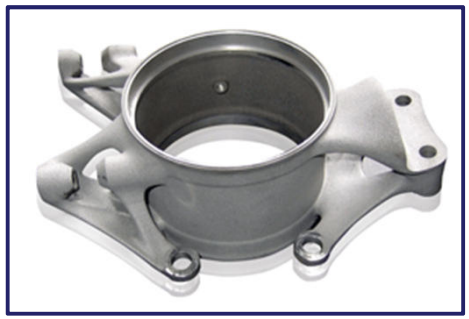
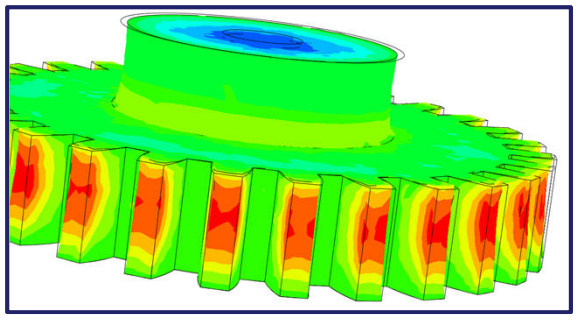
3D Printing Facility Hub:

Un progetto concreto a supporto del sistema industriale pavese

Simone Morganti

Computational Mechanics and Advanced Material Group
Prof. Ferdinando Auricchio
University of Pavia

The 4th Industrial Revolution

ECONOMIC IMPACT

February 2011

- **Wanted Analytics and Forbes (2014)**
  - ✓ **35% of USA job advertisements** ask for engineers…**experts of 3D printing!!!**
  - ✓ Demand of candidates with 3D printing expertise: **+1843% in the last four years**
- **Whooler Report (2014)**
  - ✓ The worldwide 3D printing industry is now expected to grow worldwide from $3.07B in revenue in 2013 to $12.8B by 2018, and **exceed $21B by 2020**
- **McKinsey Report (2014)**
  - ✓ The advantages of 3D printing over other manufacturing technologies could lead to **profound changes in the way many things are designed, developed, produced**, and supported

The 4th Industrial Revolution

Ministero dello Sviluppo Economico

1° Industrial revolution

Historical loom

Through introduction of mechanical production plants using water and steam power

2° Industrial revolution

Mass production and assembly line

Through introduction of work-division mass production using electrical energy

3° Industrial revolution

Automated industrial robot in manufacturing

Through use of electronics and IT to further automate production

4° Industrial revolution

Connection between physical and digital systems, complex analyses of big data and real-time settings

Through use of smart machines, inter-connected and connected to internet

Late 18th century | **Early 20th century** | **Early 1970s** | **Today and near future**

NINE TECHNOLOGY DRIVERS

1. **Advanced Manufacturing Solutions**
   - Autonomous, cooperating industrial robots
   - Numerous integrated sensors and standardized interfaces
2. **Additive Manufacturing**
   - 3D printing, particularly for spare parts and prototypes
   - Decentralized 3D facilities to reduce transport distances and inventory
3. **Augmented Reality**
   - Augmented reality for maintenance, logistics, and all kinds of SOP
   - Display of supporting information, e.g., through glasses
4. **Simulation**
   - Simulation of value networks
   - Optimization based on real-time data from intelligent systems
5. **Horizontal/ Vertical Integration**
   - Cross-company data integration based on data transfer standards
   - Precondition for a fully automated value chain (from supplier to customer, from management to shop floor)
6. **Industrial Internet**
   - Network of machines and products
   - Multidirectional communication between networked objects
7. **Cloud**
   - Management of huge data volumes in open systems
   - Real-time communication for production systems
8. **Cyber-security**
   - Operation in networks and open systems
   - High level of networking between intelligent machines, products, and systems
9. **Big Data and Analytics**
   - Full evaluation of available data (e.g., from ERP, SCM, MES, CRM, and machine data)
   - Real-time decision-making support and optimization

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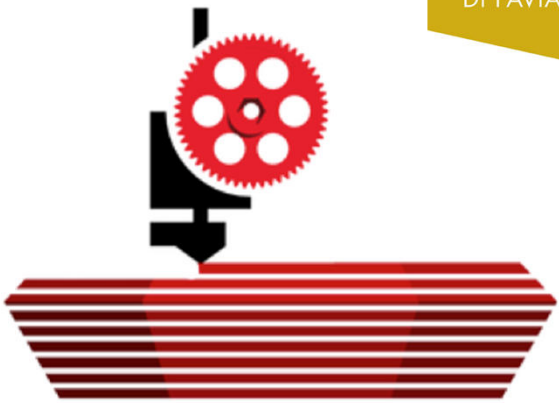
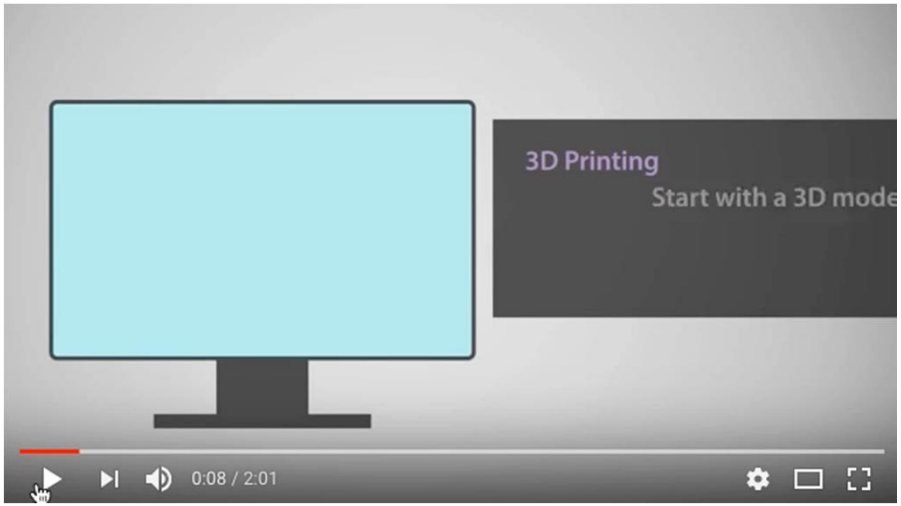
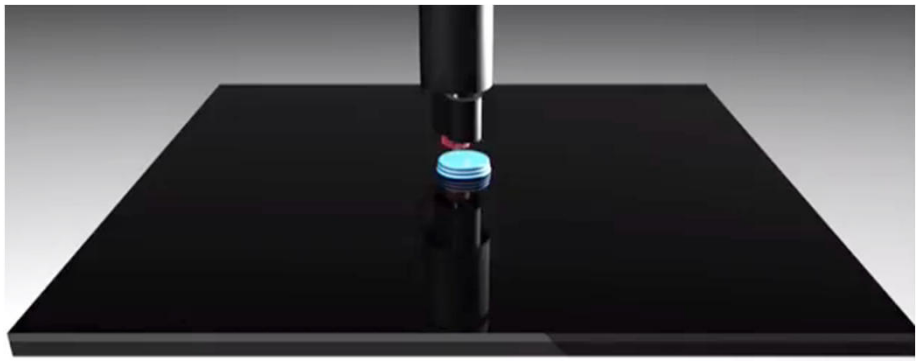
Additive Manufacturing



