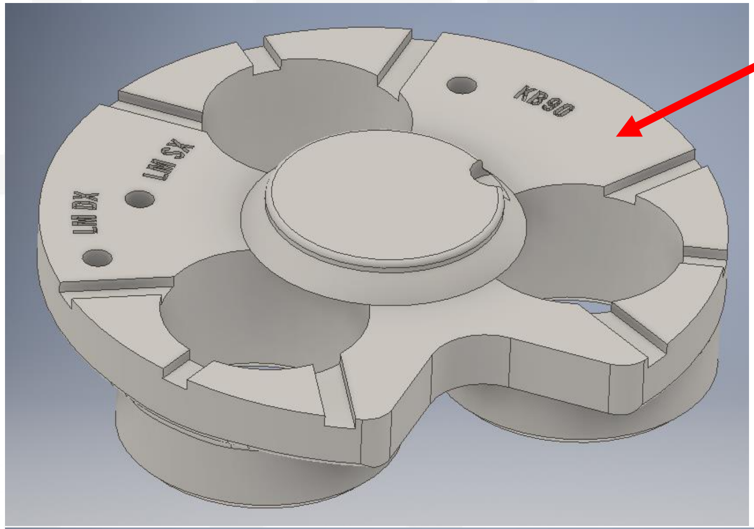


Printed compensated component

INDUSTRIAL CASE STUDIES

Electro welding guide

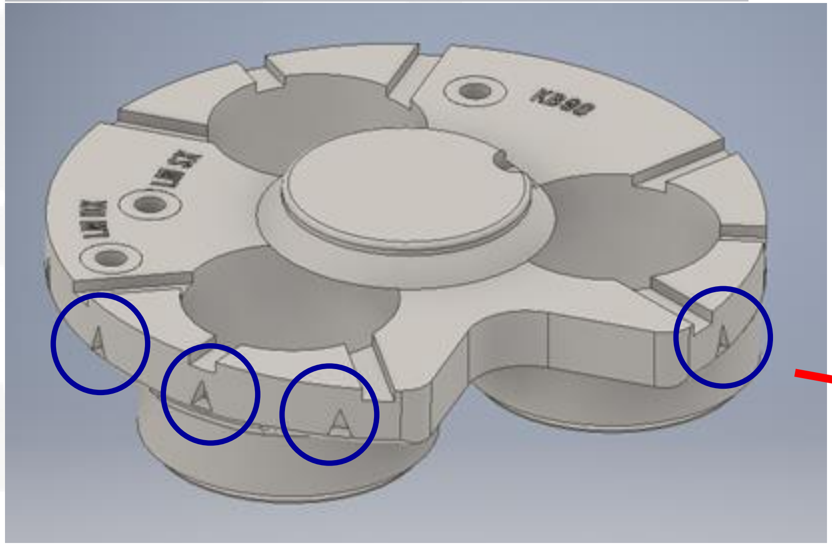
Very expensive for casting production with a small number of parts!



Original component in thermo**plastic polymer**:

- Wear problems induced by the high temperatures produced during welding process
- Need a dedicated mold to be produced
- High production costs

Production time is less than 10% of original casting by molding



AM component in Stainless Steel:

- Same weigth thanks to the **internal design**
- **No wear problems** thanks to a stiffer material
- No mold needed → **LOWER COSTS**

INDUSTRIAL CASE STUDIES

Optimized flow channel

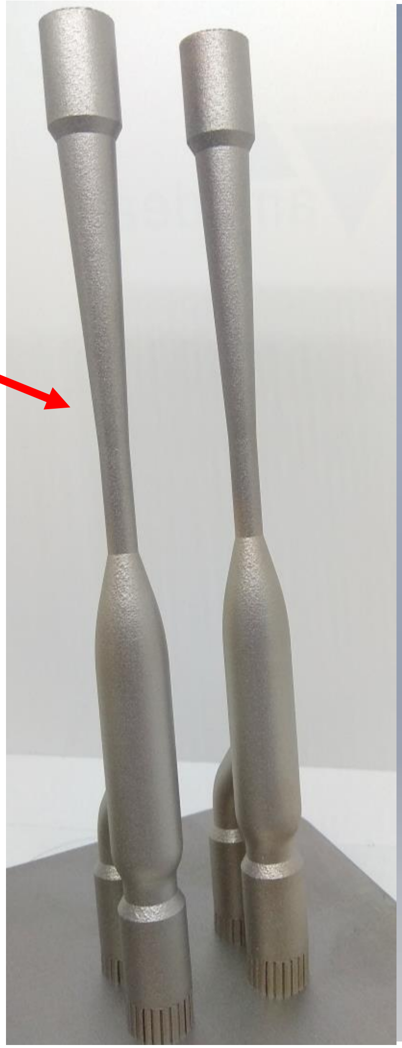
Internal channels originally realized in plastic material, then optimized for metal AM production

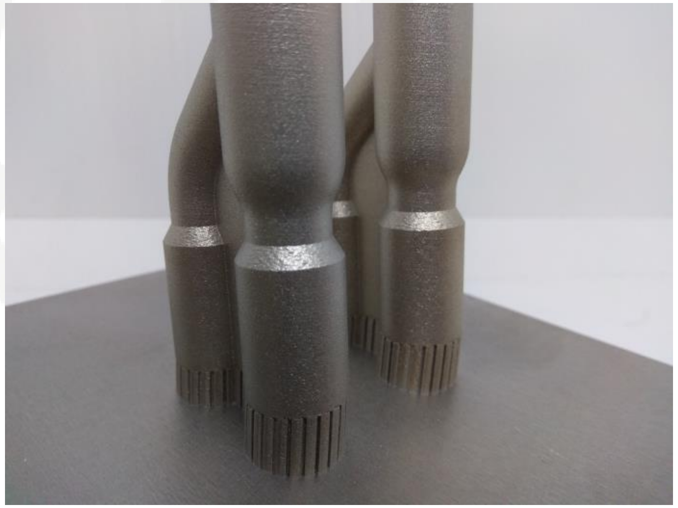
Original component in **plastic**:

- Higher mass
- Higher production time
- Higher cost

AM component in **Stainless Steel**:

- Same weight
- Lower production time
- Stiffer, and more resistant to internal pressure



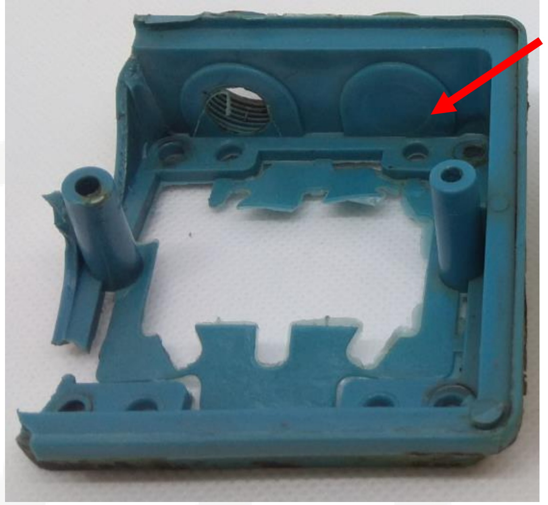


- **reduced number of supports**
- **almost no post - processing operation needed**

