3D PROTOTYPING: ADDITIVE MANUFACTURING TECHNOLOGIES AND APPLICATIONS FROM MICRO TO MACRO SCALES

Proponenti: Paolo Gaudenzi (DIMA) Silvia Masi (Dip. Fisica)

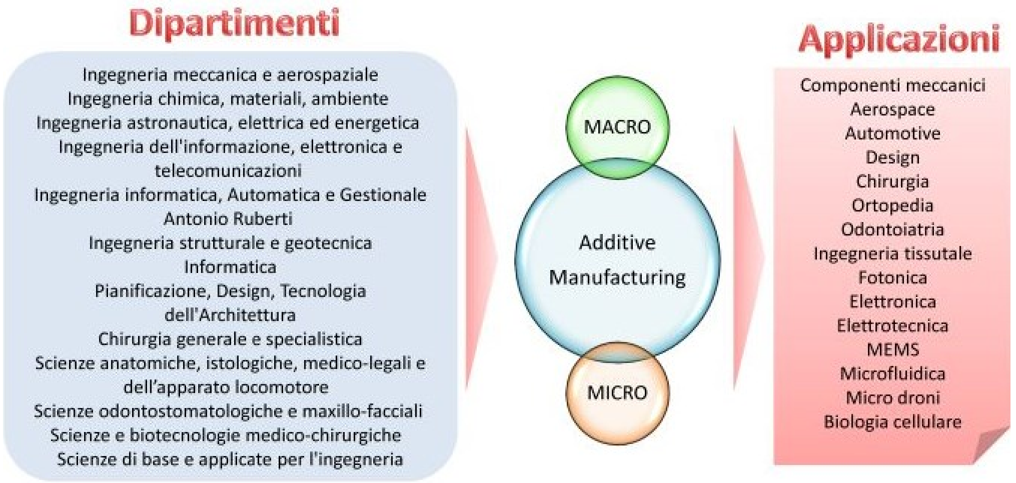
Co-proponenti: Sabrina Lucibello, Federico Venuta, Marco Balucani, Paolo Mataloni, Achille Paolone

SAPIENZA
UNIVERSITÀ DI ROMA

CARATTERISTICHE DELLA PROPOSTA

- Anno di finanziamento: 2016
- Elenco dipartimenti partecipanti alla proposta: 13+
- No. di proponenti firmatari della proposta: 115
- Installazione presso:

  Centro di ricerca e servizi SAPERI & CO



I dipartimenti coinvolti e le line di ricerca caratterizzanti il progetto di ricerca.

CARATTERISTICHE DELL'ATTREZZATURA E GLI AMBITI APPLICATIVI

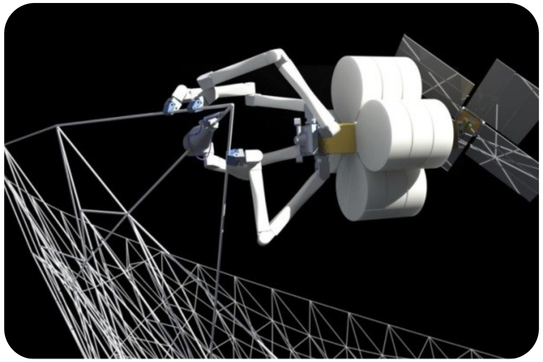
- **Il progetto nel campo dell'additive manufacturing punta a configurare la Sapienza quale riferimento accademico nel settore strategico dell'Additive Manufacturing** con applicazioni che spaziano dall'elettronica alla scienza dei materiali, dal design alla sensoristica, dall'innovazione dei processi produttivi alle biotecnologie e alla bioingegneria.

- In questi settori, nella **Sapienza, operano gruppi di diversa estrazione culturale e disciplinare, accumunati da una riconosciuta eccellenza internazionale**. E' dalla **cooperazione di tali gruppi che nasce l'esigenza di dotare la Sapienza della strumentazione richiesta per sviluppare, in modo determinante, conoscenze trasversali e all'avanguardia** inerenti, sia in termini di prodotti che di processi, al 3D prototyping su micro e macro scale.

- **La trasversalità culturale di tale iniziativa è confermata dalla multidisciplinarietà del gruppo di professori e ricercatori che propone l'iniziativa, afferenti a 13 Dipartimenti di 4 diverse Facoltà**

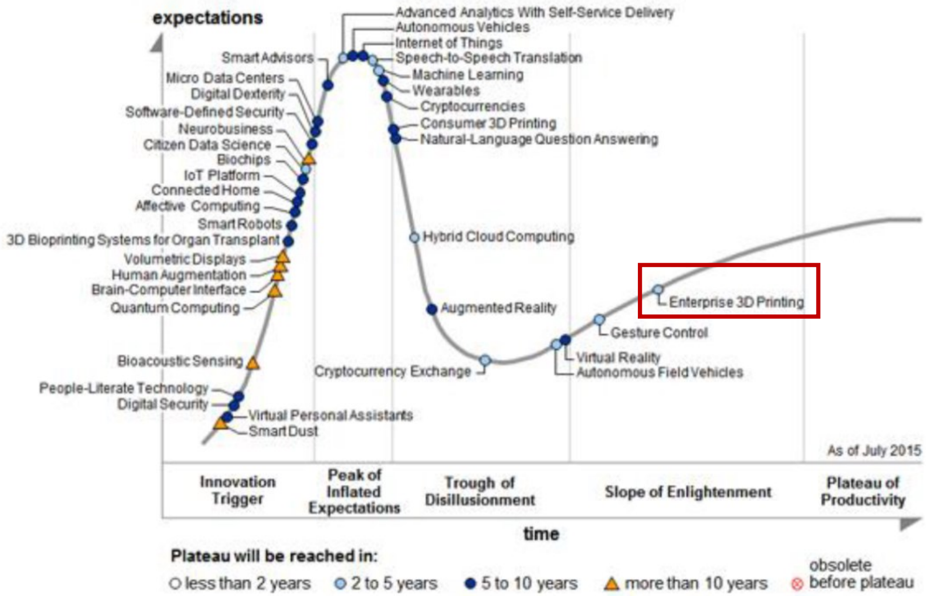
No more a hype!

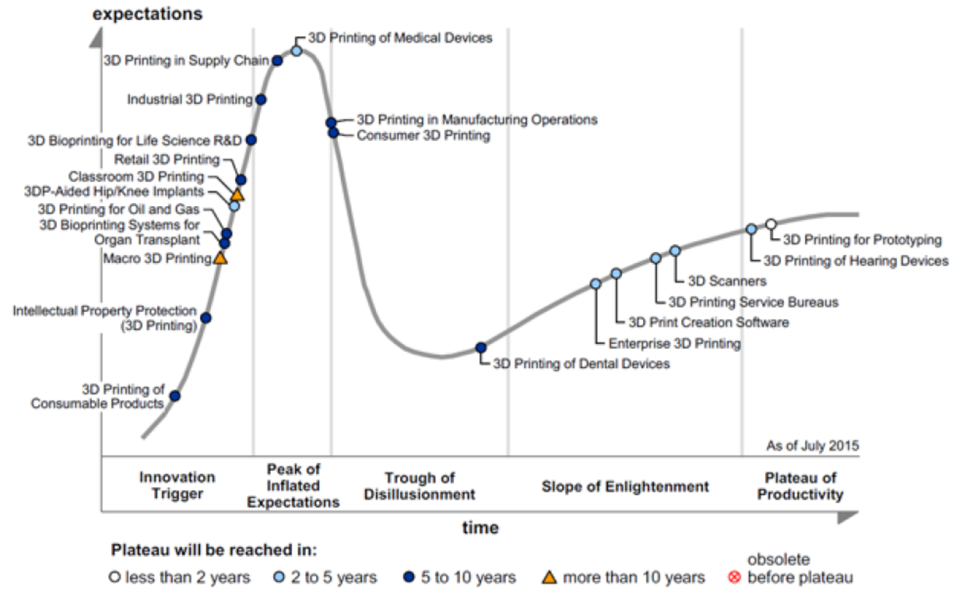
"Additive on Earth, on orbit, on planet.
Space is the ideal environment to allow the scalability of a specific technology.
Because Space is a difficult environment where it is necessary to construct ***very complex multifunctional components*** *that withstand very* ***high temperatures, high mechanical strength, very low weight*** *and with a* ***very short supply chain****.*
In a few years we will print ***also human organs***
when on planet will be essential ***to face any emergency"****. Tommaso Ghidini ESA ESTEC*



"In the next decades, Additive Manufacturing will be the key enabling technology of new space missions, bringing humans on Moon and on Mars.
But to this in necessary we must educate the future engineers to ***Additive-think,***
where Design for Manufacturing is replaced by ***Design for Performance (as Nature does).***
Then we can get the best from this disruptive technology."

No more a hype!



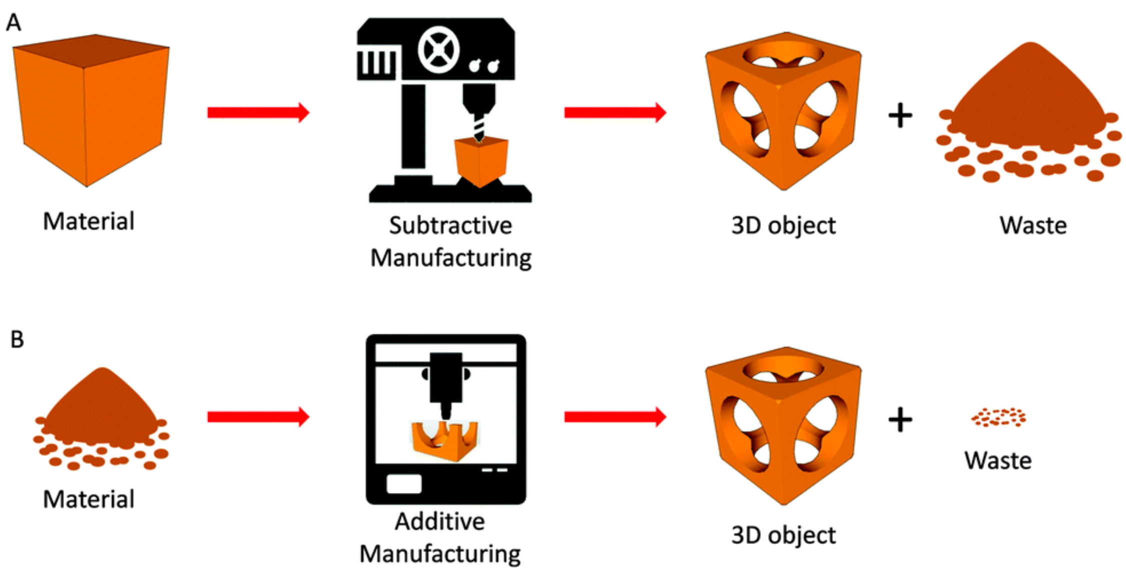


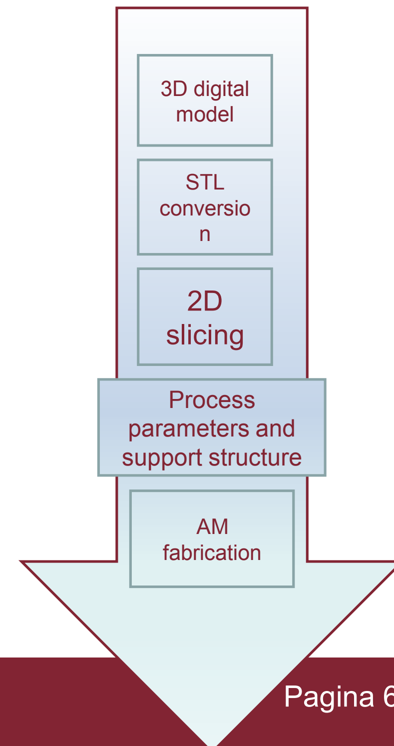
Source: Gartner (July 2015)

Additive Manufacturing

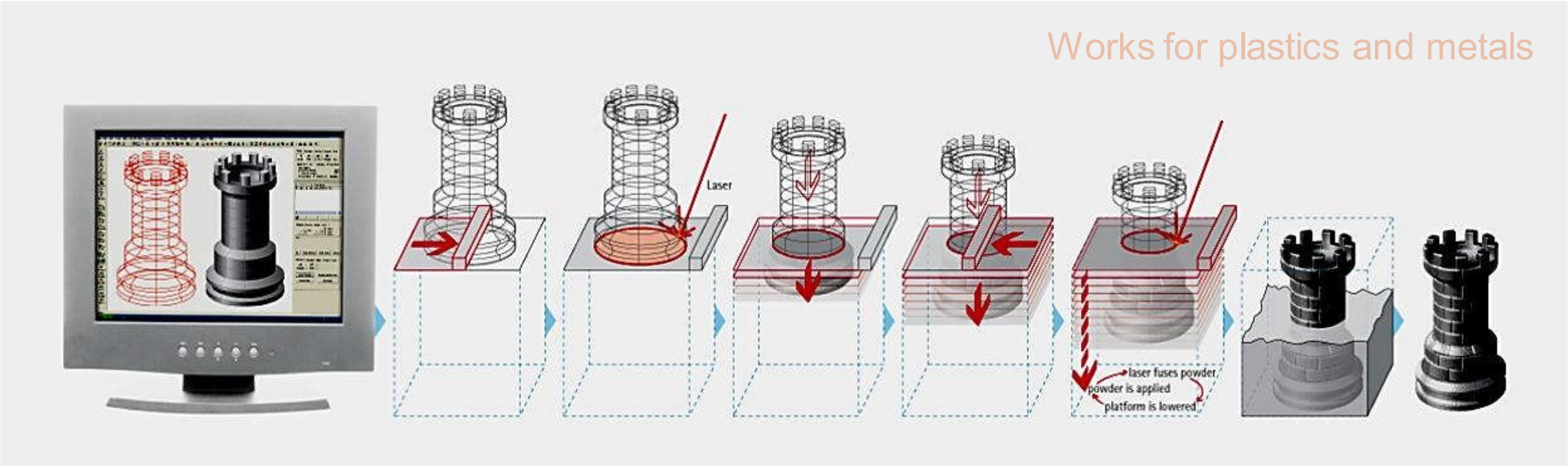
Additive Manufacturing (**AM**) summarizes manufacturing technologies which allows to create **three-dimensional objects from a 3D geometry file by successively adding material**.