Virtual Model → Slicing → Printed Model





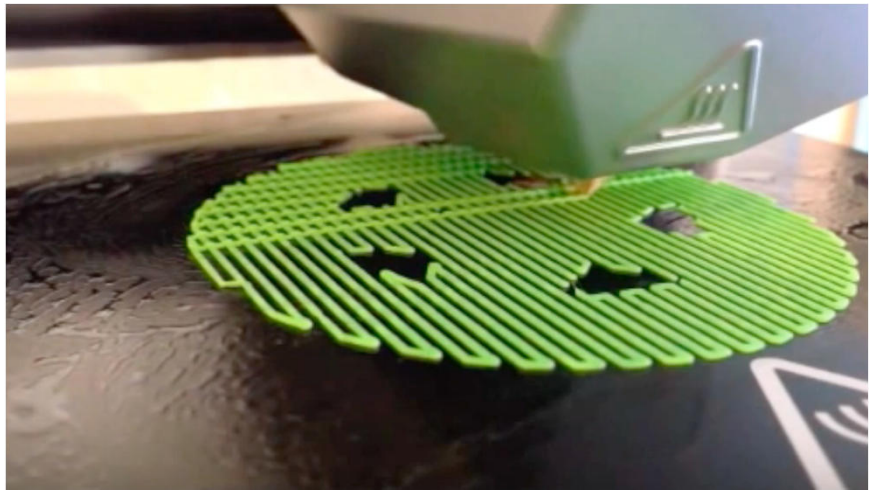
PLASTIC Technologies

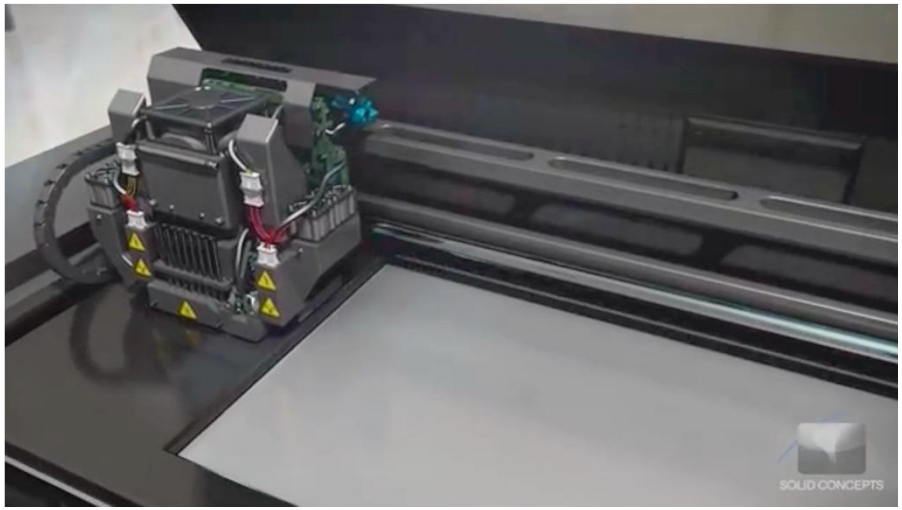
FDM uses a thermo-plastic filament, pushed through a heating chamber and extruded through a small nozzle.

- ✓ Material: **thermoplastic filaments** (PLA, ABS, HIPS,TPU, TPE, PETG, Nylon, reinforced/charged materials);
- ✓ Curing: **temperature gradient**;
- ✓ **Inexpensive** process;
- ✓ Accuracy and speed are low when compared to other process.

Material Jetting resembles inkjet paper print, since printing material is dropped through small diameter nozzles.

- ✓ Material: **photo-polymeric resins** hardened by UV light;
- ✓ Curing: **UV light**;
- ✓ Multiple material parts & colours and high accurancy;





METAL Technologies

SLM uses a laser heat source to melt powders previously deposited on the printing plate.

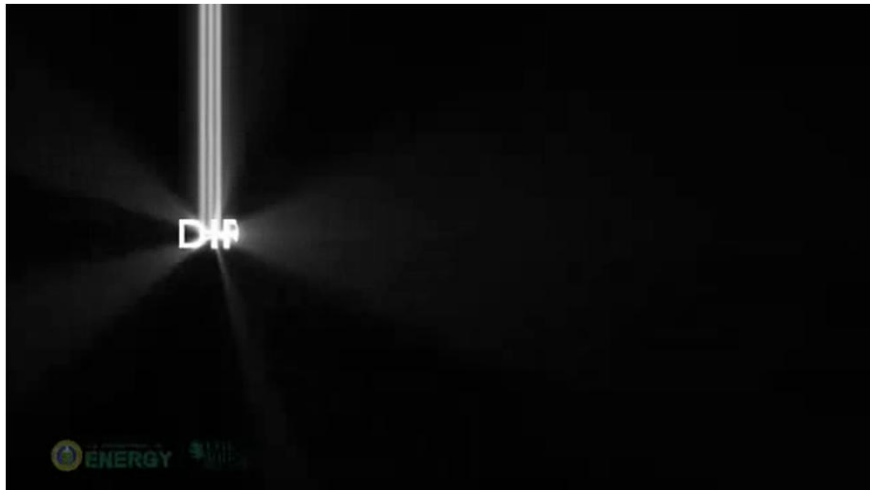
- ✓ Material: **metal alloys** (Ni, Co, Fe, Al, Steel)
- ✓ Curing: **CO_2 laser**
- ✓ **Expensive** process
- ✓ Very high printing speed

RENISHAW apply innovation™

EBM uses an electron beam heat source to melt powders previously deposited on the printing plate.

- ✓ Material: **metal alloys** (Ni, Co, Fe, Al, Steel);
- ✓ Curing: **Electron beam**
- ✓ **Expensive** process
- ✓ **More precision, power** and **higher speed** than other metal technologies

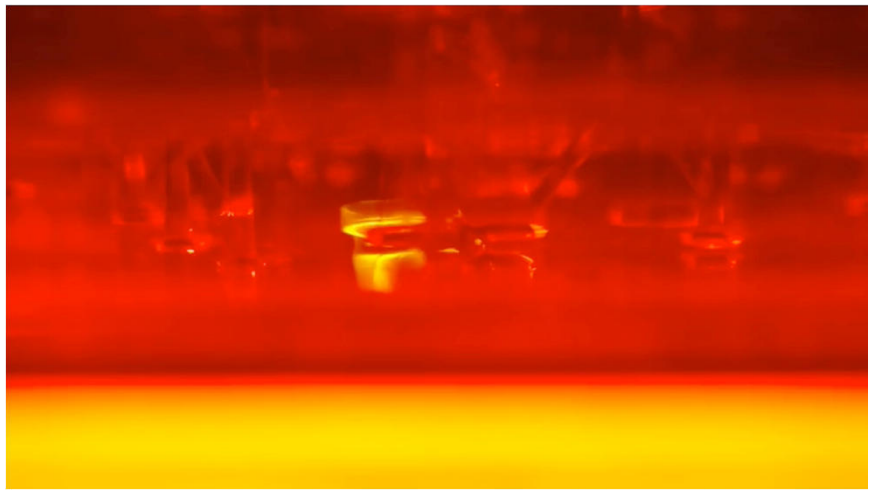
CAD TO METAL arcam Arcam AB



Other Technologies

Vat – Polymerization or **SLA** uses a container of liquid photopolymer resin, from which the model is obtained using an UV light employed to harden the resin.