INDUSTRIAL CASE STUDIES

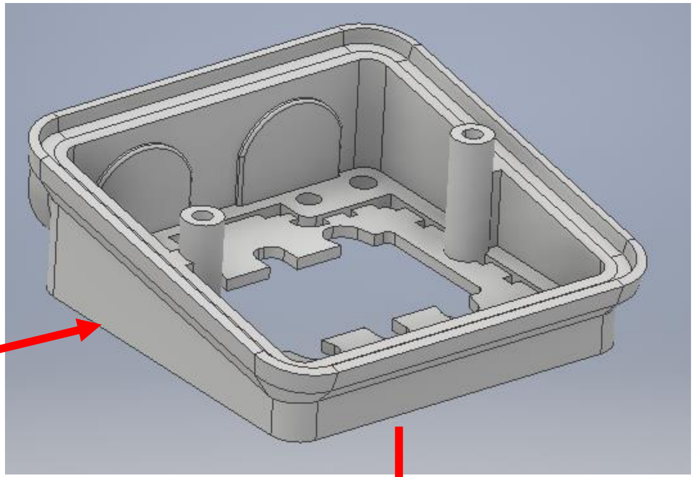
Containment box for electric component

Component originally realized in plastic material, then optimized for FDM based AM production



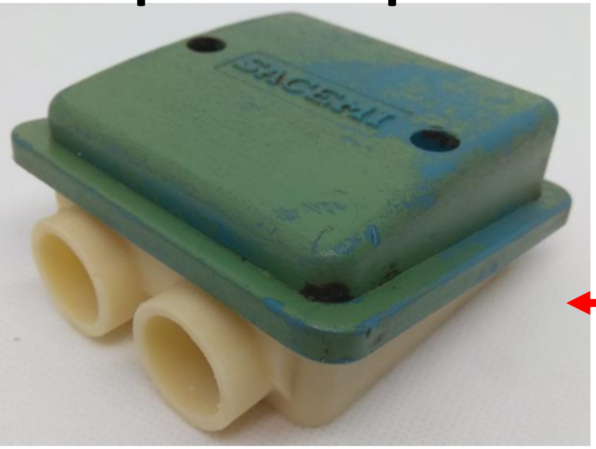
Original component in **plastic**:

- **Out of production**!!
- Indispensable for safety reasons
- Need to change the entire engine



Plastic component redesigned for AM production with PC-ABS!!

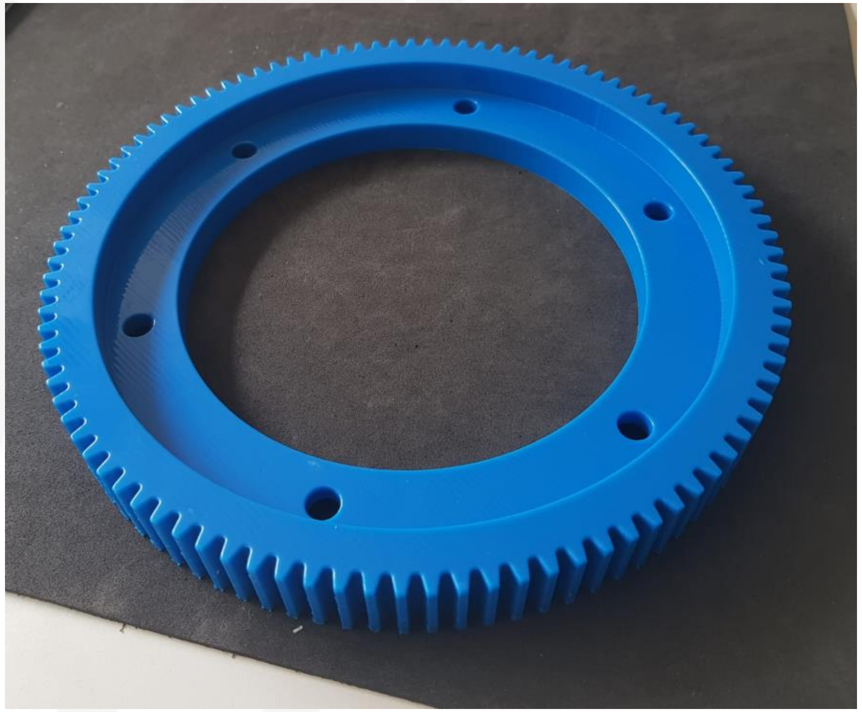
Damaged component **Replica component**



INDUSTRIAL CASE STUDIES

Structural gear realized with PolyJet technology

Gear component for a very old compression test machine

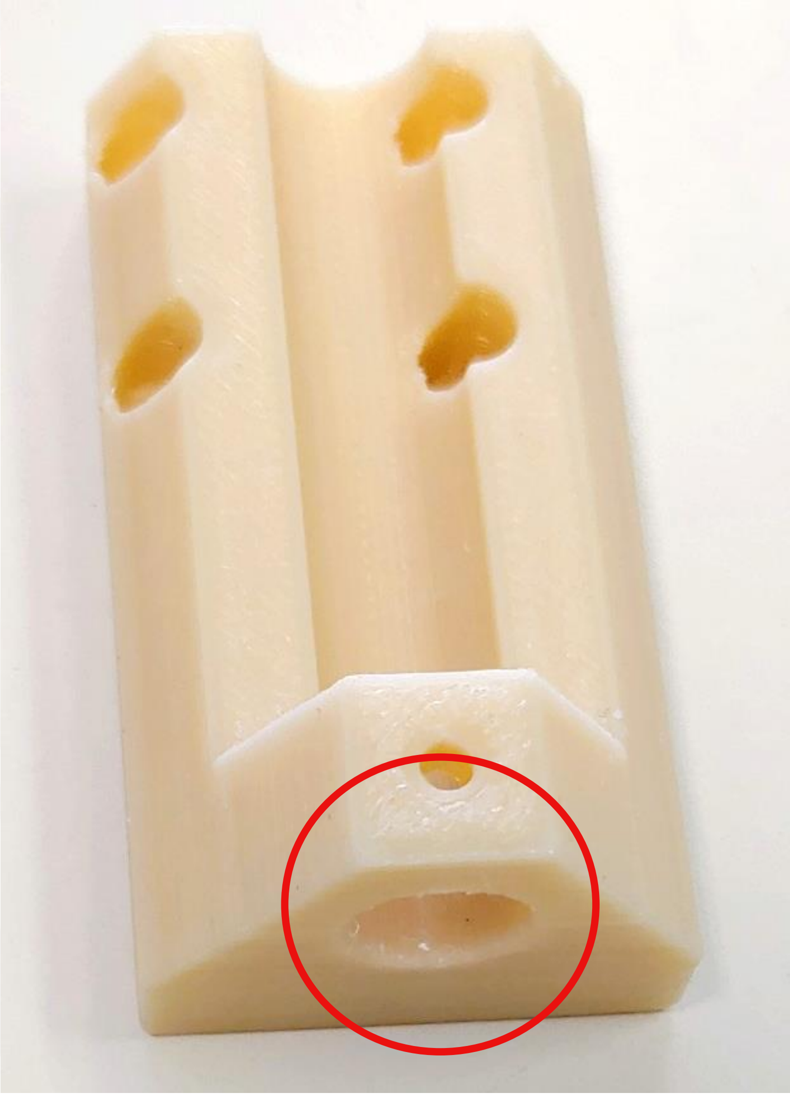


Original component in **reinforced plastic** was turned into an AM component realized with PolyJet technology in a **photo-polymeric resin**