In comparison to conventional manufacturing technologies (e.g. machining), where material is removed from a solid block in order to shape the part («subtractive manufacturing»).





From a digital model to reality



From a 3D CAD model…

- Application of powder
- Exposure by Laser

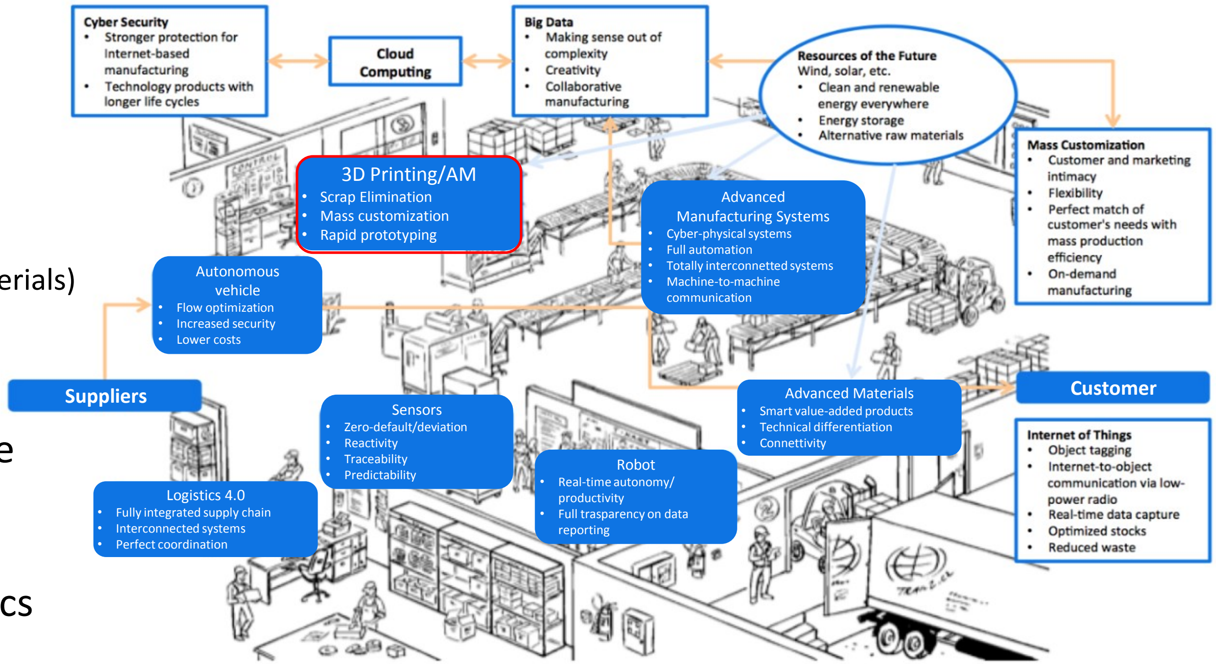
- Lowering of platform
- Re-application of powder

- Exposure by Laser

… to complete parts

AM: a part of a bigger picture

- **<u>PRODUCT</u>** INNOVATION
  - Lightweight
  - Complex shapes
  - Multifunctionality
  - Performance
  - FGM (Functionally Graded Materials)



- **<u>PROCESS</u>** INNOVATION
  - time-to-market decrease
  - waste reduction
  - increase fly-to-buy ratio
  - increased flexible logistics
  - optimized supply chain
  - cost effective production of small lots

- **<u>BUSINESS</u>** MANAGEMENT INNOVATION
  - Industry 4.0, Logistics 4.0, Space 4.0
  - Open Innovation
  - NewSpace paradigm

Design for Additive Manufacturing

- **Design for Additive Manufacturing** (**DFAM**) is a design methodology enabling to consider AM-related aspects in the design phase.

- It plays the same role of **Design for Manufacturing** (**DFM**) with respect to conventional manufacturing. Moreover, **DFAM is an environment fostering the creation of designs taking advantage of the unique AM capabilities**.

  - Shape complexity
  - Material nano, micro and meso structures
  - Integration of several functions
  - Spatial gradient of material properties

Main DFAM drivers:

- ✓ The AM is not only a process (systematic and systemic view is needed)
- ✓ The post-processing must be taken into account into design
- ✓ One material per machine (consistency of mechanical tests)
- ✓ If possible imitate the nature (biomimetic structures → **from DFAM to Design to Performance DFP**

MULTIDISCIPLINARIETA' E SINERGIA COMPETENZE

Dept. of Mechanical and Aerospace Eng.

- *Aerospace Structures*
  - Prof. Paolo Gaudenzi
  - Prof. Luca Lampani
  - Dr. Marco Eugeni
  - Ing. Valerio Cardini
  - Ing. Luciano Pollice
- *Machine Design*
  - Prof. Francesca Campana
  - Ing. Michele Bici
- *Mechanical Thecnology*
  - Prof. Francesco Veniali
  - Prof. Alberto Boschetto
  - Dr. Luana Bottini

Dept. of Physics (Prof. Silvia Masi)

Dept. of Chemical Eng. and Materials

- *Science and Technology of Materials*
  - Prof. Teodoro Valente
  - Prof. Marco Valente
  - Prof. Jacopo Tirillò
  - Prof. Fabrizio Sarasini

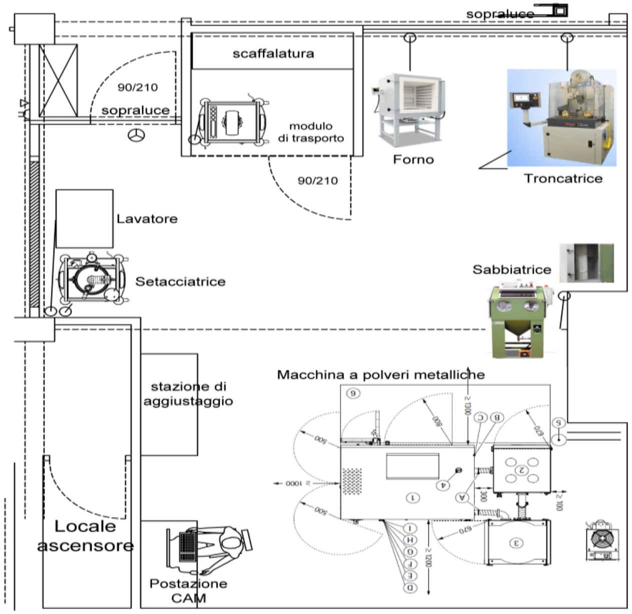
Dept. of Structural and Civil Eng.
(Prof. Achille Paolone)

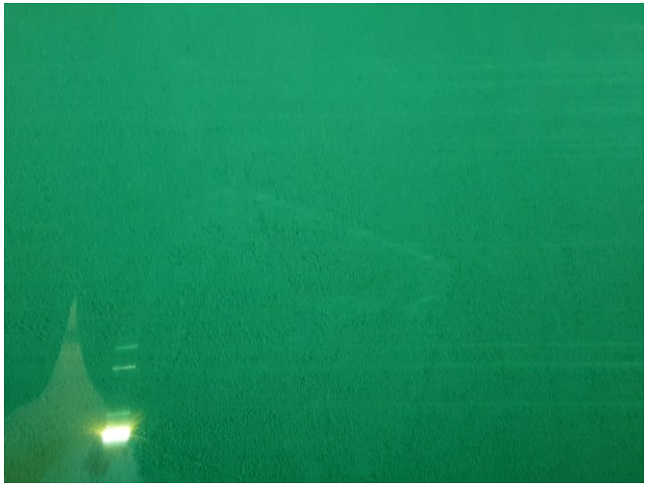
Dept. General and Specialistic Surgery
(Prof. F. Venuta)

Dept. of Planning, Design and Technology of Architecture
(Prof. S. Lucibello)

DESCRIZIONE DELLA ATTREZZATURA

- On-demand laboratory (main campus)
- EOSINT M290
- Post-processing facility
- Metal additive manufacturing





SVILUPPO TEMPORALE DELL'ATTIVAZIONE DEL LABORATORIO

- Fine 2017 installazione del Laboratorio, nell'ambito del LAB ON DEMAND AEROSPAZIO
- 2018: anno di messa a punto del macchinario e di svolgimento di progetti pilota
- 2019: avvio della fruizione a regime del laboratorio in sinergia con SAPERI & CO
- Modello di gestione per la Comunità Sapienza da attivare ultimate le pratiche su accessi e sicurezza e gestione locali e personale tecnico

MODALITA’ DI ACCESSO E DI UTILIZZO DELLA ATTREZZATURA

I Coproponenti (proponente e 3 co-proponenti), in accordo con i Direttori dei Dipartimenti interessati e sentiti i partecipanti al progetto rappresentati per aree di ricerca così come definite nel progetto, individueranno l’ubicazione della strumentazione secondo criteri di massima fruibilità in relazione alle tipologie di utilizzo che discendono dalle linee di ricerca del progetto, avendo già una base di partenza di strumentazione per il 3D Rapid Prototyping messo a disposizione dal Dip. PDTA. I Coproponenti avranno quindi come successivo compito quello di effettuare un’analisi finanziaria ed economica al fine di prendere in considerazione:

- Contratti di manutenzione per le attrezzature;
- Costi dei materiali di consumo per le diverse possibili richieste da parte degli utilizzatori;
- Personale tecnico per l’utilizzo delle attrezzature;
- Upgrading e aggiornamenti software/hardware delle attrezzature al fine di conservarle e garantirne lo state-of-art.
- Costi per la predisposizione e mantenimento di un sito web per la gestione delle prenotazioni delle macchine
- Definizione dei criteri per la stesura delle liste di prenotazione per l’utilizzo delle apparecchiature e quantificazione dei costi associati alle lavorazioni richieste

L’analisi consentirà quindi di definire le risorse economiche e il cash flow finanziario minimo necessario al funzionamento della strumentazione per il 3D Rapid Prototyping.

I Coproponenti, in accordo con i Direttori dei Dipartimenti interessati, definiranno quindi un modello di gestione delle attività e dei flussi finanziari che si prevedano siano necessari a garantire il funzionamento della struttura e a coprire tali costi.

La filosofia è quindi quella di un sistema di “membership” che vengono sottoscritte da singoli utenti o da gruppi di utenti del centro ove saranno ubicate le macchine, ovvero da strutture dipartimentali, enti esterni, PMI del Lazio, industrie, etc..

MODALITA’ DI ACCESSO E DI UTILIZZO DELLA ATTREZZATURA

I Coproponenti valuteranno le richieste pervenute, sulla base di criteri di merito.

La gestione degli accessi alla strumentazione sarà quindi gestita mediante lo sviluppo di un sito web in cui sarà possibile accedere alla sezione dedicata alla prenotazione degli strumenti. Coloro i quali avranno attivato una membership, potranno accedere a tale sezione mediante username e password. Potranno quindi effettuare la prenotazione dello strumento di interesse nella data e fascia oraria disponibile, dichiarando la tipologia e scopo dell’utilizzo ed effettuare l’up-load del progetto da eseguire.

La richiesta di servizio di ricerca mediante l’utilizzo di una determinata attrezzatura sarà inviata dal sistema al tecnico responsabile dello strumento, allo strutturato responsabile della strumentazione e al responsabile della struttura. L’accesso sarà autorizzato sulla base del criterio del “silenzio assenso”.

ATTIVITA' SVOLTE E IN CORSO, RISULTATI CONSEGUITI

- **Design for Additive Manufacturing (DIMA)**
  - Re-design of a CubeSat
- **Multifunctional components realized by FDM (DIMA)**
  - Components with Embedded Electronic realized in AM
- **SE/CE tools for Design for Additive Manufacturing applied to Space systems (DIMA)**
  - Thermal control integrated into a structural components (a collaboration with RUAG Space)
- **Additive Manufacturing for logistics (DIMA)**
  - Realization of a secondary components by a direct geometrical acquisition (a collaboration with CSV of Italian Air Force)
- **Realisation of a tiltometer (Dept of Physics)**
  - design and (additive) manufacturing of a component of an experimental Device for studies in gravitational waves
- **Optimization and development of several 90 GHz Al antennas (Dept of Physics)**
  - HFSS optimization, design and (additive) manufacturing of a 90 GHz antenna, testing in the Phys.Dept.
- **Additive Manufacturing for engineering for health (Dip. di Chirurgia Generale, Specialistica e Trapianti d'organo "Paride Stefanini")**
  - Anatomical models for surgical planning

1. Re-design of a CubeSat primary structure

Research motivations

NewSpace defines an emerging global industry of private companies and entrepreneurs who primarily target commercial customers, backed by risk capital seeking a return and profit from innovative products or services developed in or for space

MORE FLEXIBILITY & RISK TOLERANCES
FOR THE INTRODUCTION OF INNOVATIONS

NewSpace main featuring trends:

- Commercial customers
- Very large constellations of **small satellites**

The AM manufacturing of the structural sub-system of a NanoSat is considered

Design approach

Design for Manufacturing, Assembly, Integration (DFMAI)

***Designer should tailor their design to:**

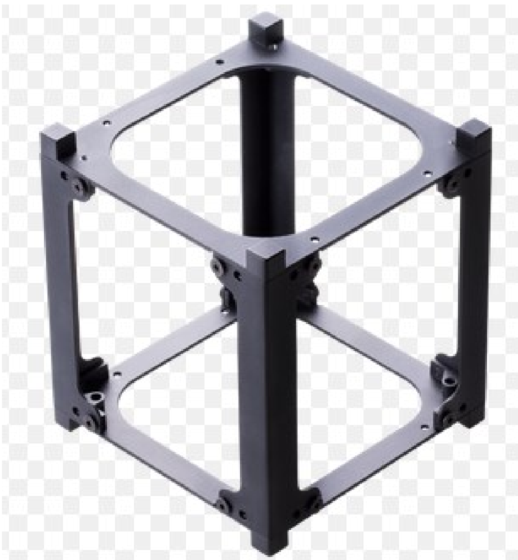
ELIMINATE manufacturing difficulties.