- ✓ Material: **photo-polymeric resins** hardened by UV light;
- ✓ Curing: **UV laser**;
- ✓ **Expensive** process;



Binder Jetting uses two materials: powder base material and a liquid binder. Powder is spread in equal layers & binder applied through jet nozzles that “glue" the powder particles.

- ✓ Material: **binder powder**;
- ✓ Curing: **binder (glue)**;
- ✓ Parts can be made with a wide range of different colours;

Our 3D Printers

ObJet 260 Connex 3

- PolyJet printer with **photopolymer resins**;
- Different colors & materials (**deformable** and **transparent**);
- Big/small models with fine details (20 μm);
- 3D printed models of the **abdominal cavity**;

FORM 2 Desktop SLA

- Printer with **photopolymer resins**;
- High precision (100/50/25 μm);
- 4 different **transparent** materials (1 **deformable**);
- Medium/small (**vascular**) models with fine details;

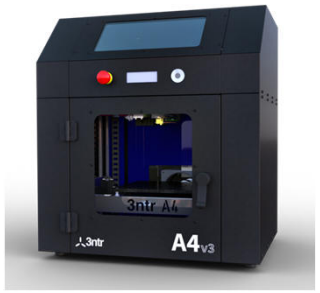
3DSystems ProJet 460 Plus

- **Binder jetting** technology;
- High precision (100 μm) and low production times and costs;
- **2.8 milion colors**;
- Big/small models with fine details, especially **bone structures**;

Our 3D Printers

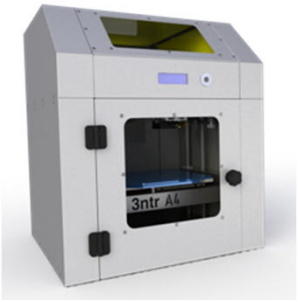
3NTR A4v3

- Professional **FDM printer**;
- **Triple** bowden extruder (water cooled extruders up to 410°C);
- **Hot chamber** (up to 70°C);



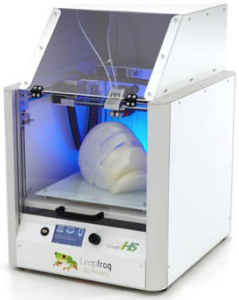
3NTR A4v2

- Professional **FDM printer**;
- Dual bowden extruder (water cooled extruders up to 410°C);



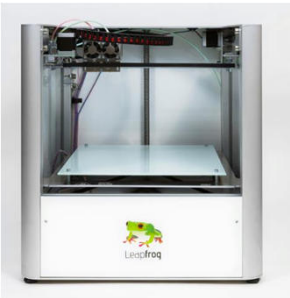
LeapFrog Creatr HS

- **FDM printer**;
- Dual bowden extruder;
- Suitable for **relatively high speeds** printing of large objects;



LeapFrog Creatr Dual Extruder

- **FDM printer**;
- Dual **direct** extruder;
- Suitable for **low modulus filaments** printing;



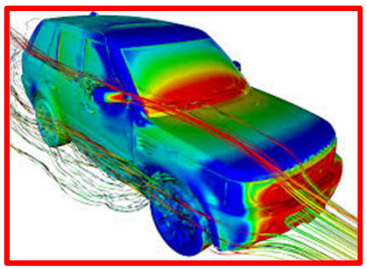
A Strategic Theme for UniPV

Involving Companies & Research Institutes

FILOALFA
SANDRETTO
D'APPOLONIA
3ntr
PSD
OSPITALE DI S. MATTEO PAVIA
Methalab
CareTronik
solutions for life
TreeD filaments
Stratasys FOR A 3D WORLD™
Fluid-o-Tech POWER THE FLOW
BIO BIOTRONIK excellence for life
ARUP
tenova

A Strategic Theme for UniPV

1. Modeling & Simulation
2. New Materials
3. Manufacturing
4. Applications
5. Socio-Economic Impact



Topics

- **Research**
- **Collaborations & Service**

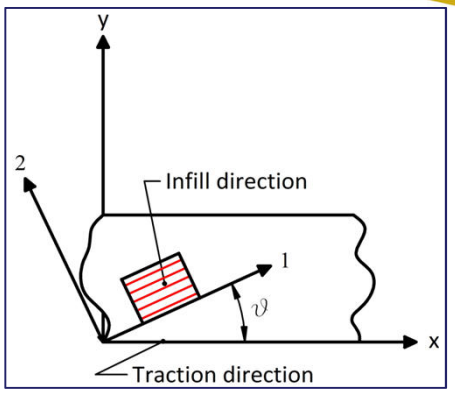
Topics

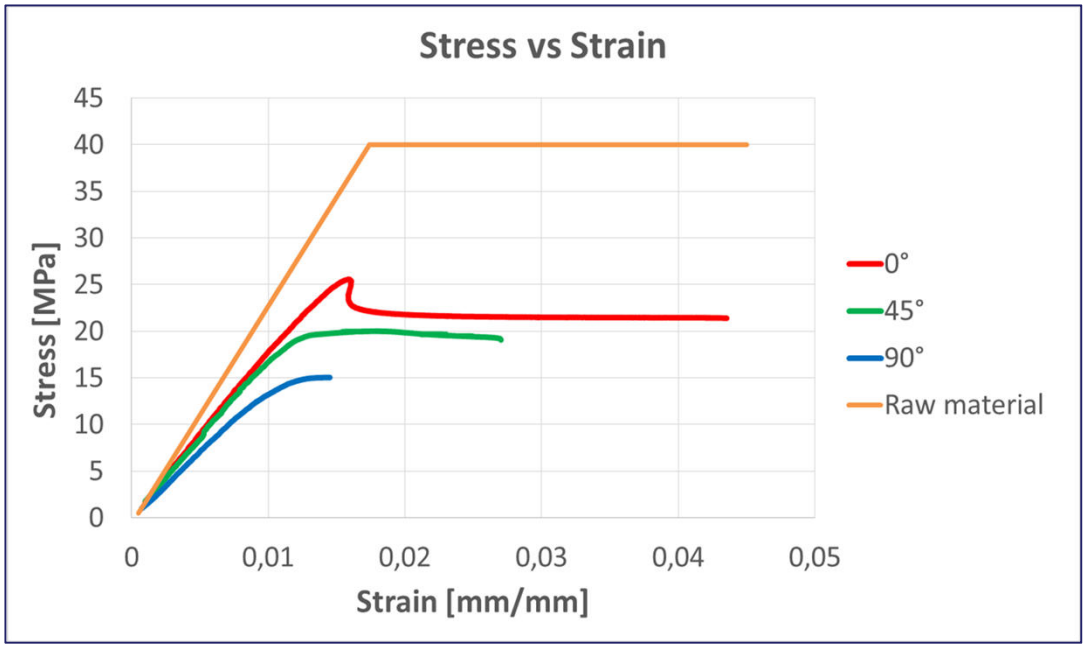
- **Research**
- **Collaborations & Service**