- **Mass reduction: 25 %**
- Production **costs and time** down 40%
- The part was out of market, we produced it with trough a **CAD reconstruction**

INDUSTRIAL CASE STUDIES

Various components realized with FDM technology

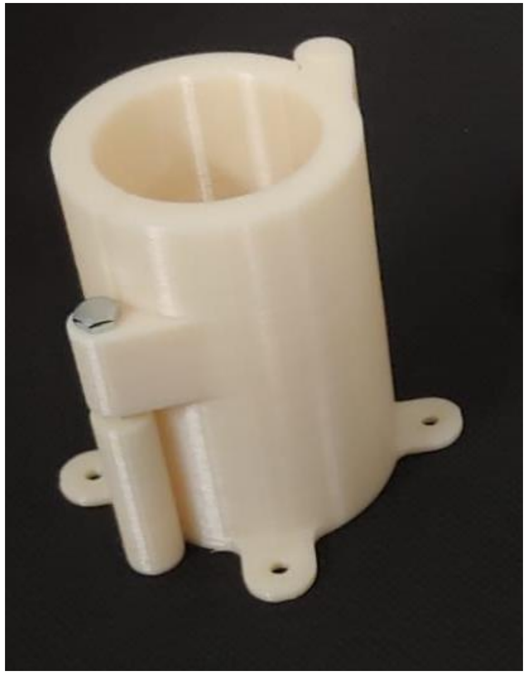


Support structure for bioprinter extruder in **PC-ABS plastic**:

- This component was realized to replace the original component realized in Aluminum
- Main challenge was to **take the red zone at a temperature as low as possible**

Mold for concrete 3D printer in **PC-ABS plastic**:

- This component is used to **realize cylindric concrete specimens** with a concrete 3D printer
- The component has been printed in two parts, then assembled



INDUSTRIAL CASE STUDIES

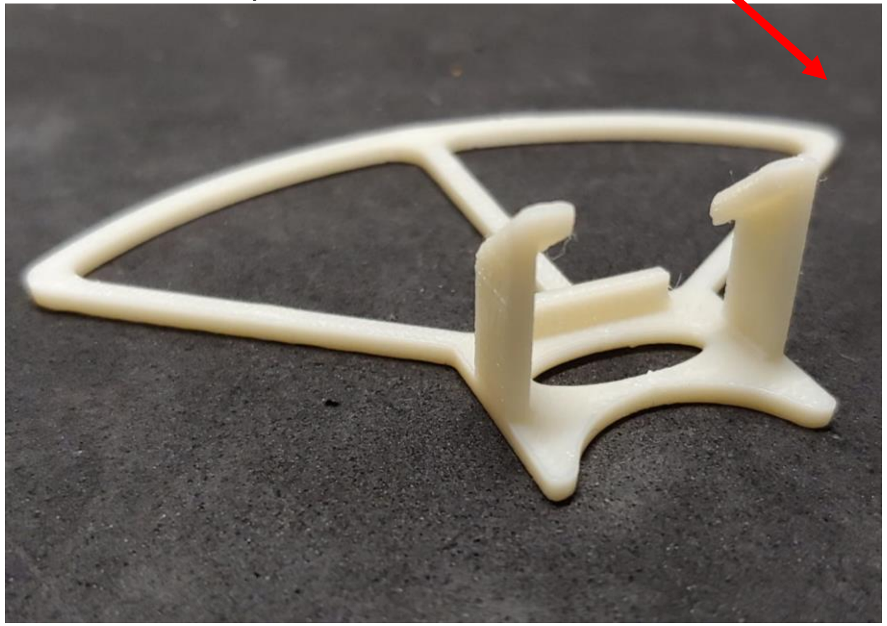
Various components realized with FDM technology

Covering part for a CNC machine in **PC-ABS plastic**:

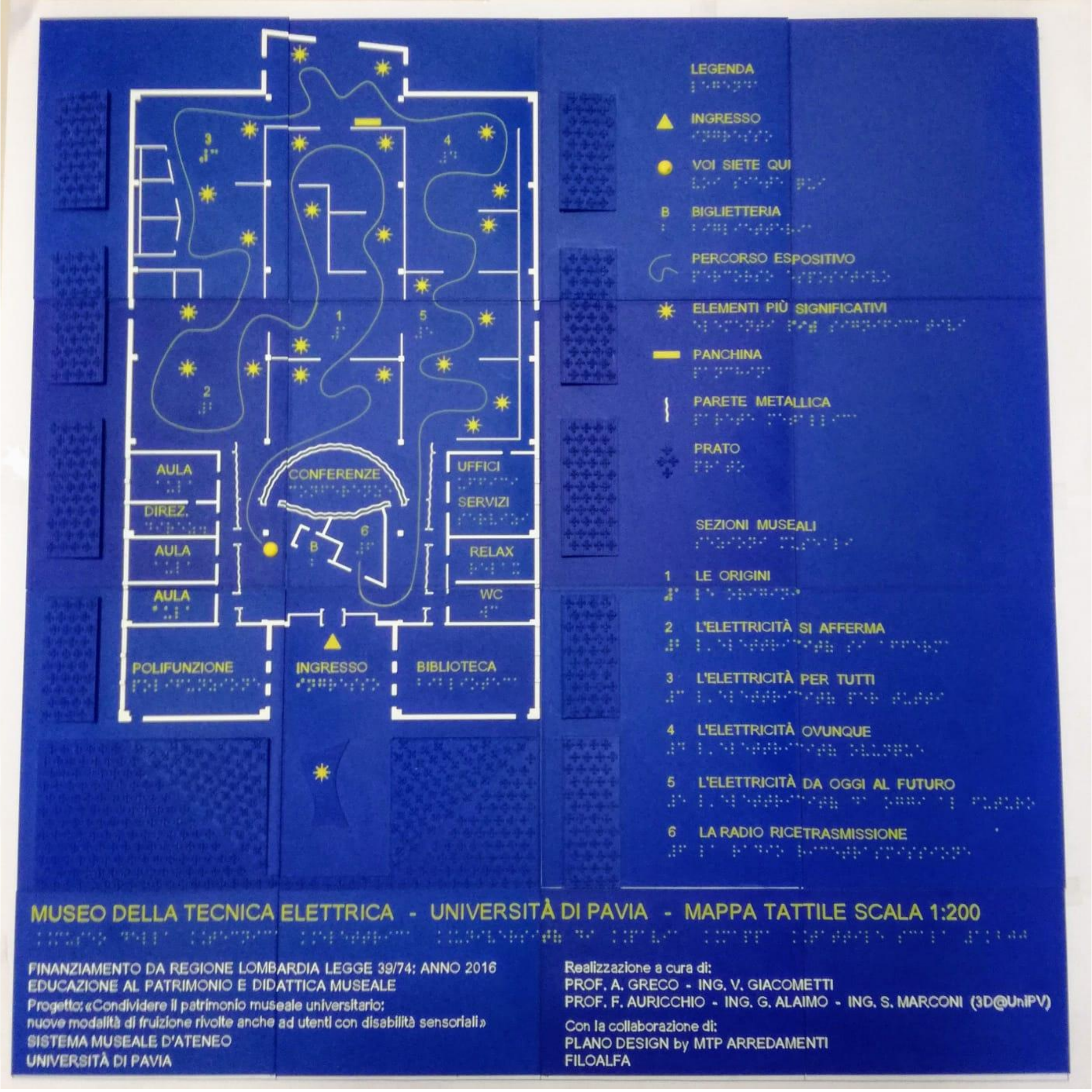
- The original component was simply reproduced with the requested tolerance