REDUCTION of cost of:

- Manufacturing
- Assembly
- Logistics

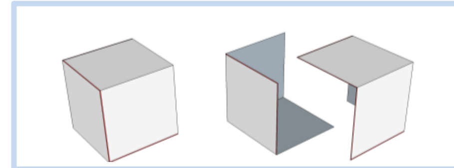
*according to: *Additive Manufacturing Technologies. 3D Printing, Rapid Prototyping and Direct Digital Manufacturing. Second edition*
Ian Gibson, David Rosen and Brent Stucker. Springer

Reduction of the part count

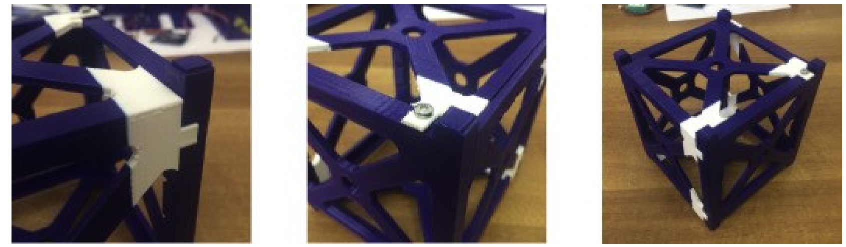


CubeSat structure by EnduroSat. It is **hard** to envision a **better mass distribution** once mechanical interface requirements are taken into account.

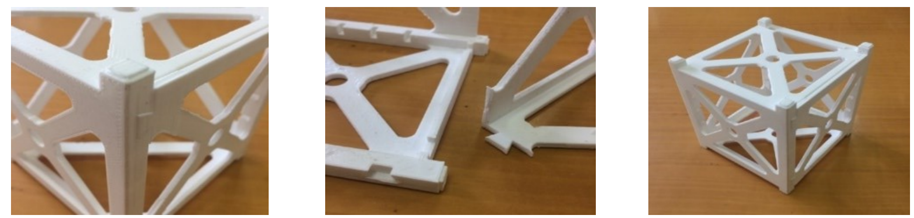
Part consolidation

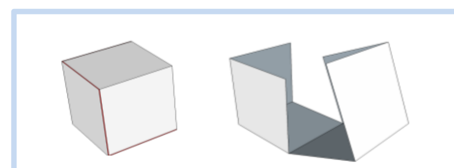


2 parts
2 fasteners

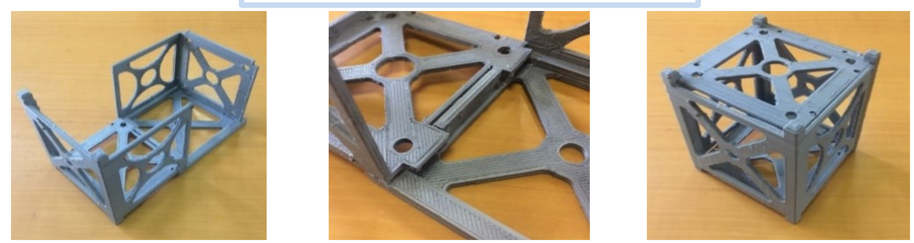


2 parts
no fasteners





2 already assembled parts



Design path

DFAM for the **reduction of the number of parts** of a **CubeSat 1U Structure**

Fused Deposition Modelling Low-Fidelity Mock-ups to study form and function design strategies

Technology understanding for a functional prototype with **metallic powder AM**

Production of a **Proof-of-Concept Mock-up** in ALSi10Mg using **DMLS**

From Low-Fidelity to Proof-of-Concept

In order to move towards a Functional Prototype a change of material is necessary. Therefore a change of Manufacturing Technology and Design Approach is required

Low Fidelity Mock-Ups
lessons learned

+

DMLS technology
requirements

+

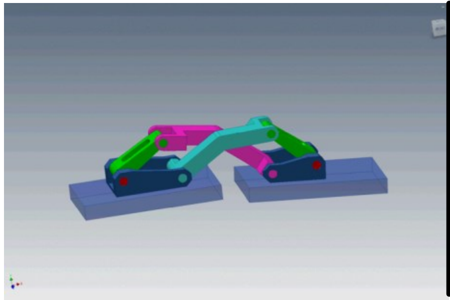
DFAM of Proof-of-Concept

Top level considerations:
- Hinge design for DMLS
- Snap-Fit interlocking design for DMLS

Second level considerations
- Geometry design for DMLS

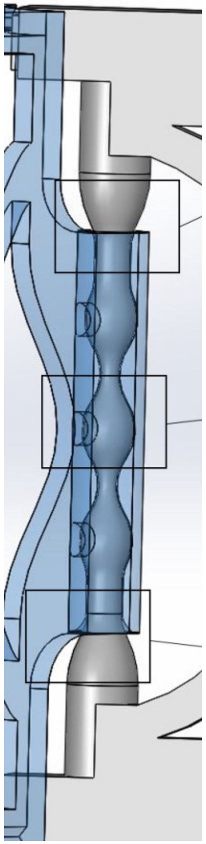
Selective Laser Melting of non-assembled mechanisms

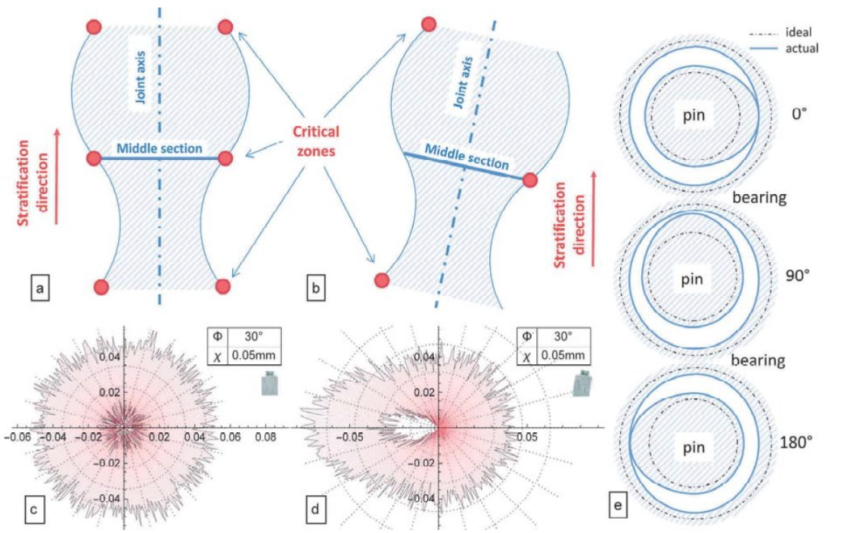
Manufacturing of non-assembly mechanisms

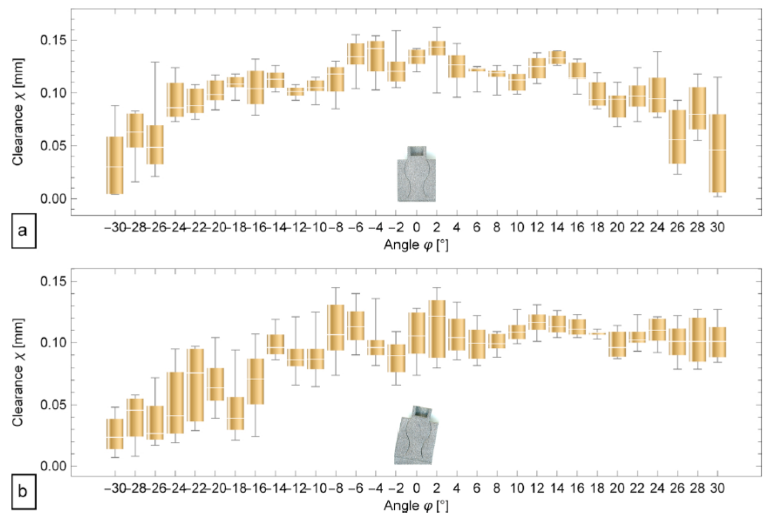


Problems:
- Choice of the clearance
- Choice of the building orientation
- Support structures removal
- Impossibility to perform finishing operation
- Measurement of the joint performance

Aim: Development of a manufacturability map for non-assembly joints taking into account the clearance, the joint shape and the building orientation

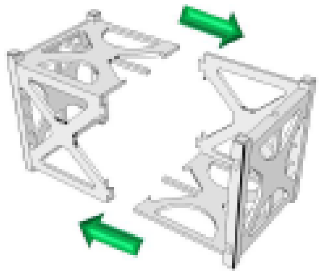




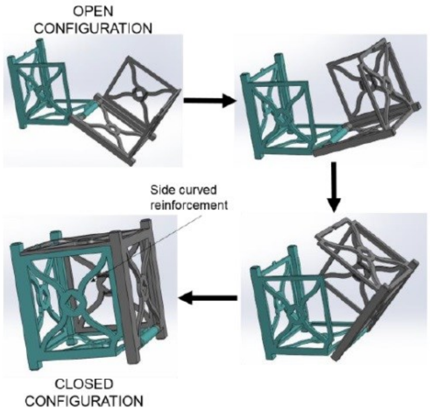


Selective Laser Melting of non-assembled Hold Down mechanisms

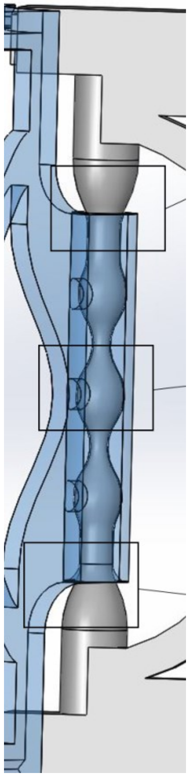
6 parts



2 parts

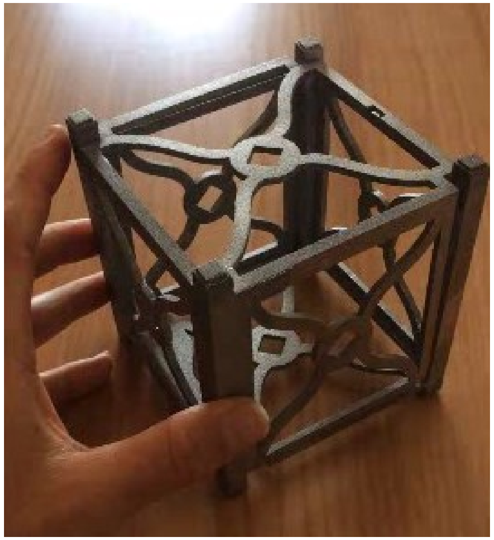


1 part



Closure guides detail

Snap-fit detail



Remarks and Future Developments

- A CubeSat 1U structural subsystem has been studied and redesigned under a **DFMAI** approach and within a **DFAM** framework focusing *on the consolidation of number of parts*.

- **Different structural configurations** have been realized **and Low-Fidelity plastic Mock-ups using Fused Deposition Modelling realized**. <u>It is to underline how having rapidly low-cost replicas, although low-fidelity ones, is *invaluable*.</u>

- The possibility to realize a metallic proof-of-concept mock-up has been considered.

- The selected design successfully led to the manufacture of a single piece, metallic 1U CubeSat structure subsystem equipped with a hinge and snap fit mechanism.

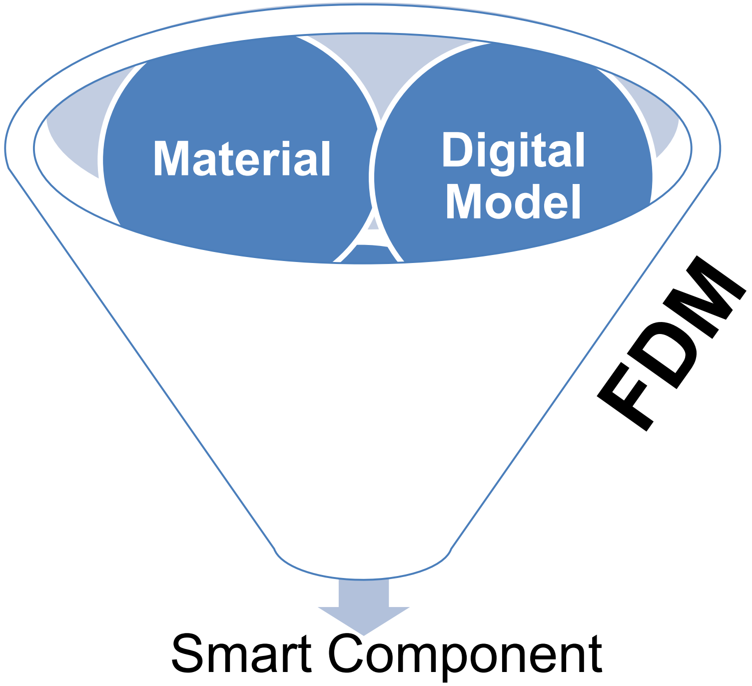
As for **future developments**:

- Re-thinking of the entire design in order to reduce manufacture problems
- Geometry and surface accuracy evaluation and analysis in order to make it compliant with CubeSat standard.
- Consideration of off-the-shelf CubeSat components mechanical interfaces currently available in the market