Research Fields

Material characterization of 3D printed materials

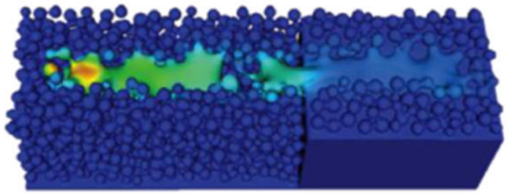
- Uniaxial tensile tests of unidirectional 3D printed specimens
- **ASTM D3039** (composite materials) guidelines followed
- Stress-strain curves obtained: mechanical and strength behavior heavily depends on the **filament deposition orientation *θ***





Raw material
≠
3D printed material
⇓
Need for a **complete mechanical characterization** of 3D printed materials

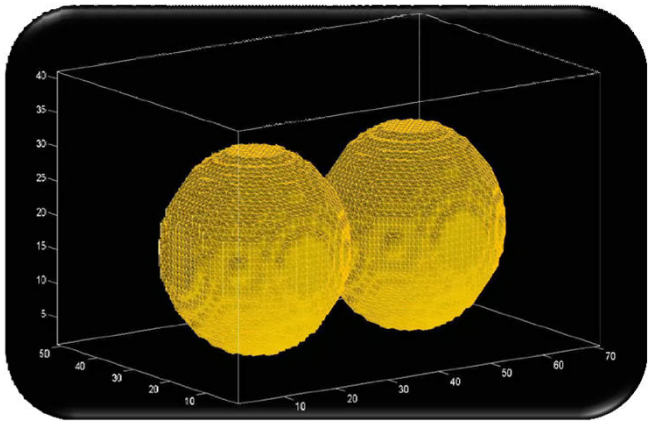
Research Fields



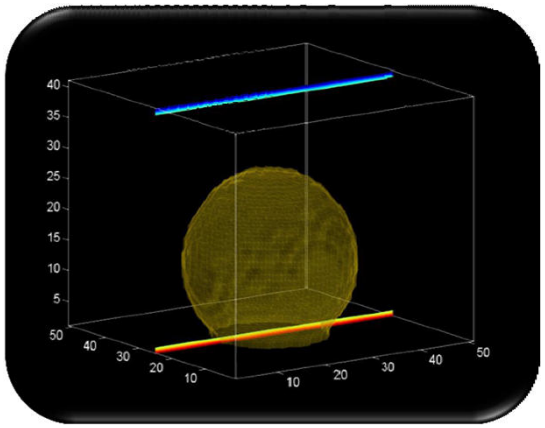
MICROscopic Simulations

SOME RESULTS

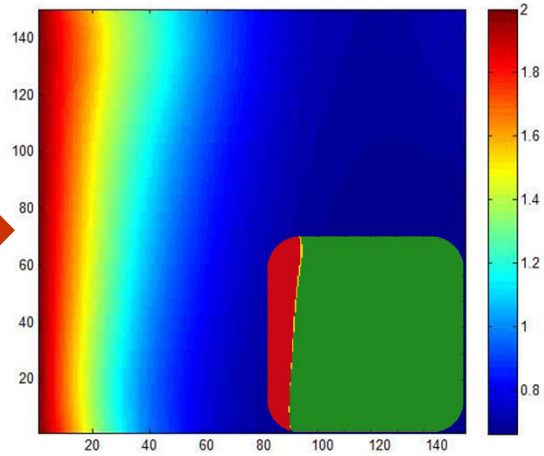
Droplet wetting



Wetting & Heat Conduction

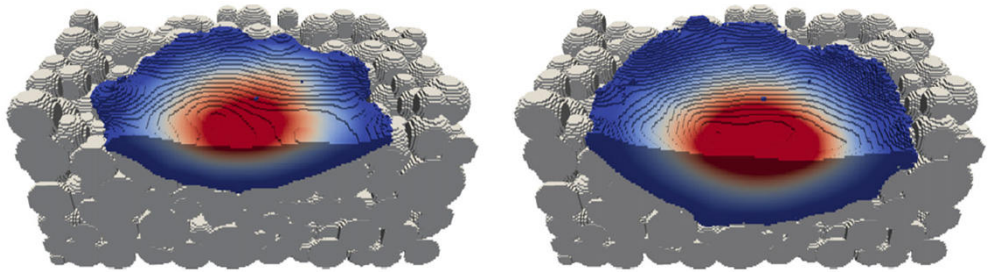


Phase Change



- **Lattice Boltzmann Method**;
- Coupled **Fluid-thermo-dynamic** problem;
- **Phase Change** problem;
- **Free surface** evolution.

Melt Pool



(c) $t = 4000$. (d) $t = 7500$.

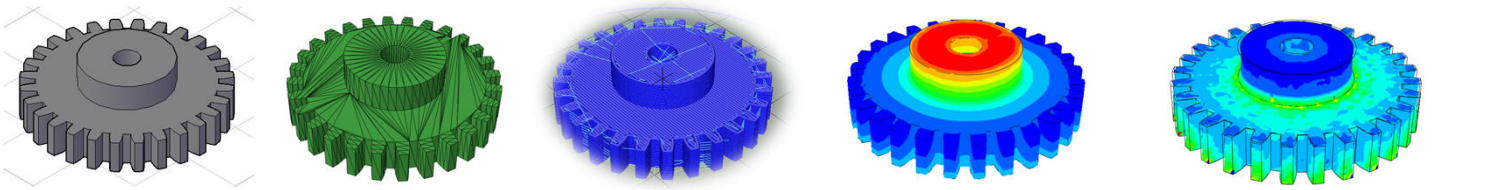
Ammer, Regina, et al. "Simulating fast electron beam melting with a parallel thermal free surface lattice Boltzmann method." *Computers & Mathematics with Applications* 67.2 (2014): 318-330.