Drone buffer in **PC-ABS plastic**:

- The component was manufactured in **PC-ABS** polymer to obtain a more ductile part, more resistant to impacts



Various components realized with FDM technology

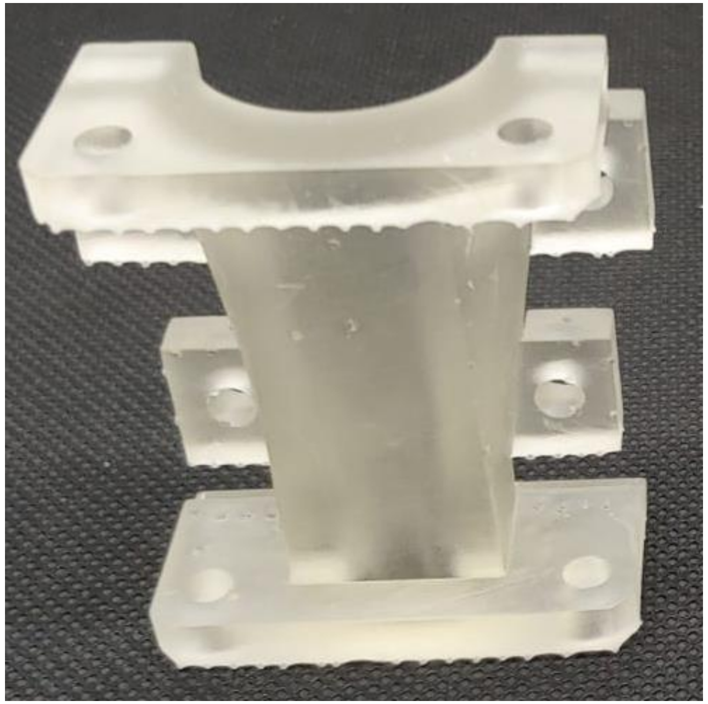


Tactile map in **ABS plastic**:

- This map was realized for the Electric Museum in Pavia

Component in **Resin**:

- The component is metalized with a copper film for microwave applications

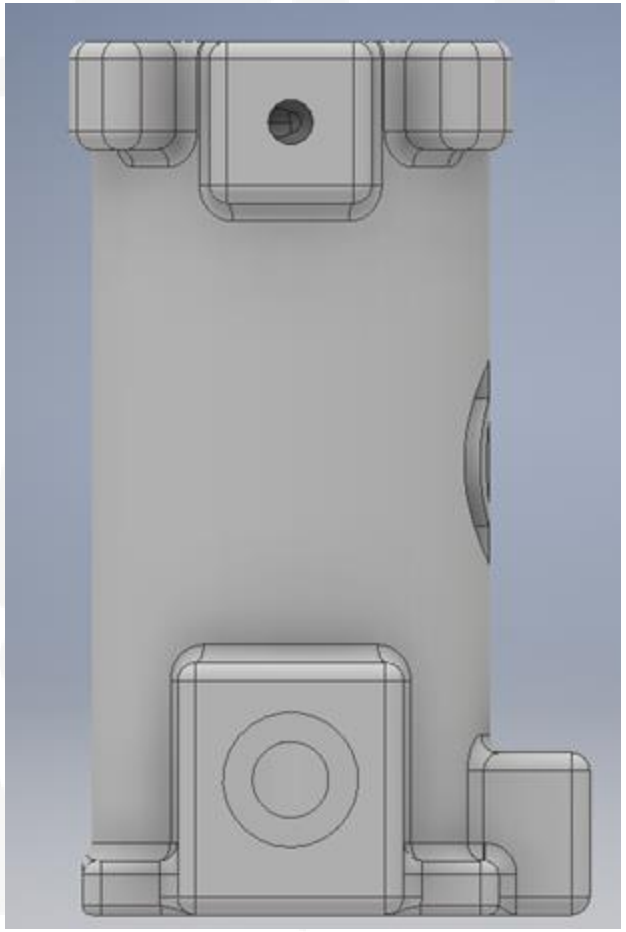


INDUSTRIAL CASE STUDIES

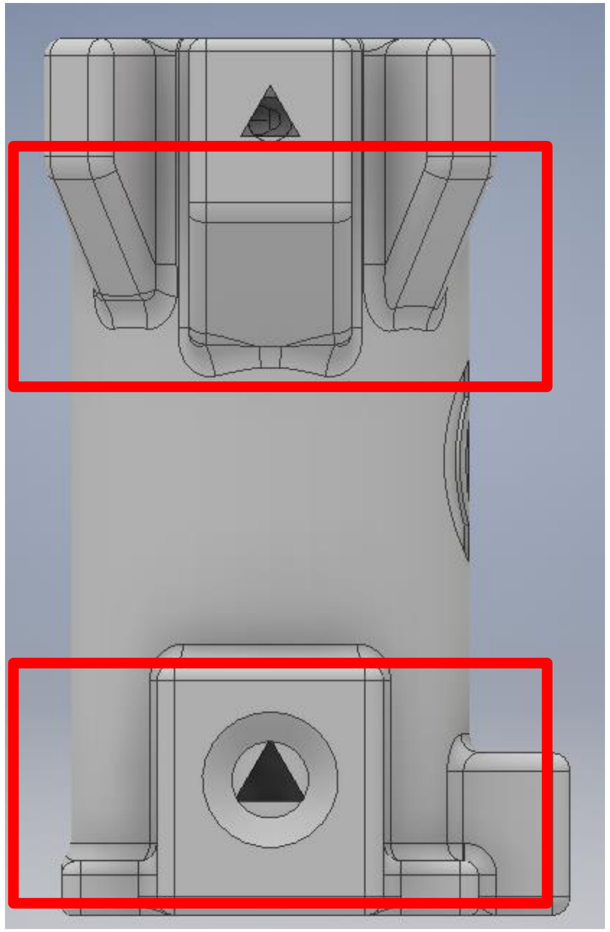
Thermo-fluid-dynamic pump component

Internal channels (not displayed) can be realized only with AM technology.