2. Multifunctional components with embedded electronics realized by FDM

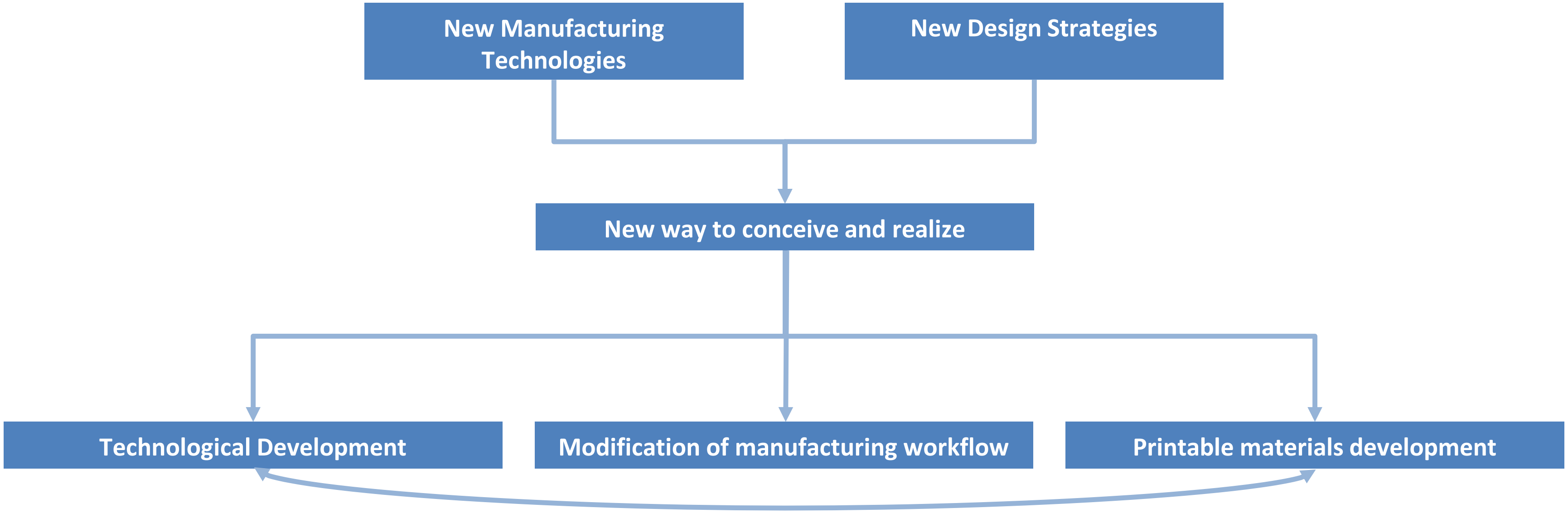
Research motivations

- The possibility to **build smart (multifunctional & composite) components with embedded electronics using single extruder Fused Filament Fabrication (FFF) additive technology** is studied
- Open desktop technology: **total control over the process** (digital model and manufacturing process)
- A methodology for production **of smart components with a low cost commercial technology** and **materials** is the main outcome



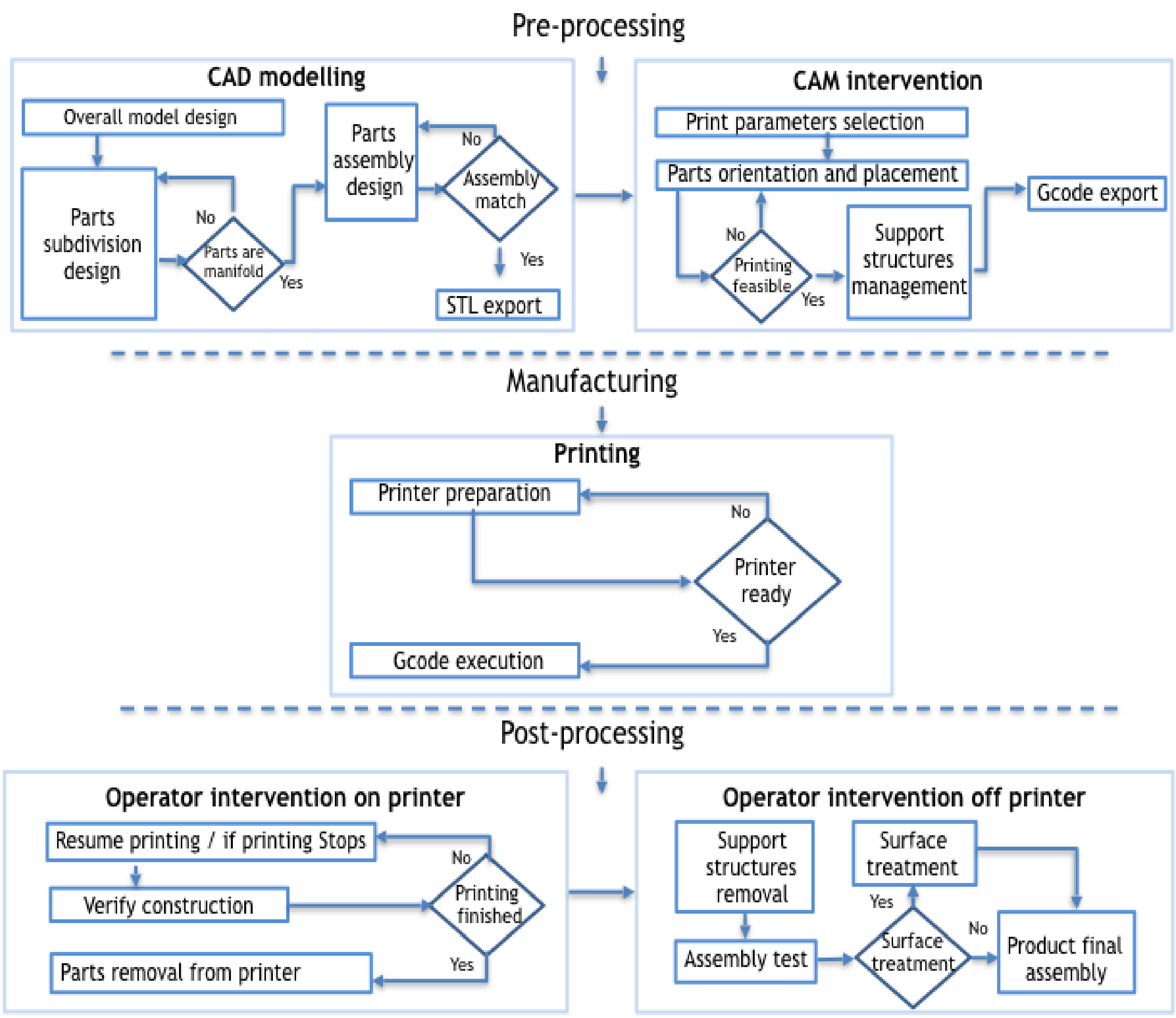
Smart Components Realization in a AM framework

- → Complexity of the component not related to its manufacturing cost
- → Strong reduction of parts number for every realized component
- → Possibility to delocalized manufacturing: long-term space-missions

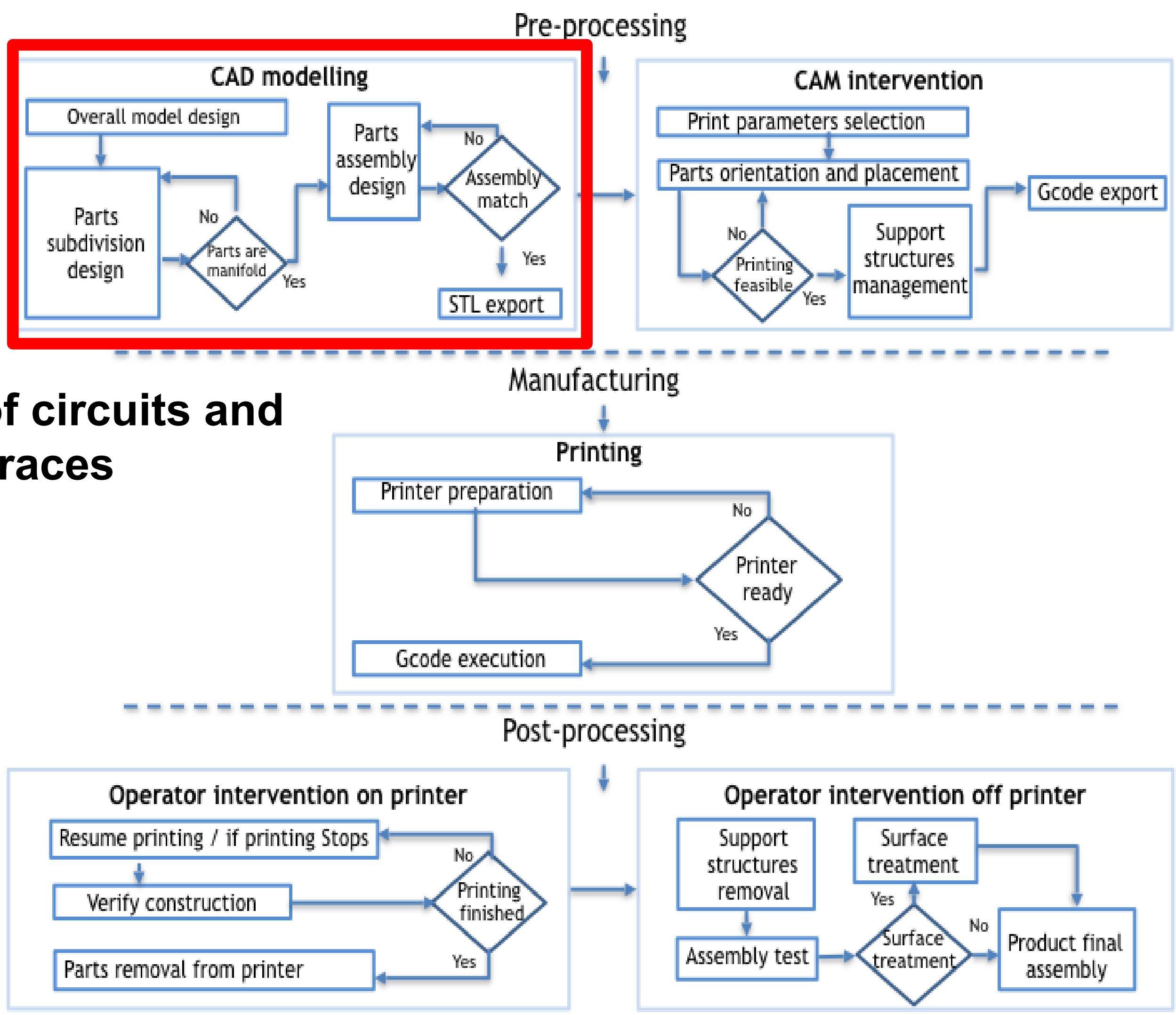


Realizing Smart Components by means of AM technologies would drastically enlarge the horizons of applications of such elements