Research Fields

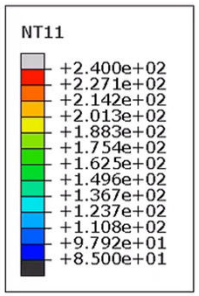
MACROscopic Simulations

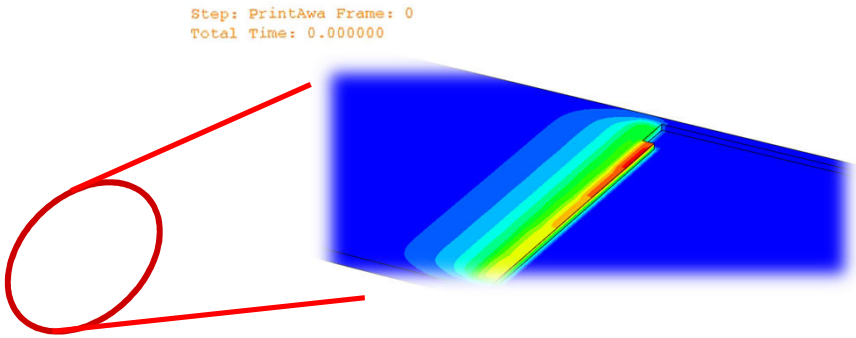
WORKFLOW

CAD → STL → GCODE → THERMAL ANALYSIS → MECHANICAL ANALYSIS



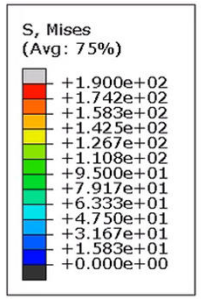
SOME RESULTS

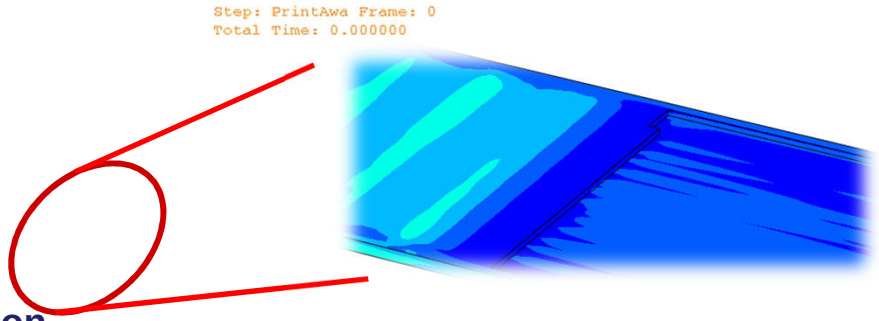




Deposition process

- **Temperature Evolution**





Deposition process

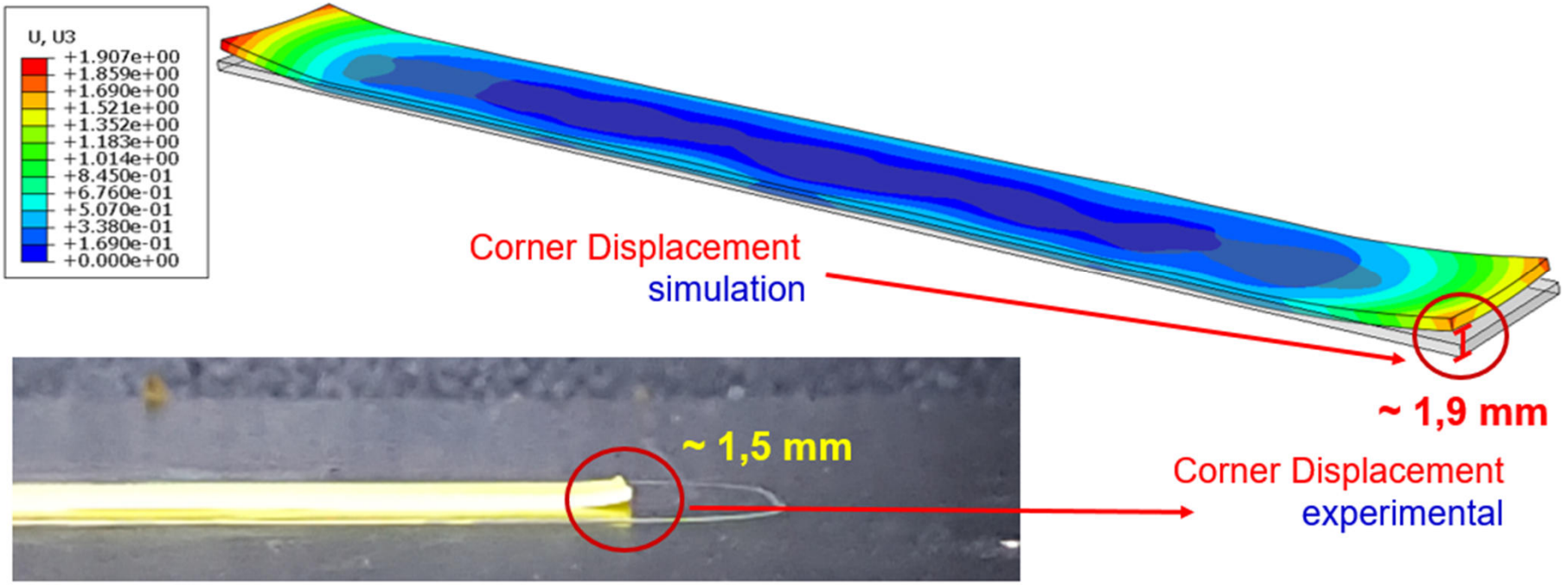
- **Residual Stresses Evolution**

MACROscopic Simulations

- ✓ **21%** error is detected between experimental results and simulations
- ✓ This mismatch is caused by **physics** and **model** reasons:

RESULTS VALIDATION

- **No adhesion** between part and plate is considered
- Material behavior is **ELASTO-PLASTIC** (elastic-linear is a simplification)
- During printing nozzle can touch the rising filament: this effect is not considered in the simulation