ORIGINAL MODEL



MODEL REDESIGNED FOR AM



3D PRINTED COMPONENT

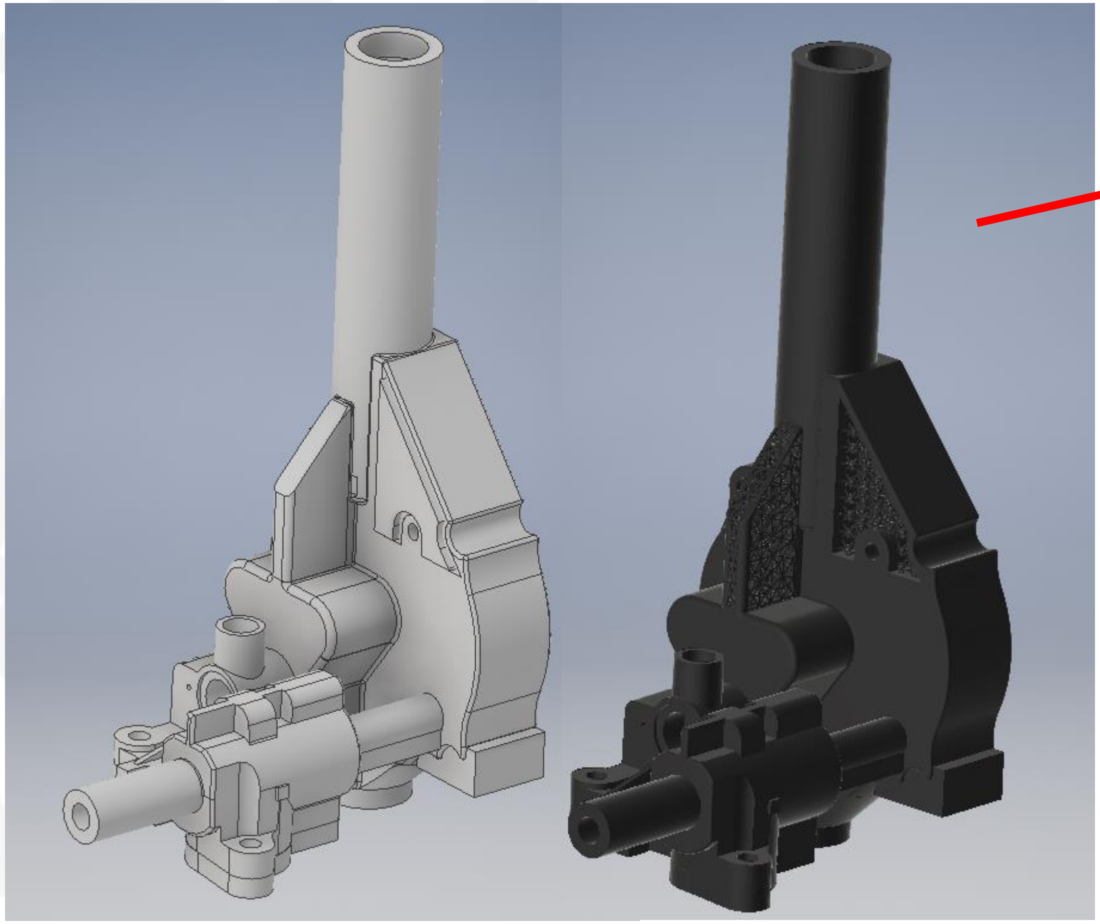
INDUSTRIAL CASE STUDIES

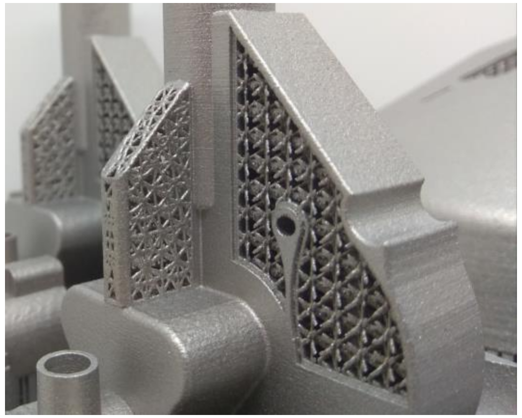
Component for alimentary industry

Component originally realized by assembling **multiple components** and lightened with usage of **lattice structures**

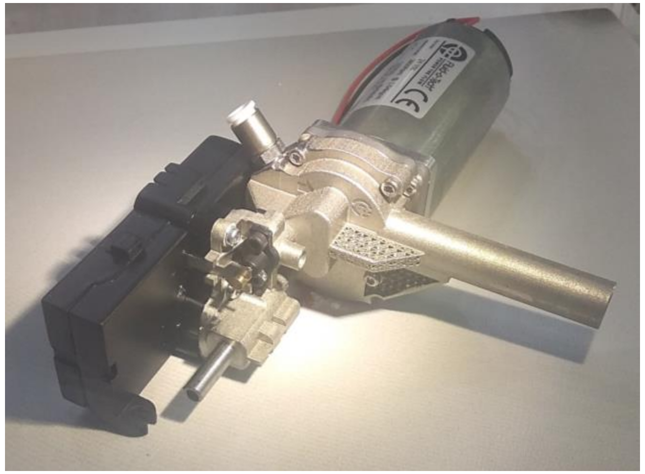
ORIGINAL MODEL

LIGHTWEIGHT MODEL WITH LATTICE STRUCTURES





FINAL COMPONENT ASSEMBLED WITH ELECTRIC ENGINE



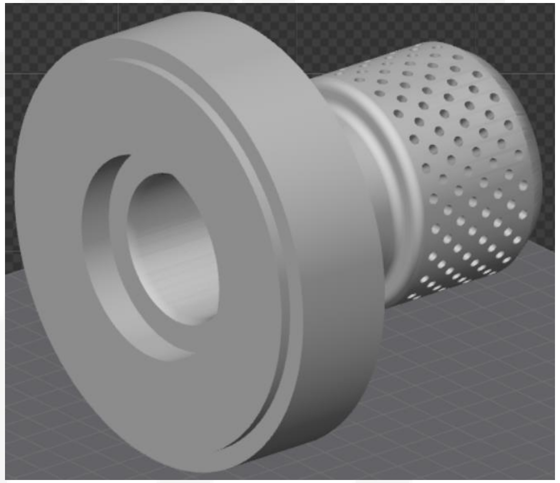
INDUSTRIAL CASE STUDIES

Component for Oil & Gas industry

Component originally realized by assembling **multiple** components was lightened with **topology optimization**

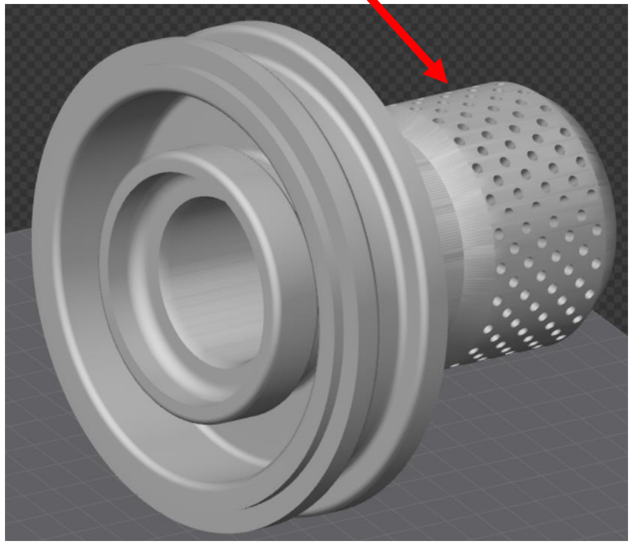
Original component in Stainless Steel

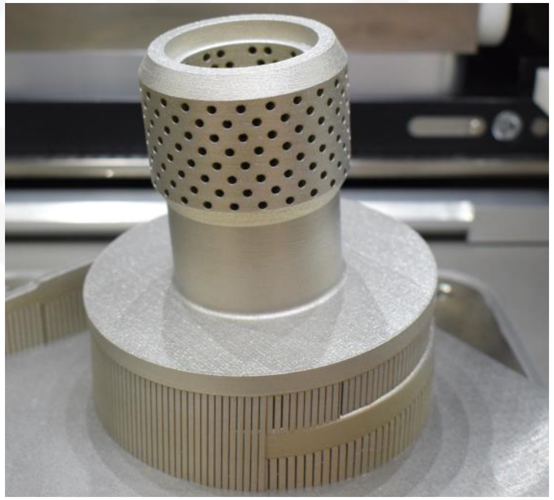
- Produced with CNC operations
- Part realized of multiple components welded together
- Production time: 7 weeks