The Additive Manufacturing Process

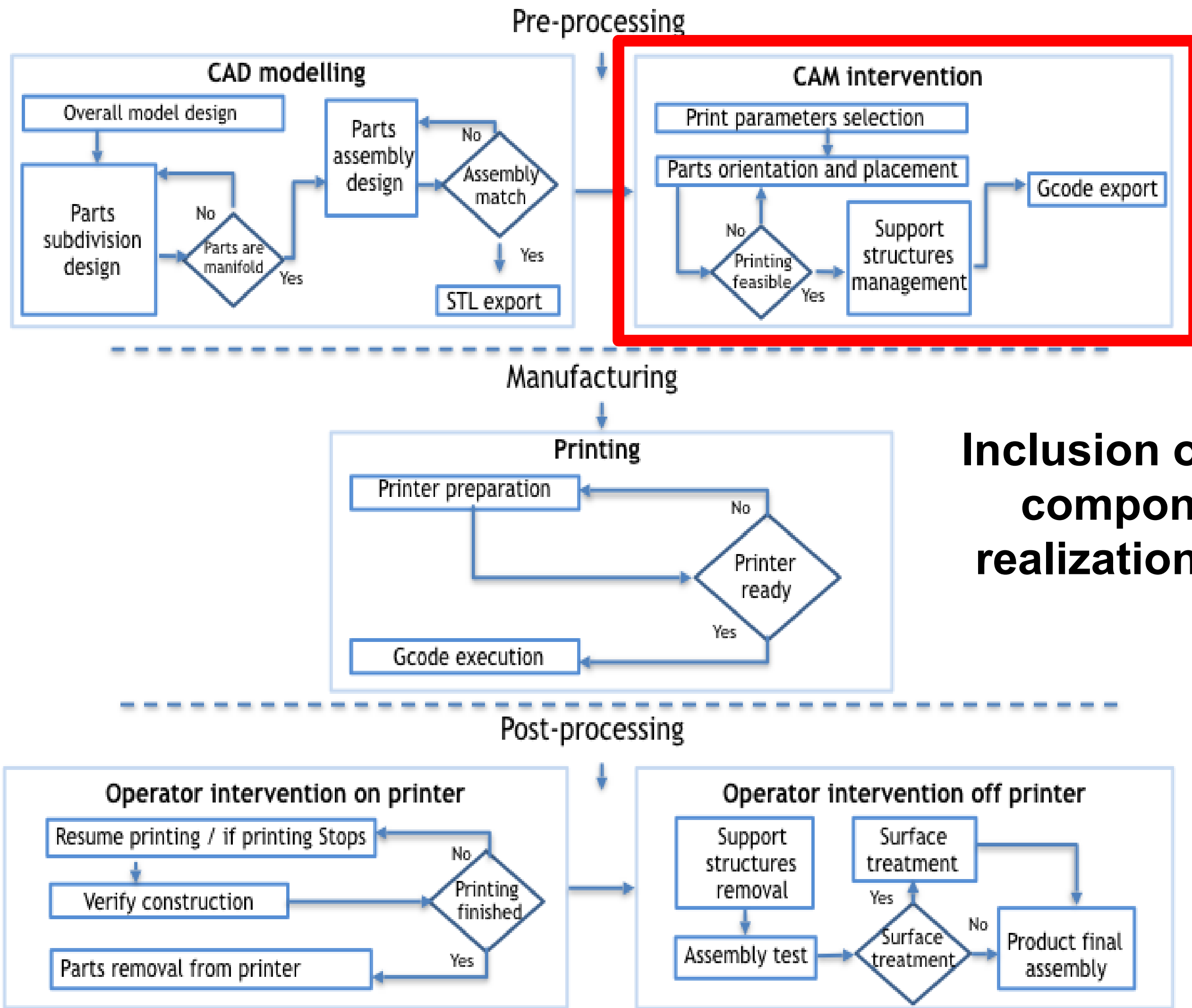


The Additive Manufacturing Process



Design of circuits and traces

The Additive Manufacturing Process

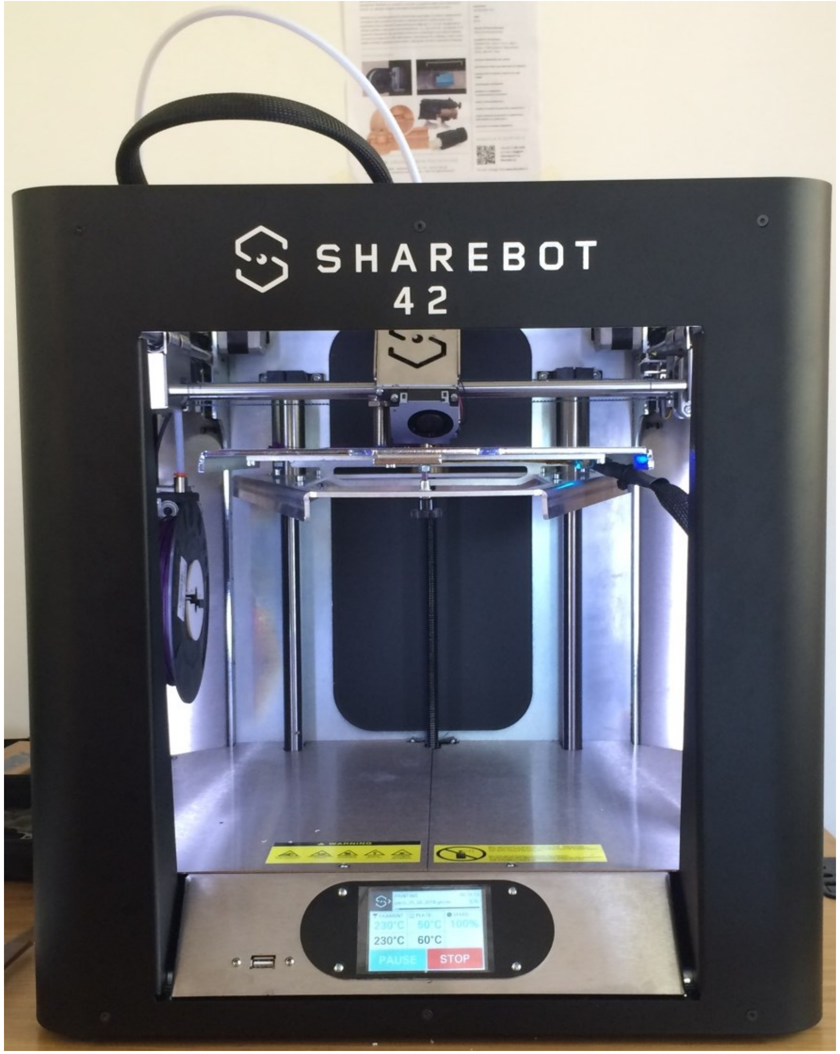


Inclusion of electronic components and realization of circuits

Experimental Campaign

The machine used is a **Sharebot42** single extruder. In the following table the basic characteristics of the machine are enlisted.

Parameter	Description
Printing volume	250 mm x 220 mm x 200 mm
Maximum extrusion flow	24 mm^3/sec
Heated printing plate max temperature	90°C
Minimum layer thickness	0.05 mm
Nozzle	0.4 mm (interchangeable)
Compatible filaments (1.75 mm diameter)	PLA-S, Nylon-Carbon, Thermoplastic Polyurethane (TPU), ABS-HF, Poly



Experimental Campaign

In order to propose a realization workflow it is necessary to:

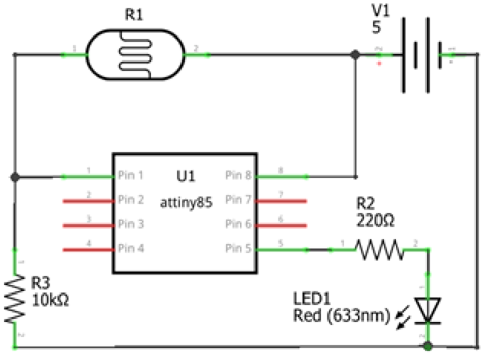
- **Choose the conductive material** and **evaluate its** conductive **properties**

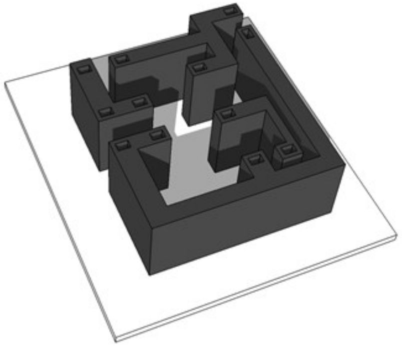
  - Evaluation of the **resistance behavior with respect the geometrical properties** of the circuits
  - **Evaluation of the repeatability** of the chosen value **of the resistance**
  - **Evaluation of the stability of the** obtained **resistance** with respect the time
  - Printing of demonstrators

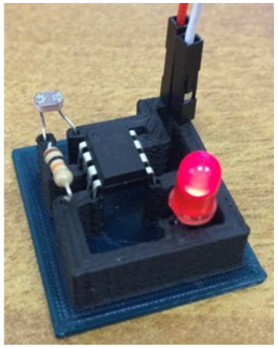
- **Evaluate the inclusion strategies** of the electronic components (once the material is choosen)

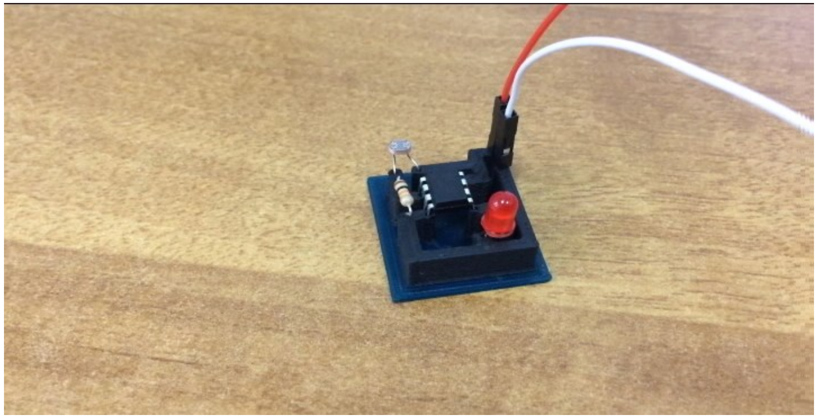
  - Inclusion test
  - Printing of demonstrators

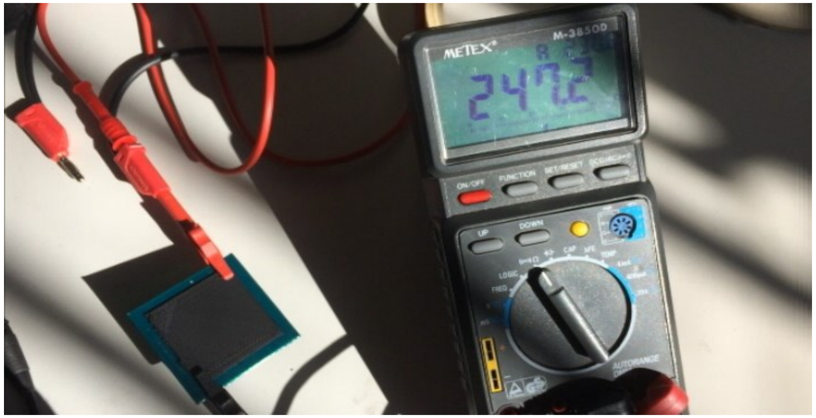
Experimental Campaign











Test Goals

- **Printing conductive traces**
- **Printing of interfaces** with electronics component
- **Analysis of resistance** behavior wrt section of traces

Experimental Campaign

The **inclusion of electronic components** stress the key aspect in the design and manufacturing processes:

- **Placement of the components**
- **Pausing of the AM machine**

- Design of the placement of the components (CAD)

  - Creation of **cavities and tracks**
  - **Distribution** and **interconnections design**
  - Identification and **design of thermal protection**

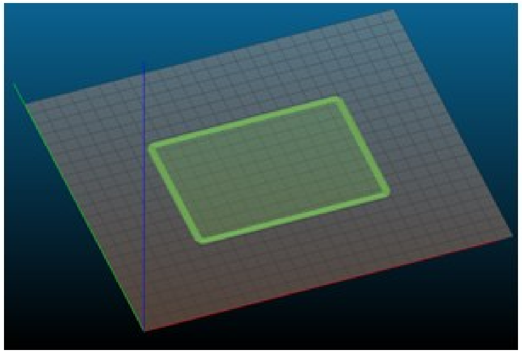
- Pausing the printer (CAM and Manufacturing)

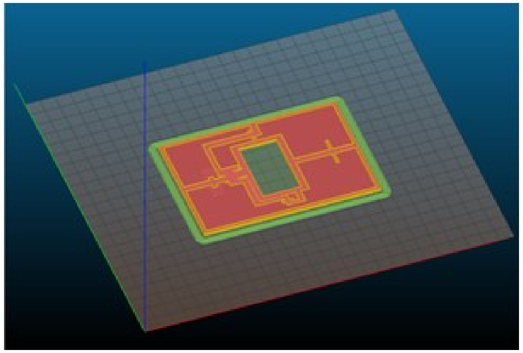
  - Precise **layer identification**
  - **Components placement**
  - **Temperature** control
  - Change of filament if single extruder

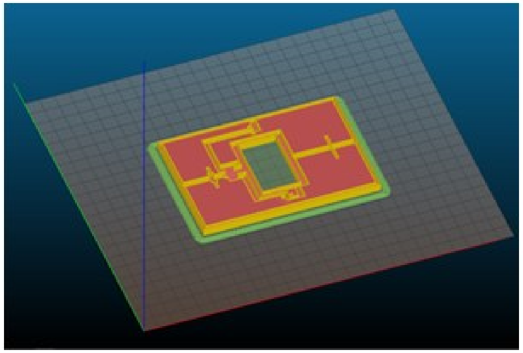
Experimental Campaign

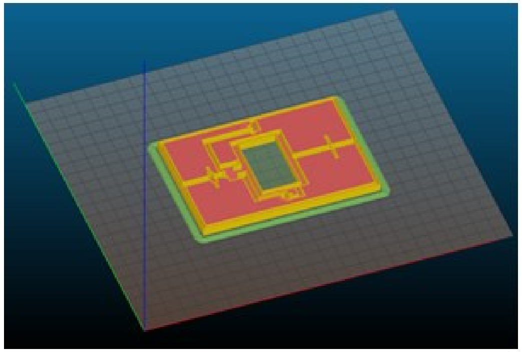
- **Layers are identified** during the slicing
- **Gcode is the edited** to define the manufacturing pausing

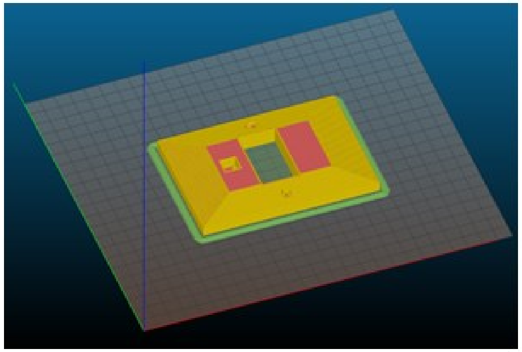
```
G1 E0.20533 F3000.00000
G92 E0
G1 Z1.300 F9000.000              // CAM individuated layer for pause
G 91                             // Set to relative positioning
G1 Z50.000                       // Lower bed by 50 mm
G90                              // Set to absolute positioning
M0                               // Pause and wait for user
G91                              // Set to relative positioning
G1 Z-50.000                      // Raise bed by 50 mm
G90                              // Set to absolute positioning
G92 E0
```

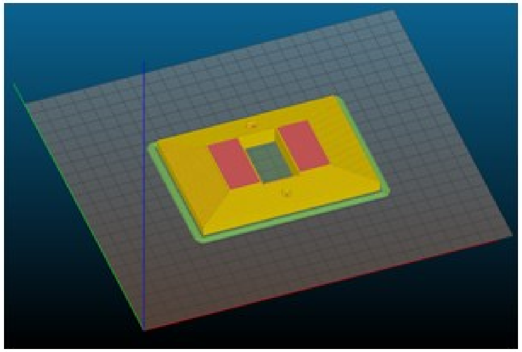

Printing start. Raft layers


First interruption. Filament change 1


Second interruption. Filament change 2

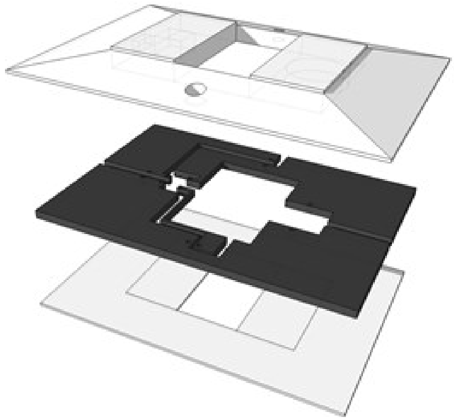

Third interruption. Resistor Inclusion

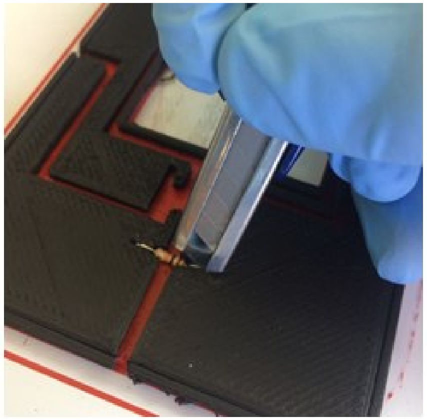

Fourth interruption. Microcontroller, LED and photoresistor inclusion

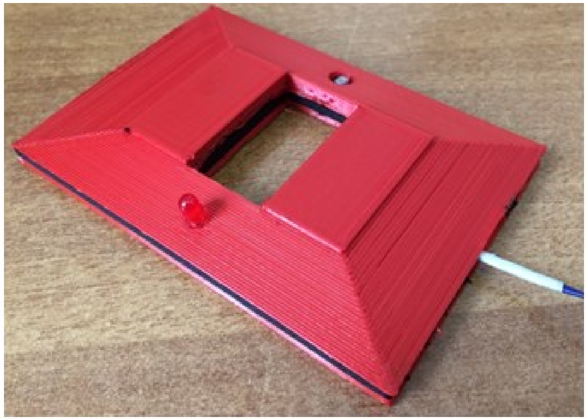

Final interruption. Printing finish

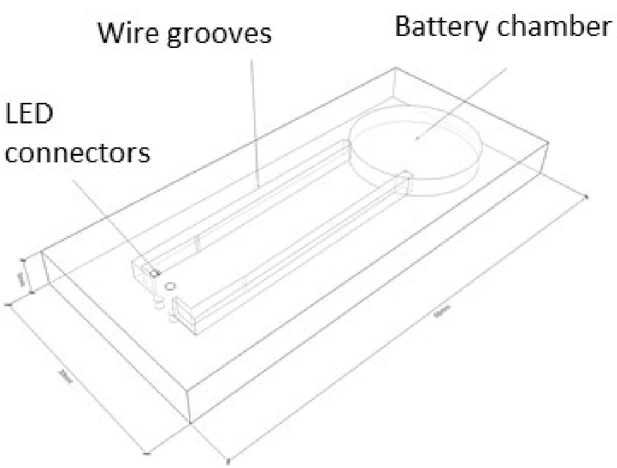
Experimental Campaign

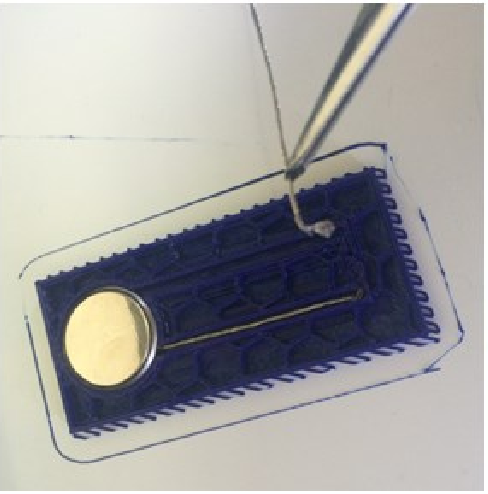
When the printer is paused, a manual operation is performed to place the components in the respective positions.