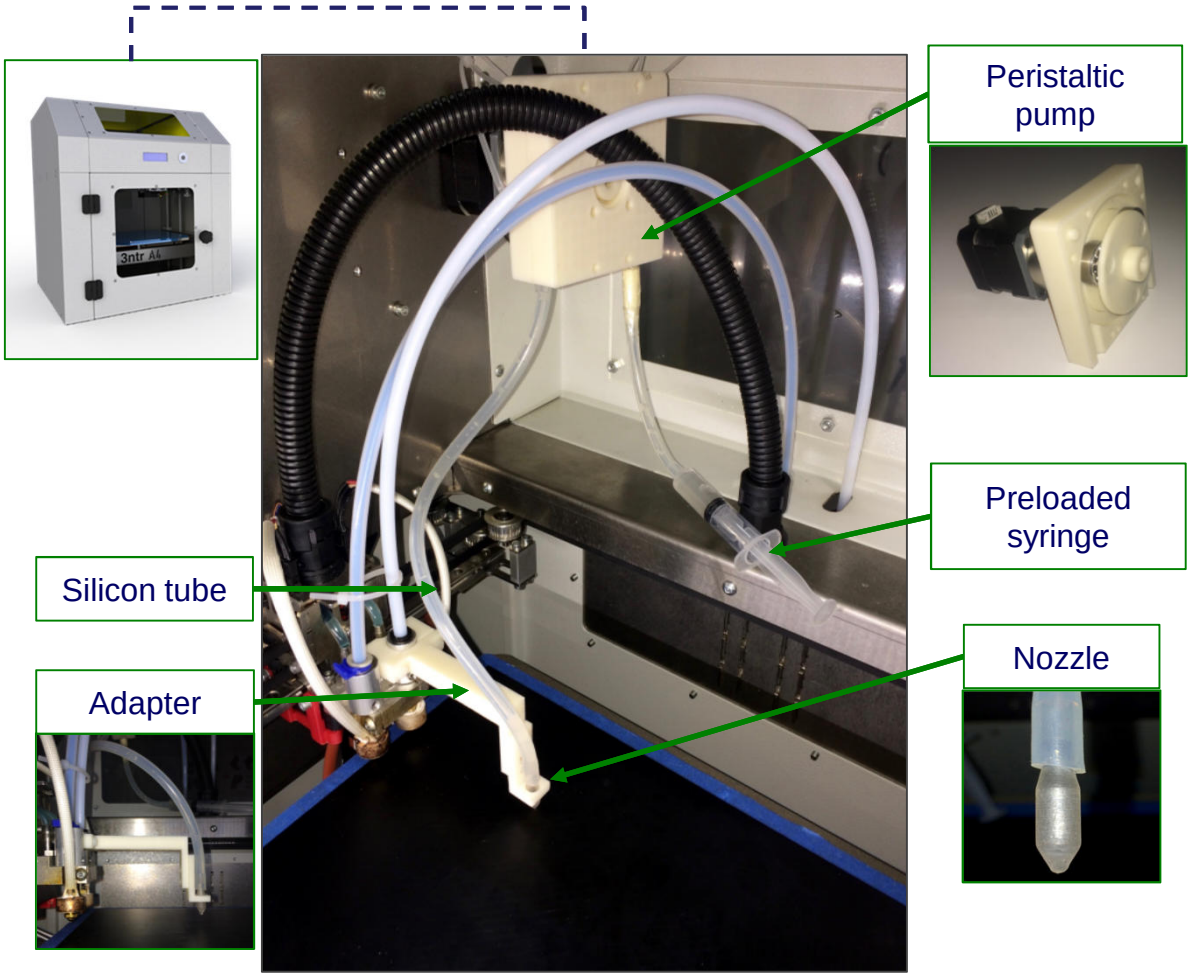
Research Fields

Customization of a commercial FDM 3D Printer

Goal: extrude hydrogel suitable for **bioprinting** purposes with a FDM 3D printer

Hardware modifications:

- Peristaltic pump
- Silicon tube
- Preloaded syringe
- Nozzle
- Adapter



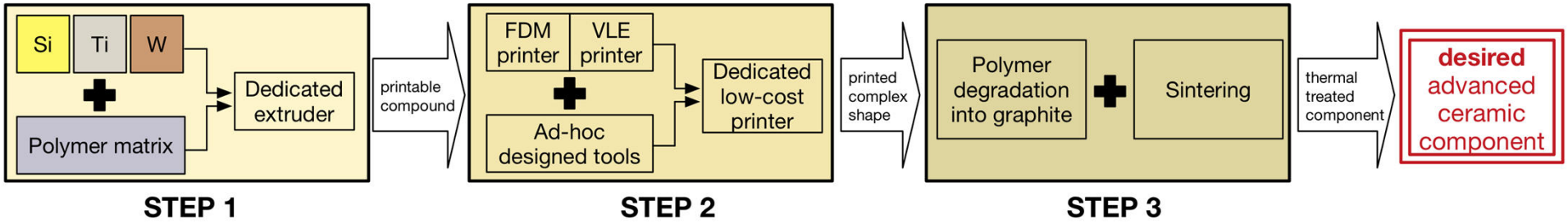
Research Fields

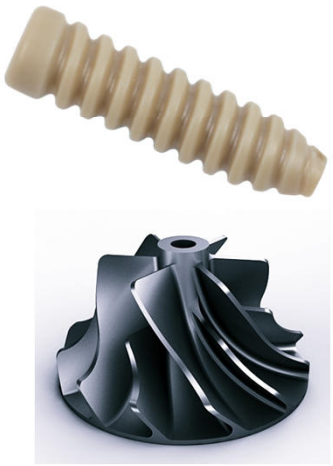
In collaboration with:

Dipartimento di Chimica
Università di Pavia
Prof. Anselmi-Tamburini U.

Advanced Ceramic 3DP components

- Metals and ceramics printing using **low-cost** 3D printing technologies
- Design specific processes to synthesize components with a **complex shape** made of **advanced ceramics**





Preliminary **results**:

Patent: *PCT/EP2017/059932, Additive manufacture of ceramic objects*

Research Fields

GRAPHENE Based Materials

Graphene **properties**:

- Mechanical resistance
- Thermal and electrical conductivity
- Optical transparency
- Hardness

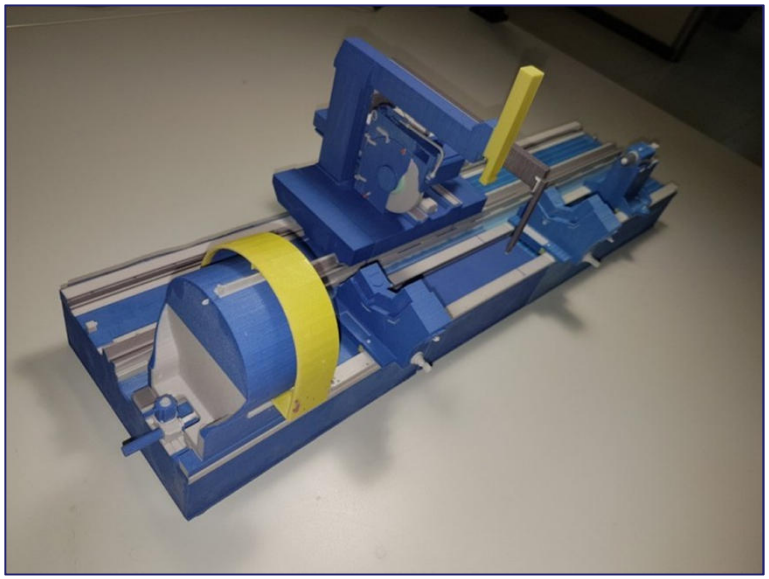
Graphene **applications**:

- Biosensors and bioelectrodes
- Optical and photovoltaic devices
- Automotive
- Smart textile and ink
- Batteries and photovoltaic panels

Topics

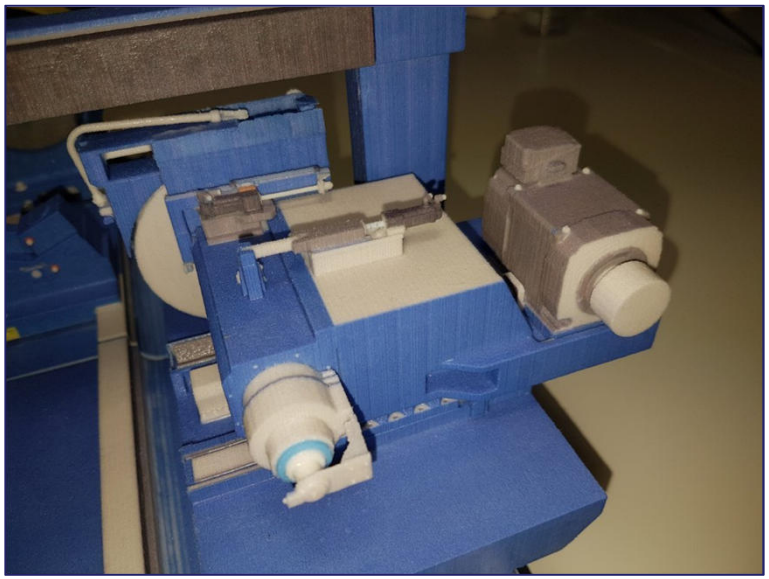
- **Research**
- **Collaborations & Service**