AM component in Stainless Steel: **50% of the original weight**

- Produced in a single component
- Production time: 40 hours
- **Same yielding safety factor**





3DMetal@UniPV

Fluid-o-Tech®
POWER THE FLOW

UNIVERSITÀ DI PAVIA

la marzocco
handmade in florence

3DMetal@UniPV

- Il progetto unisce mondo dell'impresa e della ricerca allo scopo di sviluppare un **percorso di crescita delle competenze nel campo della stampa 3D metallica,** tecnologia che offre grande versatilità
- Ha lo scopo di **produrre componenti metallici** di interesse dei partner industriali e di **svolgere attività di ricerca** su ottimizzazione dispositivi e simulazione del processo di manifattura additiva
- Il progetto ha 3 partner
  - **Fluid-o-Tech**: azienda leader nella progettazione e produzione di pompe volumetriche e sistemi per la gestione dei fluidi
  - **La Marzocco**: azienda leader nella produzione di macchine per il caffè
  - **Università di Pavia**

Fluid-o-Tech POWER THE FLOW
la marzocco handmade in florence
UNIVERSITÀ DI PAVIA

Budget reporting:

- **Project budget:** **1,029,669.16 €**
  - Companies contracts: 257,417.29 € x 2 + IVA
  - UniPV: 514,834.58 €

- **Investments:** **640,000.00 €**
  - 3D printer and accessories rental: 390,000 € + IVA
  - Dedicated Personnel costs: 120,000 €
  - Machining center: 90,000 € + IVA
  - EDM Machine: 40,000 € + IVA
  - Other costs: to be computed and retributed depending on the amount of printed components

NOTE: IVA is a cost for the project !!

Software for PRINTING SETUP and SIMULATION:

QuantAM
RENISHAW apply innovation™

- Part orientation on building plate
- Material development
- Orientation of multiple components on building plate
- Laser exposition control and management

Altair
HyperWorks

- Topology optimization for AM
- Weight reduction
- Stiffness maximization
- Lattice structures optimization

ANSYS

- Finite Element Simulation
- Residual stresses and displacements prediction
- Geometry compensation and STL generation

ABAQUS
DASSAULT SYSTEMES

- Finite Element Simulation
- Plugin for AM simulation
- Residual stresses and displacements prediction
- Geometry compensation and STL generation

We have signed a partnership with **CAETECH** for using commercial products dedicated for AM Simulation like **3DExperience**

CAETECH PERFORMANCE EXPERIENCE

Come approcciare il mondo stampa 3D

- **Individuare un componente di forte interesse**
  - Componente per il quale sia necessario un miglioramento delle prestazioni o
  - Necessario un investimento in termini di tempo / risorse di progettazione / eventualmente economiche

- **Particolari vantaggi se si integrano funzioni o si ottimizza (migliorano) le prestazioni**
  - Necessario avere un “parziale” margine di azione

- **Università / laboratory di ricerca devono giocare un ruolo fondamentale**
  - Università ed aziende devo giocare insieme
  - Ricerca ha tempo e può investire in sviluppo
  - Aziende hanno competenze sul prodotto finale
  - Università può anche essere un terreno “neutrale” per la gestione di investimenti condivisi → riduzione di rischi e riduzione di impegno economico


QUALI DIVENTANO LE COMPETENZE
RICHIESTE PER SFRUTTARE AL MEGLIO
LE TECNOLOGIE ADDITIVE?

COVID-19: role of AM

- ✓ COVID-19 devices shortage →AM can help to promptly produce the required stuff, shortening the time from design to production;

- ✓ **We are dealing with medical devices**, subjected to strict certification processes before coming to the market

- ✓ The current emergency **allows exceptions to the use of not certified medical devices**
  - if proved that no certified choices are available
  - in accordance with the local ethical committee

- ✓ Due to the short time required for the production, **it is not possible to run extensive testing campaigns on the components**

Attention to the selection of materials and technologies suitable for the specific application, considering the risk classification of the components to be produced and their operational environment

COVID-19: a workflow for AM production

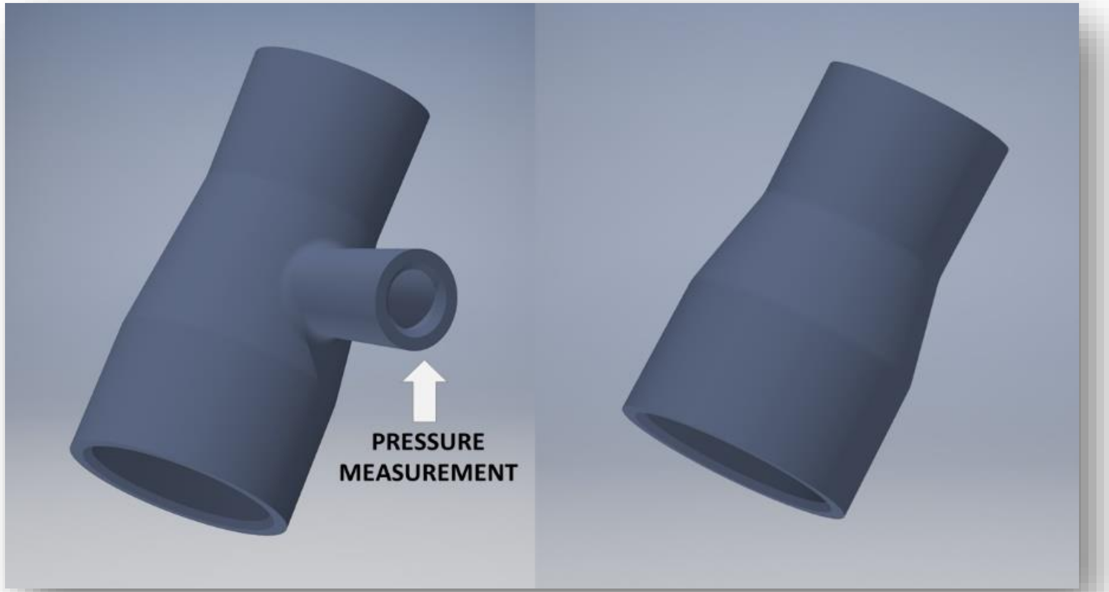
Attention to the selection of materials and technologies suitable for the specific application, considering the risk classification of the components to be produced and their operational environment

Workflow to approach requests of production:
Our experience at Clinical 3D Printing Laboratory "3D4Med"