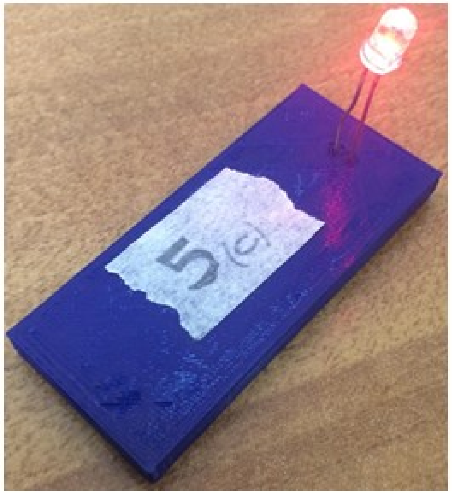




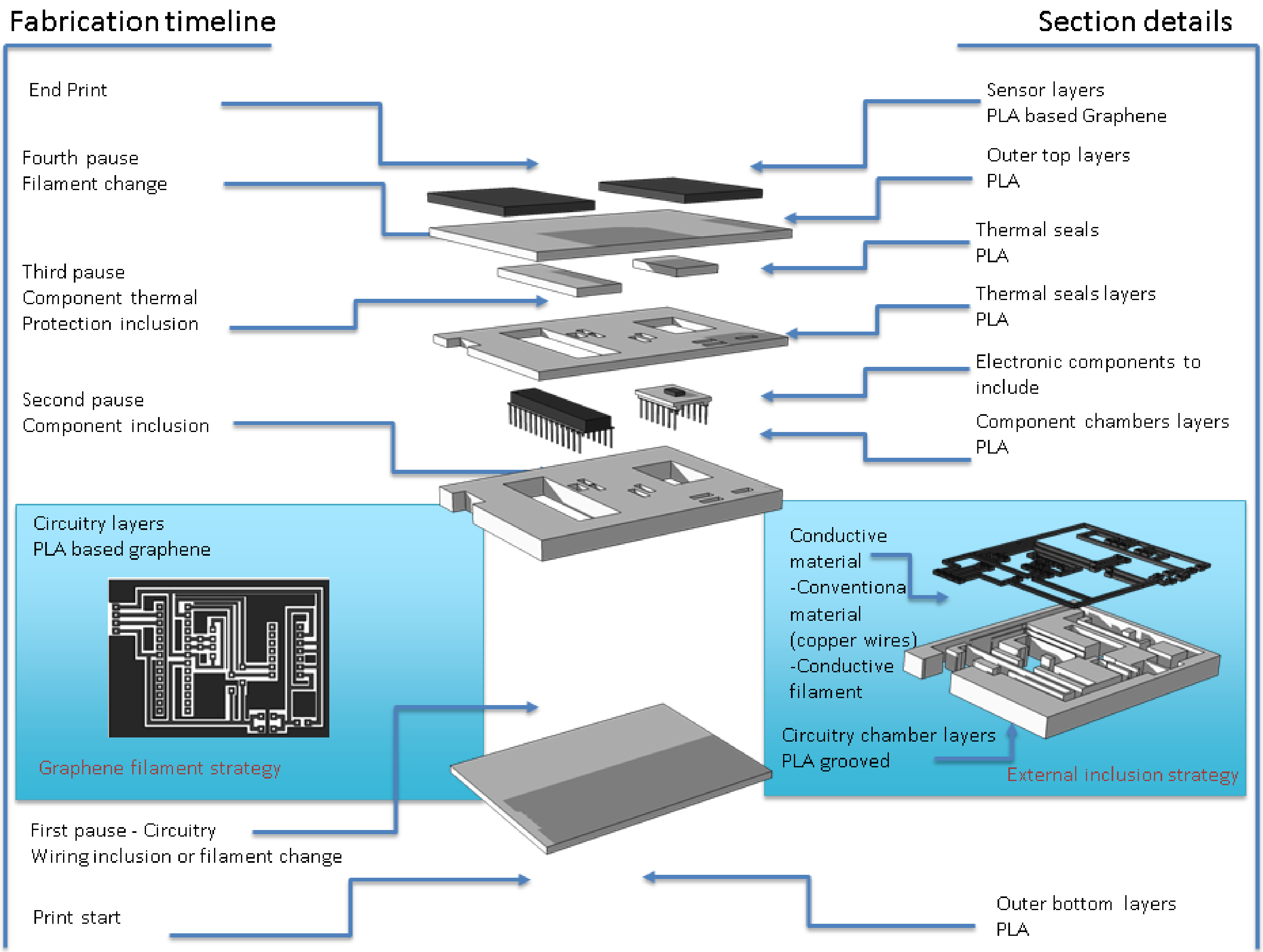




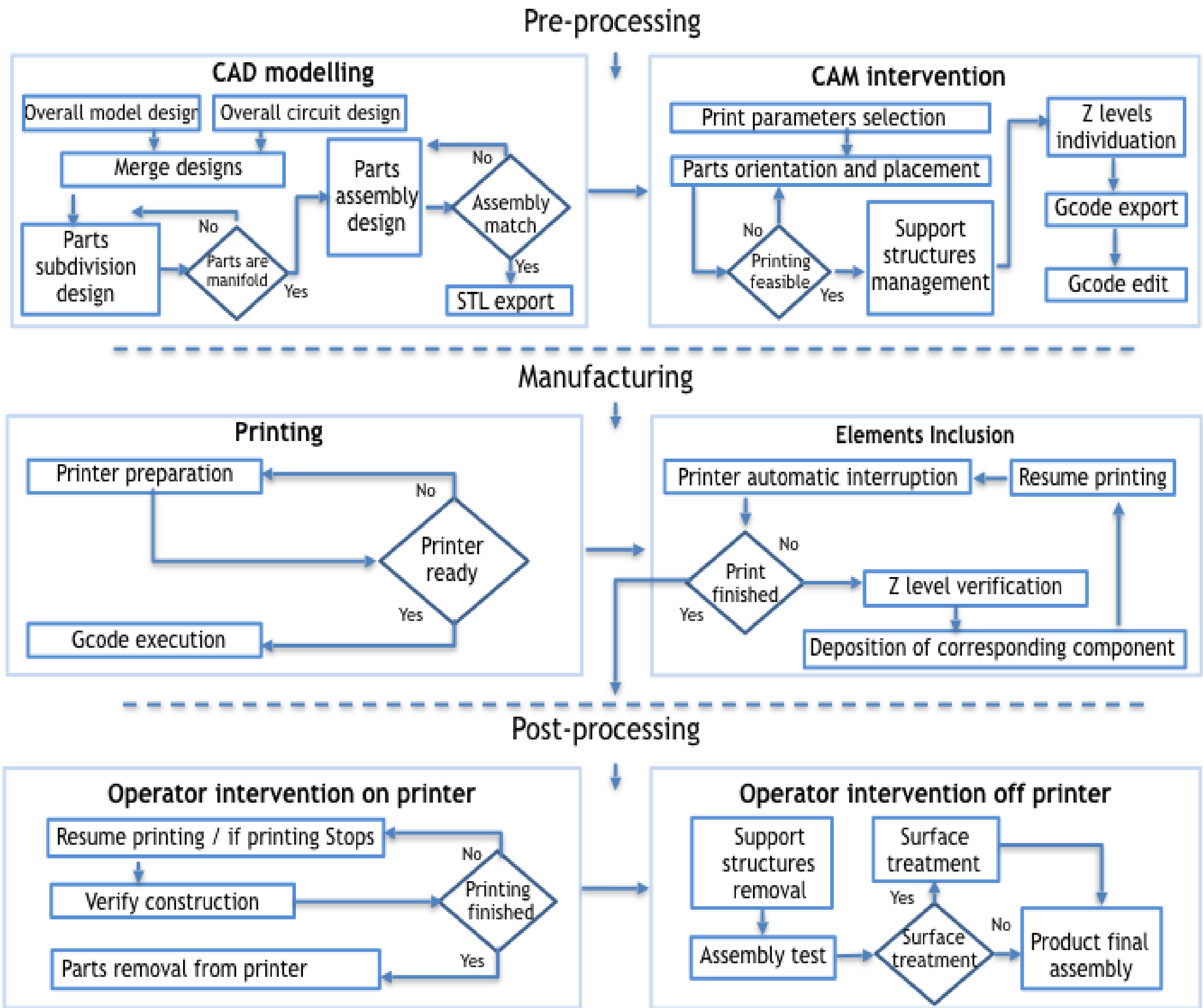




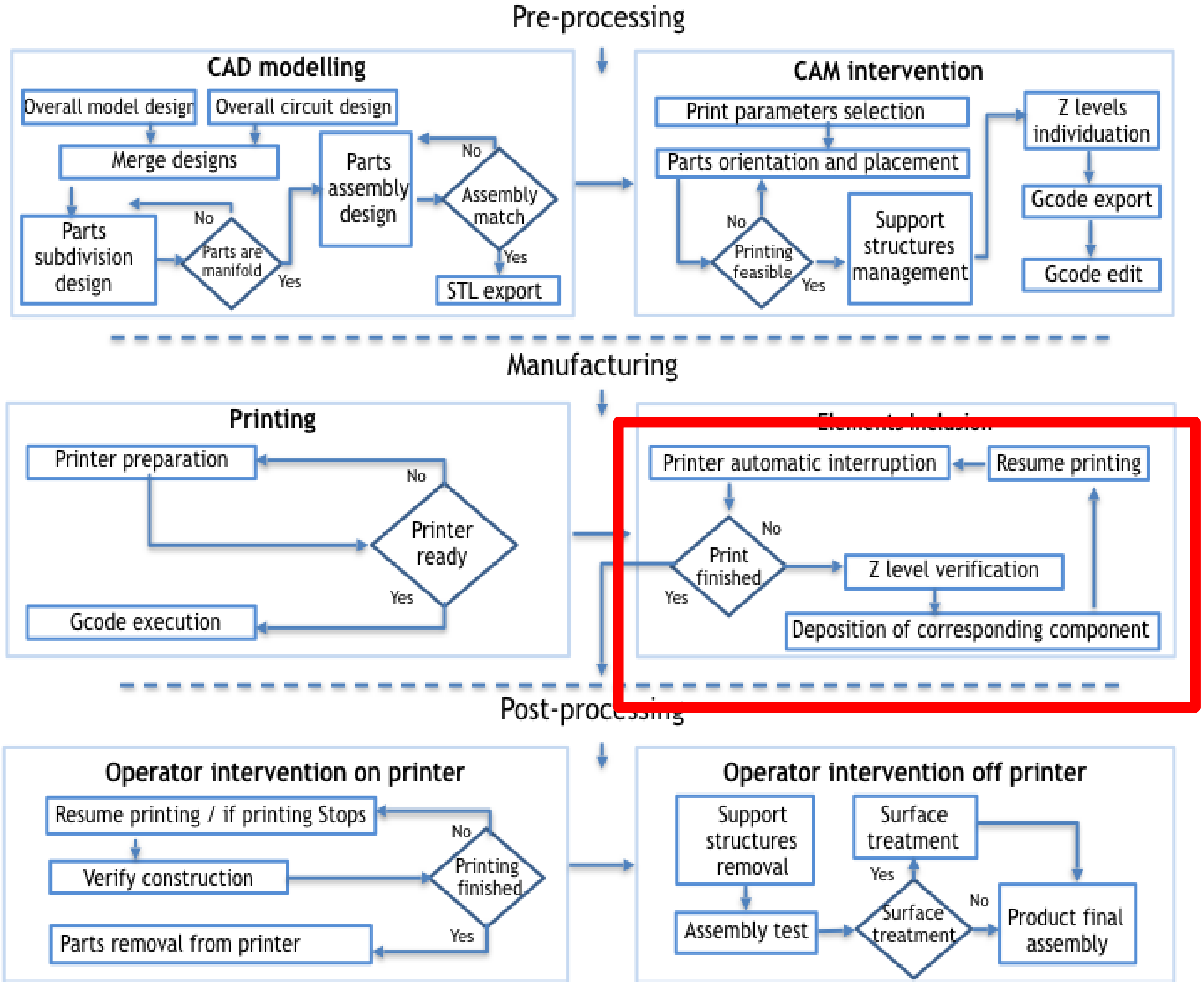
Proposed Fabrication Process



A new step in the Additive Manufacturing Process



A new step in the Additive Manufacturing Process



Remarks

- The possibility to build **smart sensorised components with embedded electronics** using a low cost additive technique without the intervention of any other manufacturing machine has been studied