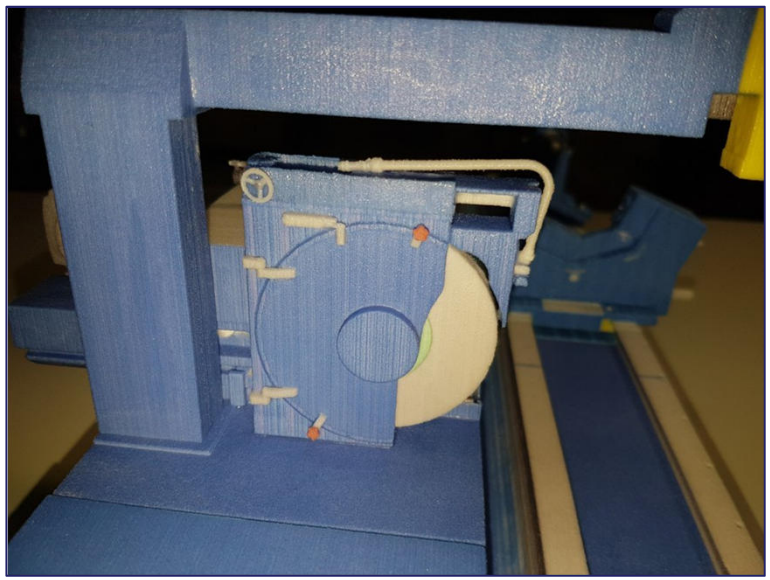
Collaborations: TENOVA



tenova

- 1:5 scale reproduction of an industrial rectifier, for illustrative purposes
- **Binder jetting** technology: chalk powder, binding agent, color ink
- Very **high resolution** and detailed reproduction





Collaborations: FLUID–O–TECH

Fluid-o-Tech
POWER THE FLOW

Italian market leader for quality and innovation in the design and production of **volumetric pumps** and **fluid management systems**

Collaboration with the Department of Civil Engineering and Architecture of the University of Pavia within the project "**Fluidica Intelligente**" funded by Regione Lombardia

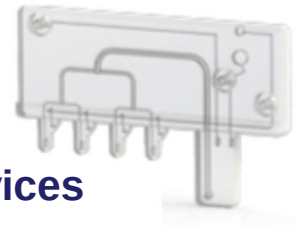
3D printing in **Fluidic Applications**

Factory 3D Printer – Dolomite
→ 3D printer for Fluidic applications

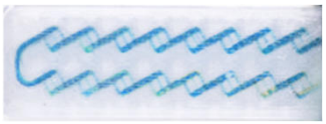
- Microfluidics **chips**

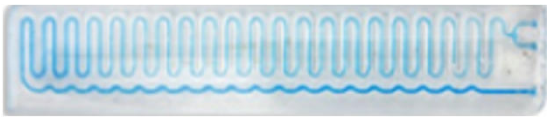
- **Connectors**

- **Manifolds**



- Microfluidics **mixing devices**





Collaborations: 3NTR

For years we cooperate with **3NTR®** company, one of the Italian leading manufacturers of FDM 3D printers, in a **bilateral scientific** and **technological exchange**.

- **Mechanical characterization** of **new printable materials**;
- **Optimization of layers' filament orientation** to obtain the most suitable mechanical properties for 3D printed components;
- **Prototyping** and **testing** of a **peristaltic pump** to equip commercial 3NTR 3D printers in order to extrude viscous materials.

Topics

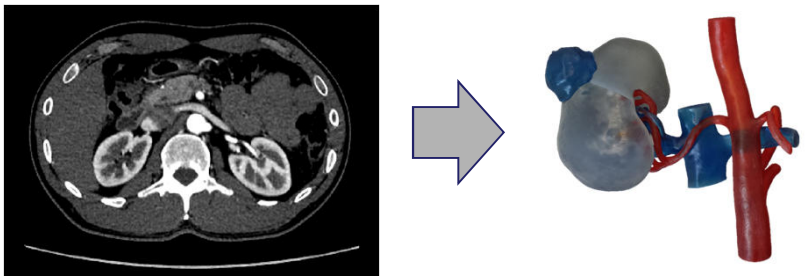
- **Research**
- **Collaborations & Service**
  - **3D4MED**
  - **3DMetal@UniPV**

Collaborations & Service: 3D4MED

A new technology for an effective and customized surgery

Idea

To transform **medical images** in a **3D printed object** to hold in your hands



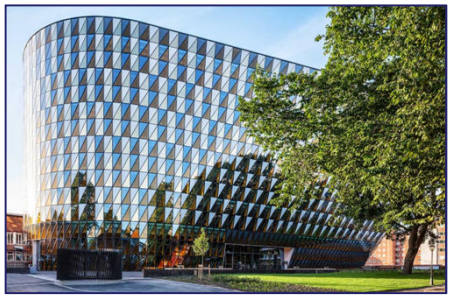
Why

To assist surgeons during the **surgical planning**, the **surgery** or in the **communication with the surgical team** and **with the patients**.

For years we cooperate with prestigious hospitals and IRCCS, including…

IRCCS Policlinico San Matteo
Pavia, Italy

IRCCS San Donato
San Donato, Milan, Italy

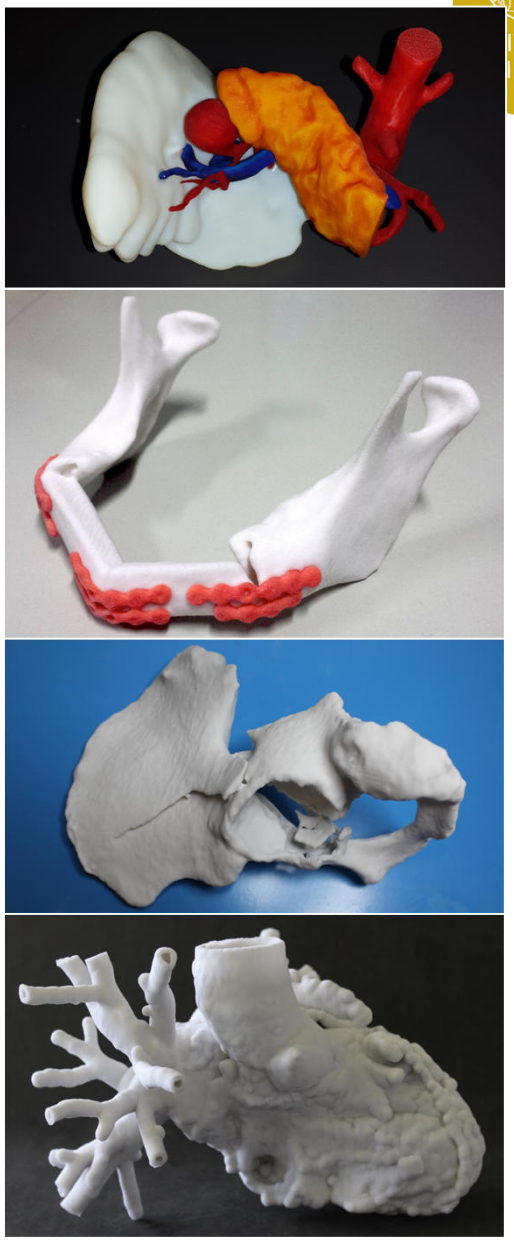


Karolinska Institutet
Stockholm, Sweden

Collaborations & Service: 3D4MED

Our 3D printed models are intended for **all medical specialities**. To date, we have several years of experience in the areas of:

- Abdominal Surgery
  (Prof. Pietrabissa) → > 40 cases
- Otolaryngology and Maxillofacial Surgery
  (Prof. M. Benazzo, Prof. P. Canzi) → > 15 cases
- Orthopedics
  (Prof. F. Benazzo) → > 10 cases
- Vascular Surgery
  (Prof. Marone, Prof. S. Trimarchi, Prof. P. Quaretti) → > 30 cases



Collaborations & Service: 3D4MED

Prices of individual 3D printed models depend on the analyzed anatomical district and the technology used to reproduce the prototype.