1. Definition of the required cleaning, disinfection, or sterilization procedures
2. Compatibility of available commercial disinfectants against viruses
3. Compatibility of available commercial disinfectants with 3D printed materials
4. Mechanical resistance of 3D printed materials to disinfection
5. Gas permeability tests of 3D printed components

Examples of AM production

Adapters to Connect Ventilation Systems Outflow to the Anesthetic Gas Scavenging System



Aim: to reduce the environmental contamination of the personnel working in with Covid-19 patients who require ventilation

Requirements:

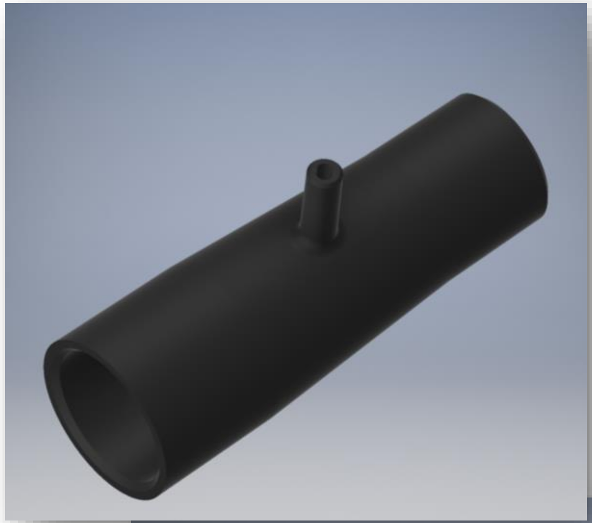
- no sterilization/disinfection constraints.
- For disinfection after use: soak for 30 minutes in IPA

Tubing Connector for Continuous Positive Airway Pressure (CPAP) Systems

Aim: to provide substitutes for a tubing connector which has rapidly run out of stock in the hospital due to the unprecedent high demand. Original component: Covidien oxygen adapter for CPAP, for single or modular use. Suitable for 22mm corrugated breathing tube.

Requirements:

- Disinfection: tested with BIONIL (NADCC) at 10.000 ppm for 30 minutes. No mechanical impairment occurred;
- No gas leak: No gas leak occurred with the specific printing parameters



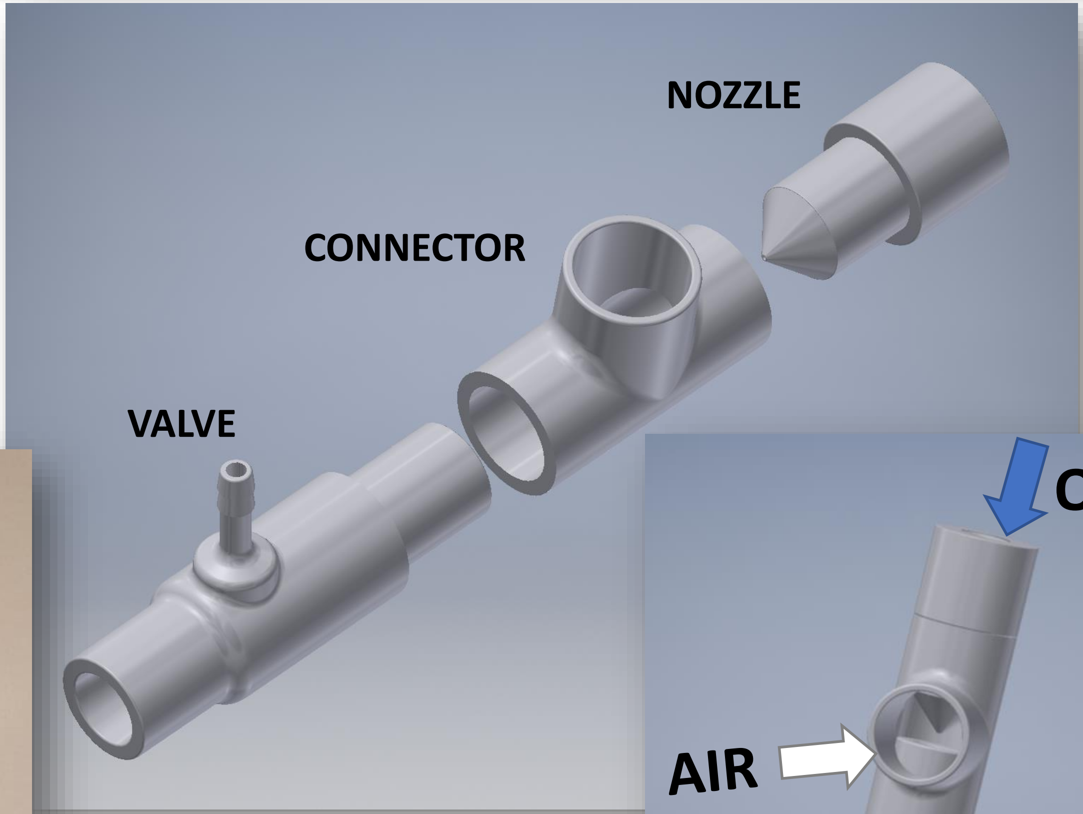
Examples of AM production

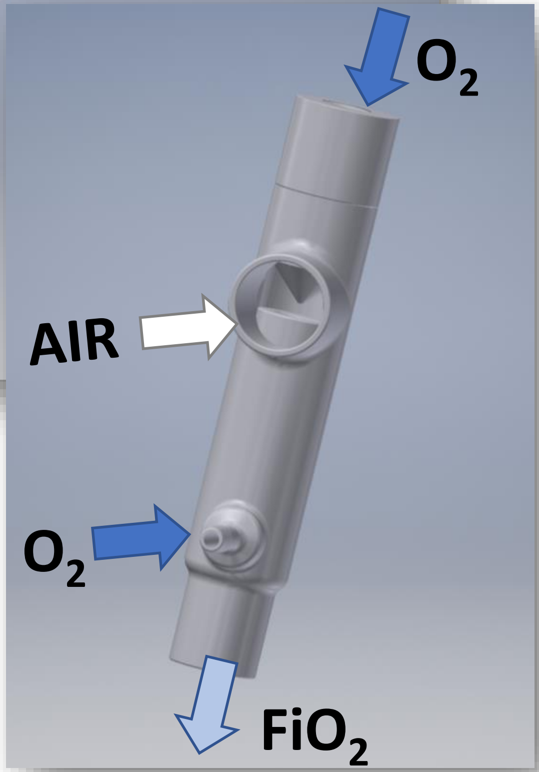
Venturi System Suction Unit

Aim: to provide substitutes for a commercial Venturi System Suction Unit. Original component: Starmed Venturi System.