- A **methodology for the inclusion of electronic components in the manufacturing process** has been presented and discussed

- The presented new methodology of **design** and **manufacturing** allows the **production of a smart component without the need of any hardware modification to the manufacturing machine or the implementation of additional manufacturing technologies**

- The methodology enables the FDM technology to embedded circuits and sensors which **can adapt to the structures geometry**

- The obtained results pave the way for further developments in the **production of smart components with low cost commercial technology**

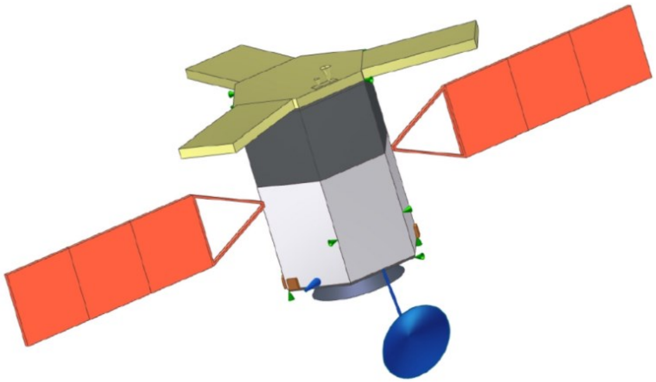
3. SE/CE design for AM technologies for Space systems

A Sapienza and RUAG collaboration

Research motivations

- **AM:** a new manufacturing paradigm
- **DFAM:** an innovative design thinking
- **Advanced Systems and Concurrent Engineering**

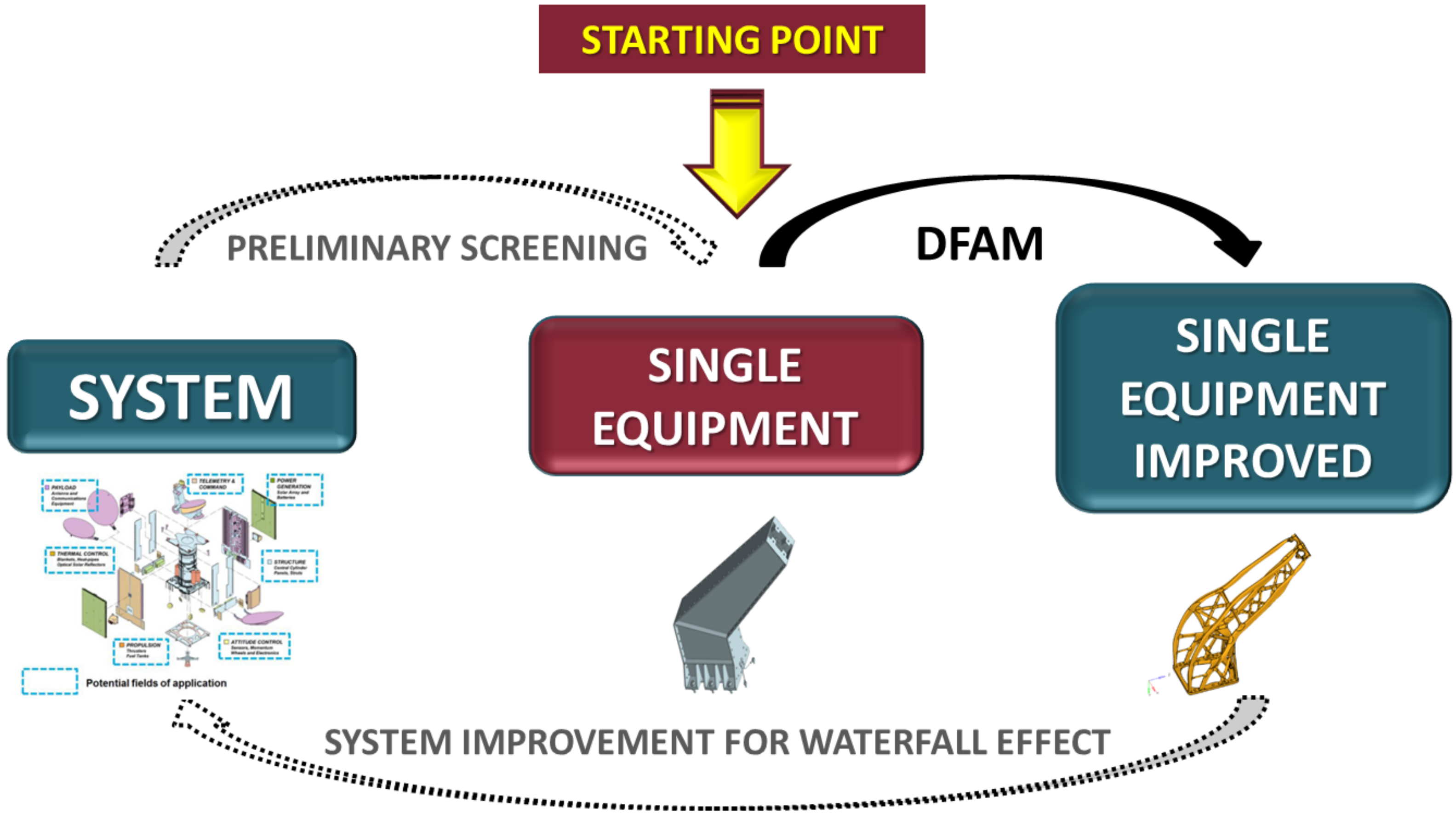
Maximization of AM benefits in Space systems design and manufacturing → Design to performance



INNOVATIVE SATELLITE ARCHITECTURES

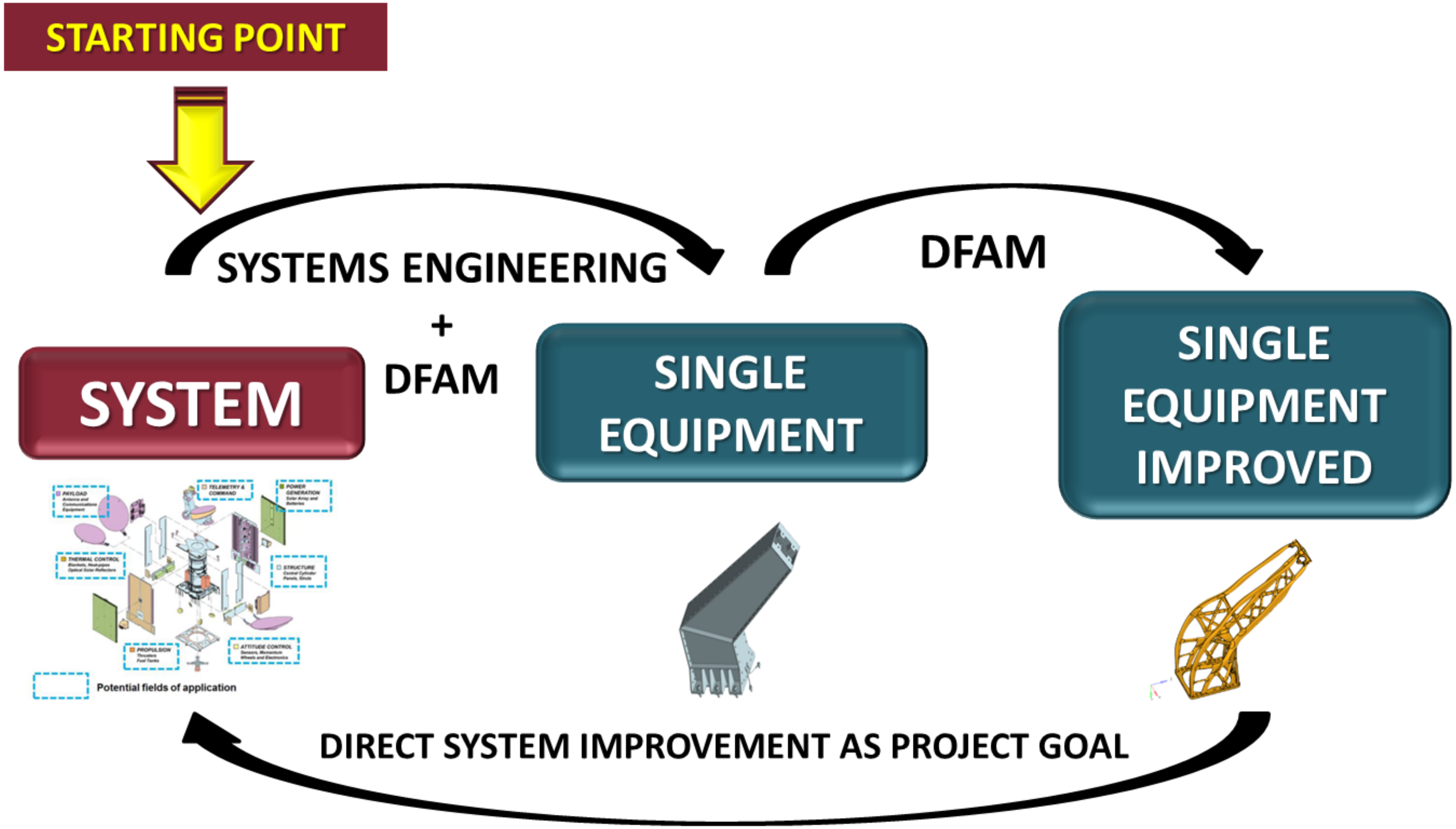
SE/CE design for AM methodologies for Space systems
A Sapienza and RUAG collaboration

TRADITIONAL WORKFLOW



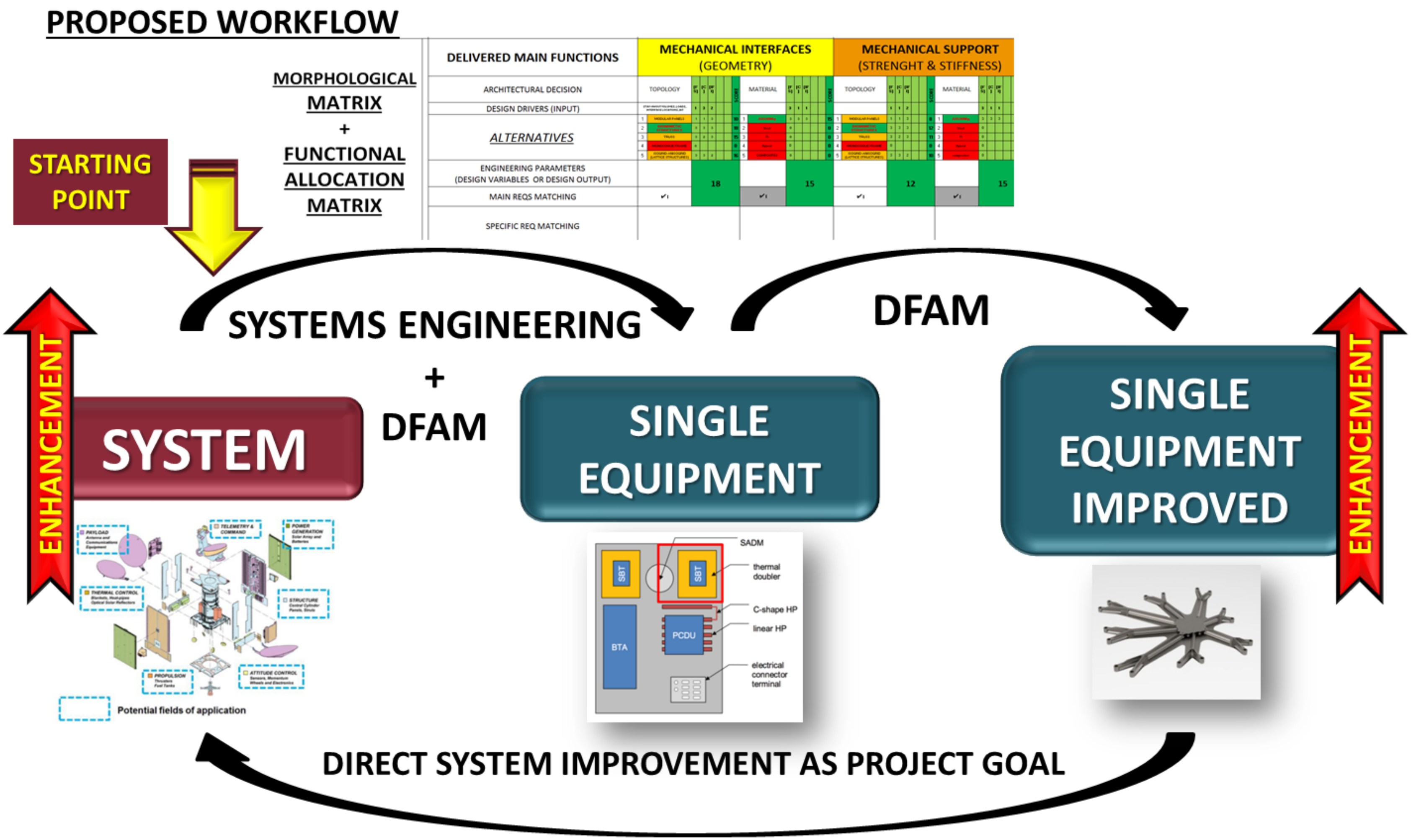
SE/CE design for AM methodologies for Space systems
A Sapienza and RUAG collaboration