Medical Area	Costs (€)*	Time (h)**
Abdominal Surgery	300 – 450	24 – 48
Otolaryngology & Maxillofacial Surgery	200 – 250	12 – 48
Orthopedics	300 – 350	12 – 48
Vascular Surgery	350 – 750	24 – 72

** Average price per model, variable depending on the used technology and the model dimensions. IVA included.*

*** Average time required for the delivery of the 3D printed model.*

Collaborations & Service: 3D4MED

Two types of **offered services**:

3 Different **Packages**

Single Models*

TRIAL PACK ≃ 3.500€
- To engage customers and let them try out the service
- Duration of 3 months
- 8/10 3D printed models
- Buying the starting package costumers would have a 30% discount on the first annual package

STANDARD PACK ≃ 10.000 – 85.000€
- Three different annual packages
- Small (36 models)
- Medium 130 models)
- Large (270 models)

CUSTOMIZED PACK
- Offer to Clients the possibility to customize their packages
- The high customization is based on the Hopsital number of surgery of the last years, that help to make quantitative expectations of the required surgical cases

** Printed and sold on request, for the specific clinical case.*

Project: 3DMetal@UniPV

Motivazioni

- **Aziende** sempre più attratte dall' *Additive Manufacturing* → potenzialità in termini di **flessibilità**, **velocità**, **impatto tecnologico**;
- Il **mondo universitario** è consapevole delle sfide che tali nuove tecnologie comportano → **comprensione dei fenomeni fisici** coinvolti, dei loro **effetti sulle proprietà del prodotto** finito, delle sfide e opportunità che nuove tecnologie di produzione pongono dal punto di vista **progettuale** e **produttivo**;
- **Costi** di accesso alla stampa 3D metallica **non trascurabili** e difficoltà nello sperimentare nuove modalità di produzione e di progettazione → fattori che oggi più **ostacolano gli investimenti** da parte di nuovi soggetti potenzialmente interessati alla tecnologia.

Inquadramento Progetto

- Tra le tecnologie di manifattura additiva, la stampa 3D metallica potrebbe avere grande interesse per le Aziende operanti nei settori della **meccanica avanzata** → le **leghe metalliche** (acciaio, titanio, alluminio) rappresentano la principale materia per la produzione di **componenti meccanici ad elevate prestazioni** e contenuto tecnologico

Project: 3DMetal@UniPV

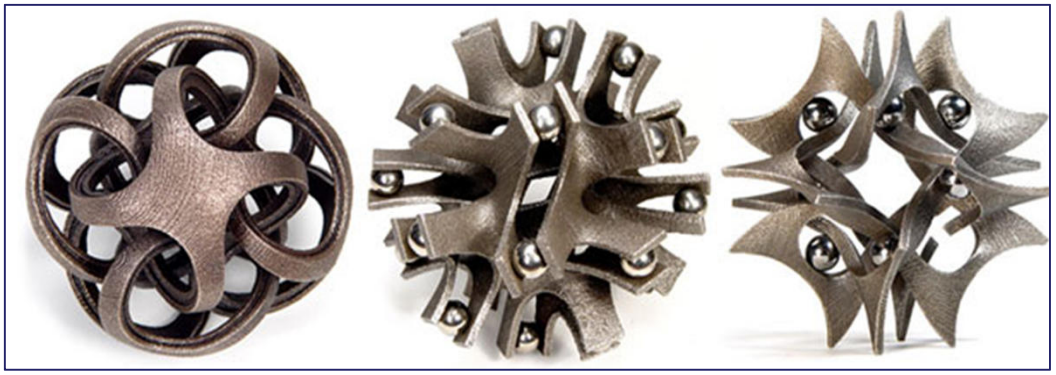
Scopo del progetto

- Unire risorse e competenze dal mondo delle Aziende e dell'Università con focus sulla stampa 3D metallica

Obiettivi progetto

Unire risorse e competenze al fine di:

1. creare **linea produttiva dedicata SLM** (*Selective Laser Melting*)
2. studiare **potenzialità e limitazioni** della tecnologia SLM
3. sviluppare competenze di **progettazione** per componenti realizzati con SLM
4. comprendere processo SLM per **ottimizzare le prestazioni** di parti prodotte
5. fornire alle Aziende componenti ottimizzati e realizzati con SLM



Project: 3DMetal@UniPV

Linea Produttiva

- Stampante 3D metallica Renishaw AM400;
- Forno per i trattamenti termici;
- Macchina per la sabbiatura;
- Centro di lavoro per le operazioni di finitura per asportazione.

Le attrezzature saranno utilizzate da **tecnici completamente dedicati** al progetto, in stretto contatto con i ricercatori UniPV e con progettisti delle Aziende.

La linea produttiva verrà utilizzata per **progettare e realizzare parti di interesse** per Aziende ed Università attraverso “casi studio”, presi dalla produzione delle singole Aziende.

Per ogni caso, oltre agli aspetti economici, verranno considerate le **caratteristiche di interesse tecnologico** come proprietà meccaniche, termiche e dimensionali. Il **confronto** con parti ottenute con tecnologie tradizionali sarà funzionale a capire benefici e limitazioni della stampa 3D metallica.

Si svilupperanno competenze di **progettazione**, **simulazione** e **ottimizzazioni** per sfruttare al meglio la versatilità della nuova tecnologia di produzione.

Modalità di esecuzione del progetto

- **Acquisizione attrezzatura**
- Individuazione e **assunzione personale**

o Personale completamente dedicato (presso l'Università)

- **1 tecnico operatore stampante metallica:**
  - Esperienza come operatore macchine utensili presso officina meccanica
  - Perito tecnico/perito meccatronico/Ingegnere Junior
  - Conoscenza parametri di utilizzo utensili e cicli di lavoro
  - Conoscenza dei software CAD/CAM;
- **2 studenti di dottorato**
  - Uso software di simulazione multifisica, disegno CAD, ottimizzazione

o Personale parzialmente dedicato (presso Università ed Aziende)

- Università: 1 professore, 1 ricercatore, 1 tecnico laureato
- Singola Impresa: 1 progettista, 1 tecnico di produzione

Project: 3DMetal@UniPV

- **Durata temporale del progetto: 3 anni**
- **Budget complessivo: 775.000 €**

Valore attrezzatura	Fattore riduttivo	549.300 €		
Iperammortamento		0,64		
Costo attrezzatura		351.552 €		
Costo totale impianto		386.552 €		**386.552 €**
Gestione impianto	Costo annuo	51.360 €	3	154.080 €
Estensione garanzia	2' e 3' anno	24.000 €		24.000 €
Personale nuova acquisizione	Costo annuo: 1 tecnico + 2 ph.d. completamente dedicati	70.000 €	3	210.000 €
Costo finale progetto				**774.632 €**

An example!

Partner progetto: 1 Università + 3 Aziende
Costo progetto / partner: 775.000 $/ 4 = 193.000 $

Thanks for Your Attention

Simone Morganti

Computational Mechanics and Advanced Material Group
Prof. Ferdinando Auricchio
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