Requirements:

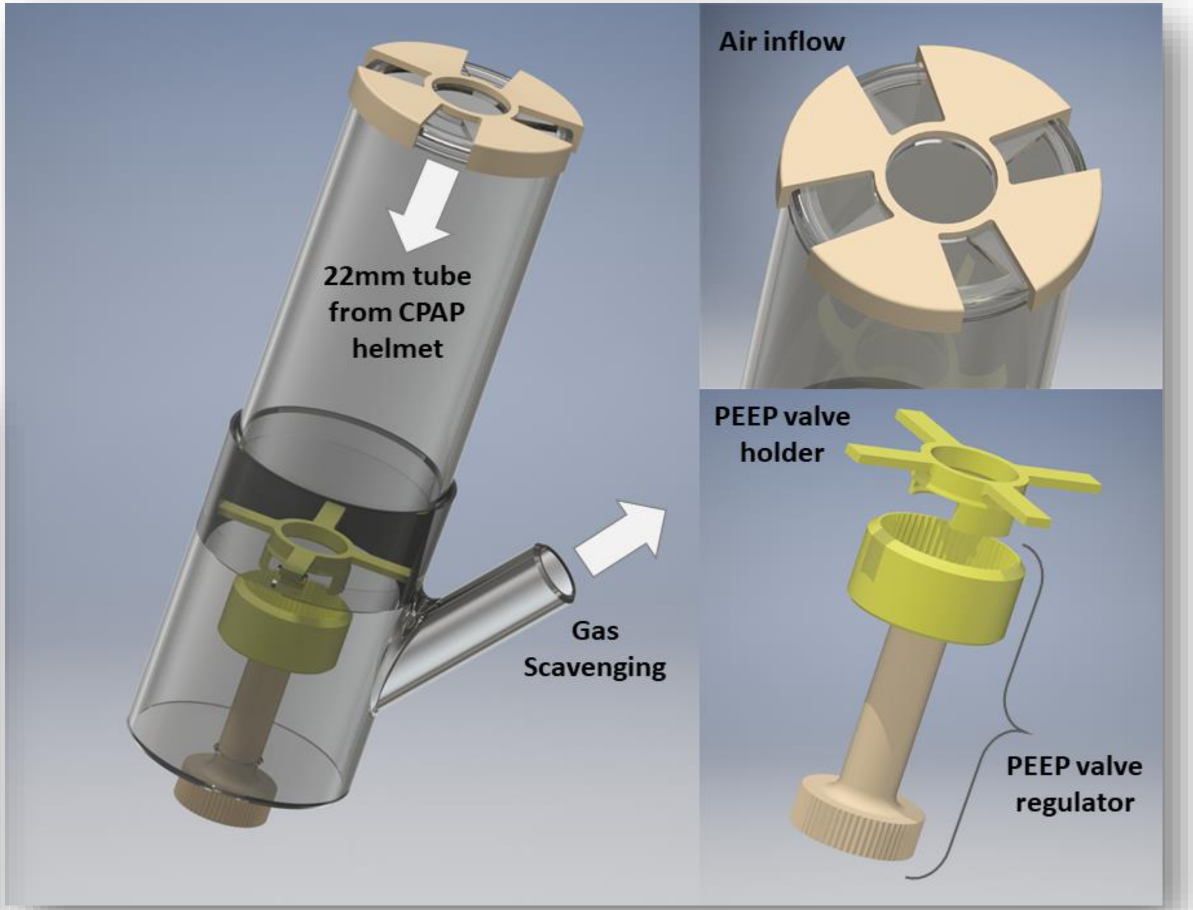
- Disinfection: soak 30 minutes in IPA (chemical resistance of the material validated by the producer);
- No gas leak: tested at 4 bar.





Scavenging System for CPAP outflow

Aim: to reduce the environmental contamination of the personnel working in with Covid-19 patients who require CPAP systems.



Requirements:

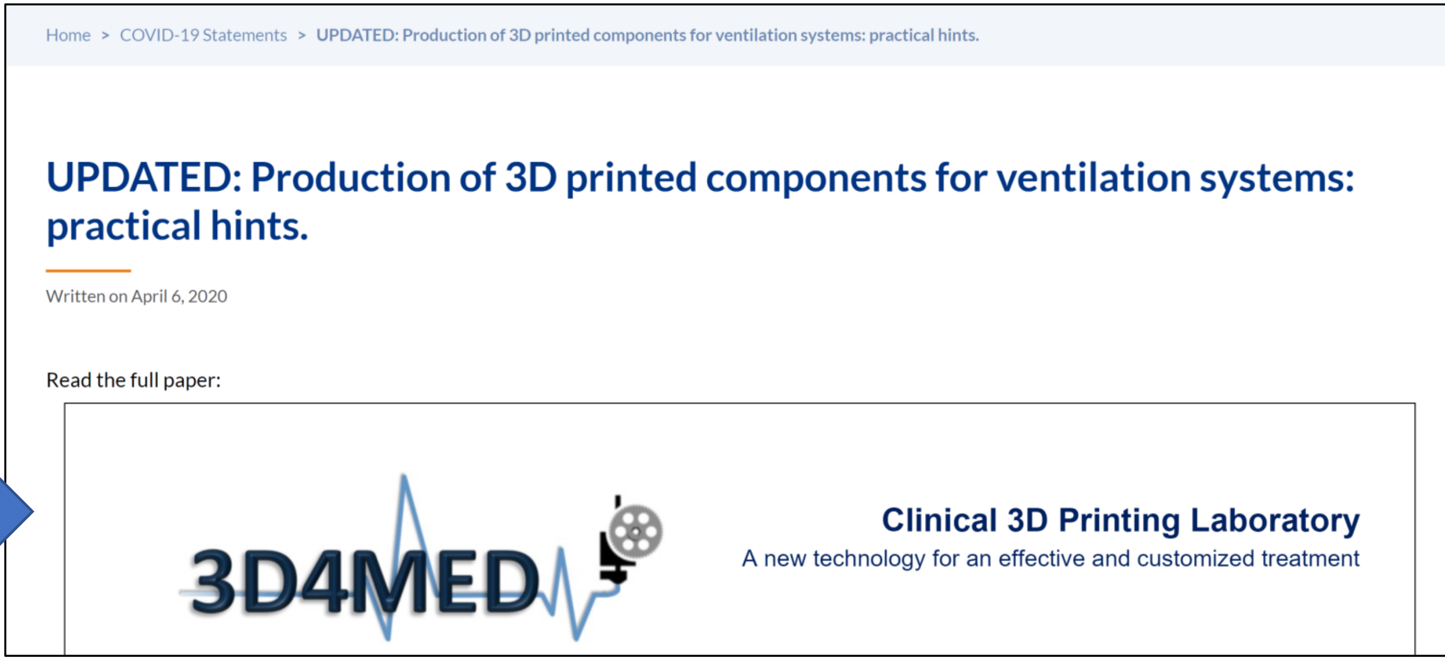
no sterilization/disinfection constraints.

Conclusions

- ✓ AM can help to promptly produce the required stuff, shortening the time from design to production;
- ✓ Even in an emergency context, attention must be paid to the medical devices’ constraints
- ✓ **Materials and technologies must be selected accordingly**

For further details and to request 3D models, refer to

https://eaes.eu/category/covid-19-statements/



❑ *Q&A*

Calendario prossimi webinar

29 giugno, ore 17.00 - Industria 4.0 per la ripartenza - Focus **Industrial IOT**
L'esperienza di Luca Cremona, Head of Industrial di Rold

8 luglio, ore 17.00 - Industria 4.0 per la ripartenza - Focus **Cybersecurity**
L'esperienza di Andrea Provini, Global CIO di Bracco Imaging e Presidente di Aused

15 luglio, ore 17.00 - Industria 4.0 per la ripartenza - Focus **Integrazione dei Processi**
L'esperienza di Stefano Ripamonti, Controller & Industria 4.0 di Castel

innovazione@assolombarda.it

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