PROPOSED WORKFLOW



SE/CE design for AM methodologies for Space systems

A Sapienza and RUAG collaboration



CASE-STUDY
MULTIFUNCTIONAL INTEGRATED S/C LATERAL PANEL

DESIGN APPROACH

QUANTITATIVE THERMAL ANALYSIS

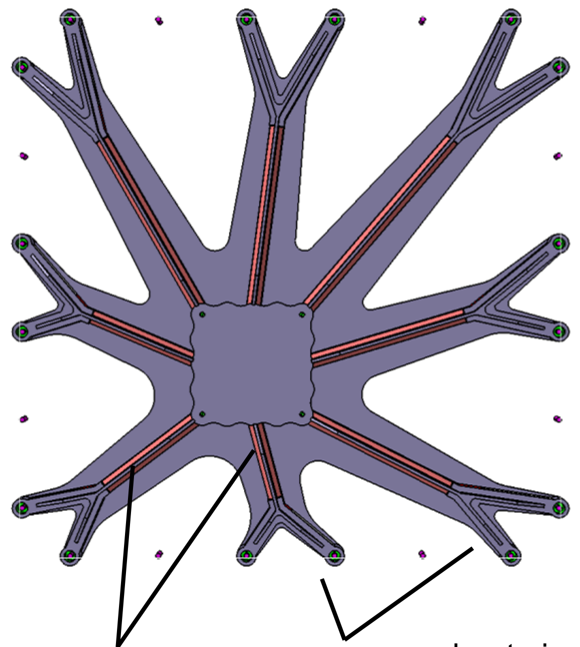
EQUIPMENT DEFINITION (TRADITIONAL HEAT PIPE)

QUANTITATIVE STRUCTURAL ANALYSIS (TOPOLOGY OPTIMIZATION)

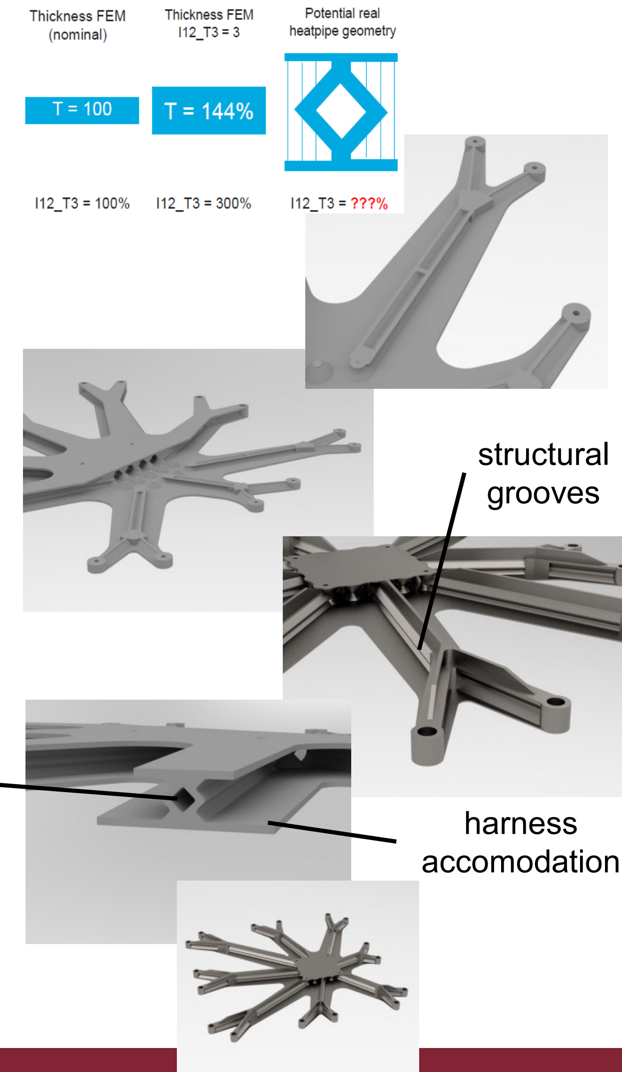
CUSTOMIZED TOPOLOGY CONFIGURATION

CONVERGENCE VERSUS A HEAT PIPES CUSTOMIZED CONFIGURATION (AS COMPROMISE OF BOTH ANALYSIS, only minor compromises were necessary))

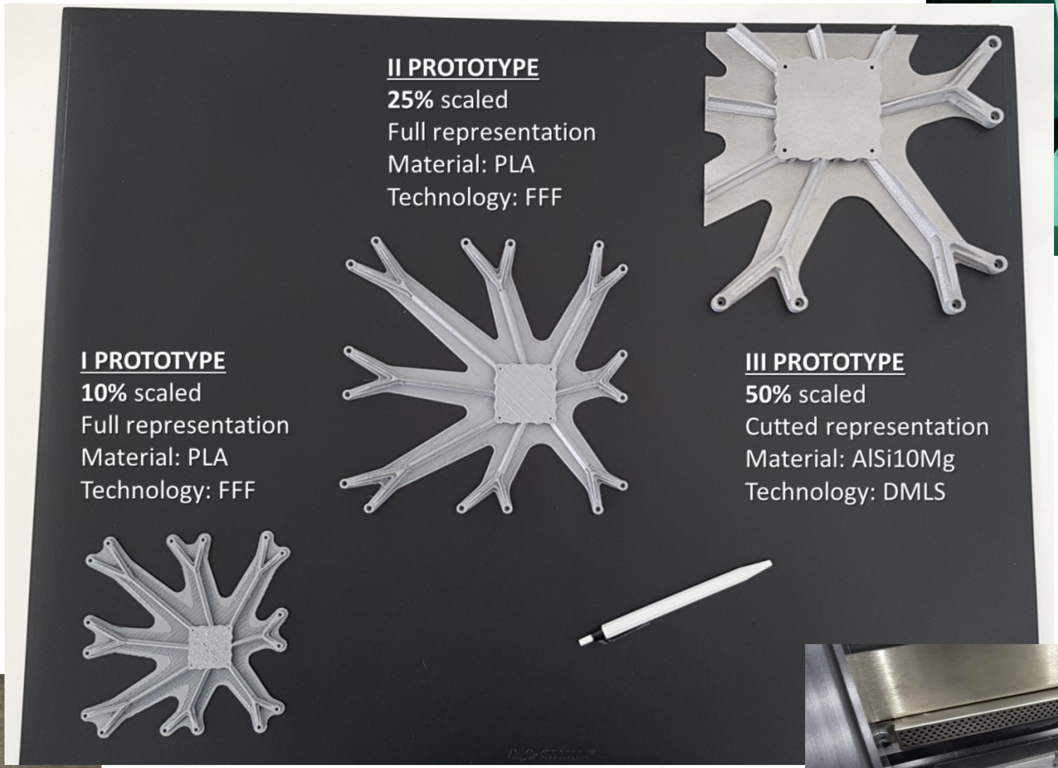
FINAL DESIGN

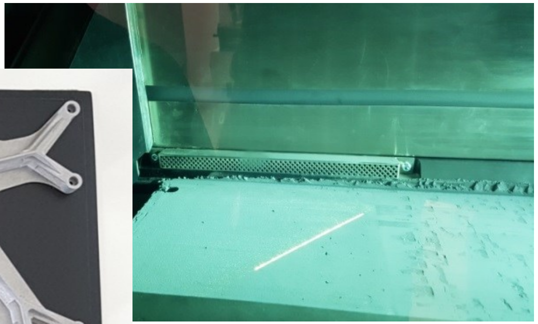


AM BIOMIMETIC RADIATIVE-STRUCTURAL PANEL



CASE-STUDY
MULTIFUNCTIONAL INTEGRATED S/C LATERAL PANEL





Remarks

- **Through some specific test cases of industrial relevance new methods, processes and tools implementing innovative design strategies and MAIT logics & techniques for the development of new space systems characterized by enhanced performance have been proposed**

- **Specific technological issues aiming to reduce the traditional schedule and cost of space missions have been considered**

  - integration of functions within the same equipment improving the traditional MAIT logics
  - design and manufacturing logics of harnessing smart embedded sensors
  - novel techniques for the connection points by using advanced manufacturing technologies and materials
  - new product life-cycle design methodologies by applying and improving the actual Systems and Concurrent Engineering approaches

- The **systemic and systematic Systems Engineering (SE) approach has been stressed as the enabling environment for the development of the design for additive manufacturing**

4. Additive Manufacturing for logistics: a cooperation with the Italian Air Force

Research motivations

- ❑ Development of a logical workflow from the geometrical acquisition to the validation and certification

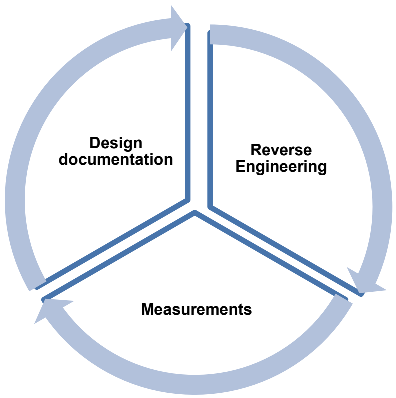
- ❑ Additive Manufacturing as a new possibility for logistics: obsolescence management and remote manufacturing

- ❑ Understanding of the limitations of the available documentation

Stand-by-compass MB-339: components objective of the study

Methodological Workflow

Geometrical acquisition



Digital Model → **Numerical Modelling**

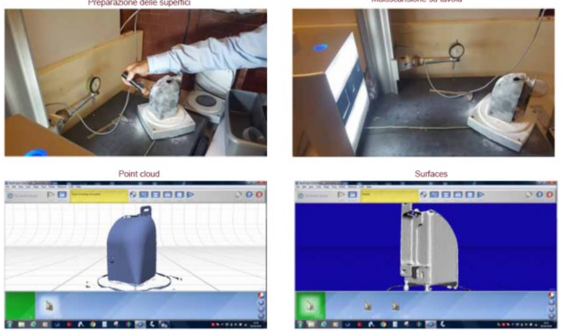
Prototyping (FDM)

Validation (FEM)

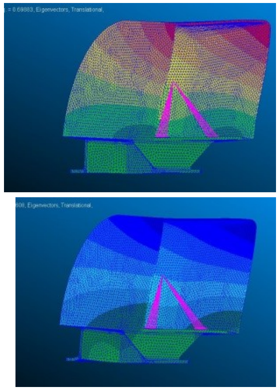
Realization (SLM) → **Flight Test**

Selective Laser Melting fabrication of a FT-339C compass case

3D model reconstruction through Reverse Engineering

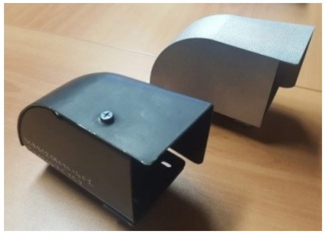


Dynamic simulation

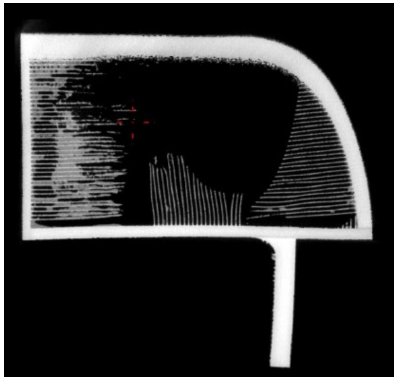


Flight test

Customized SLM process flow



Computerized tomography for defect control



Functional flight test

- Functional verification (assembling)
- Operative functional verification
- A sensorised flight is scheduled in 2019

Remarks

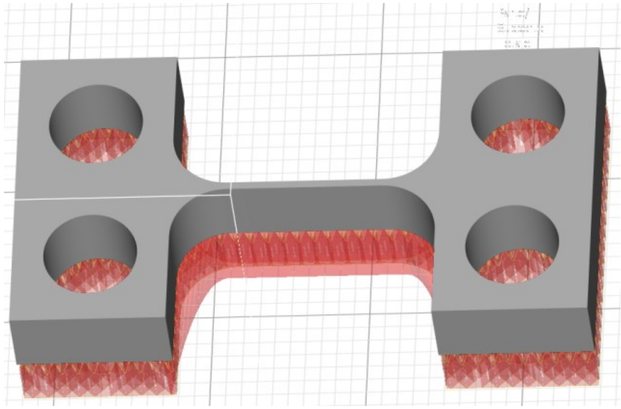
- **The role of Additive Manufacturing in a logistic chain has been explored**
- **The whole workflow from geometrical acquisition to production has been investigated**
- **All the limitations of the actual technical documentation have been stressed**
- **The realized components has been tested by a functional operative flight**
- **Further sensorised flights have been scheduled**

5. Realisation of a tiltometer (Physics Department + DIMA, Sapienza)

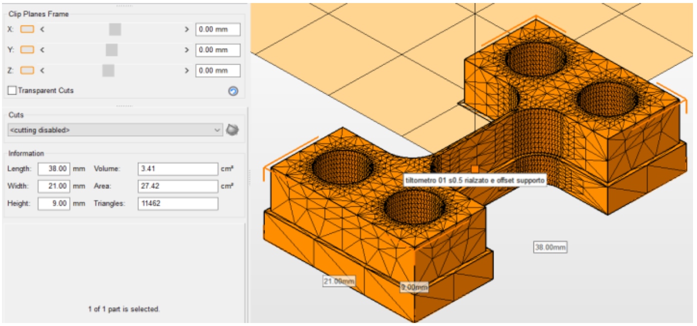
AM SLM manufacturing of a tiltometer (spring) (Prof.F. Ricci)

Fabrication of a deformable component for the measurement of damping properties

Specialized fabrication for thin wall component



Special support structures generation, novel process parameter set for improvement of surface properties



Checking and simulation

6. Optimization and development of microwave antennas (Physics Department + DIMA, Sapienza)

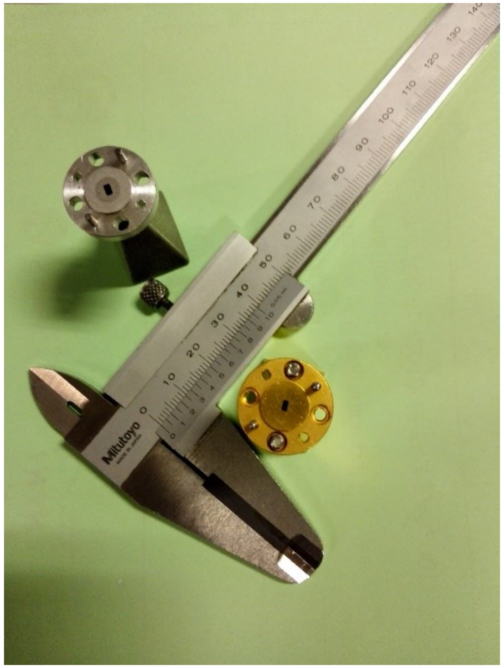
W-band antennas for ultra-wide band communications and radioastronomy

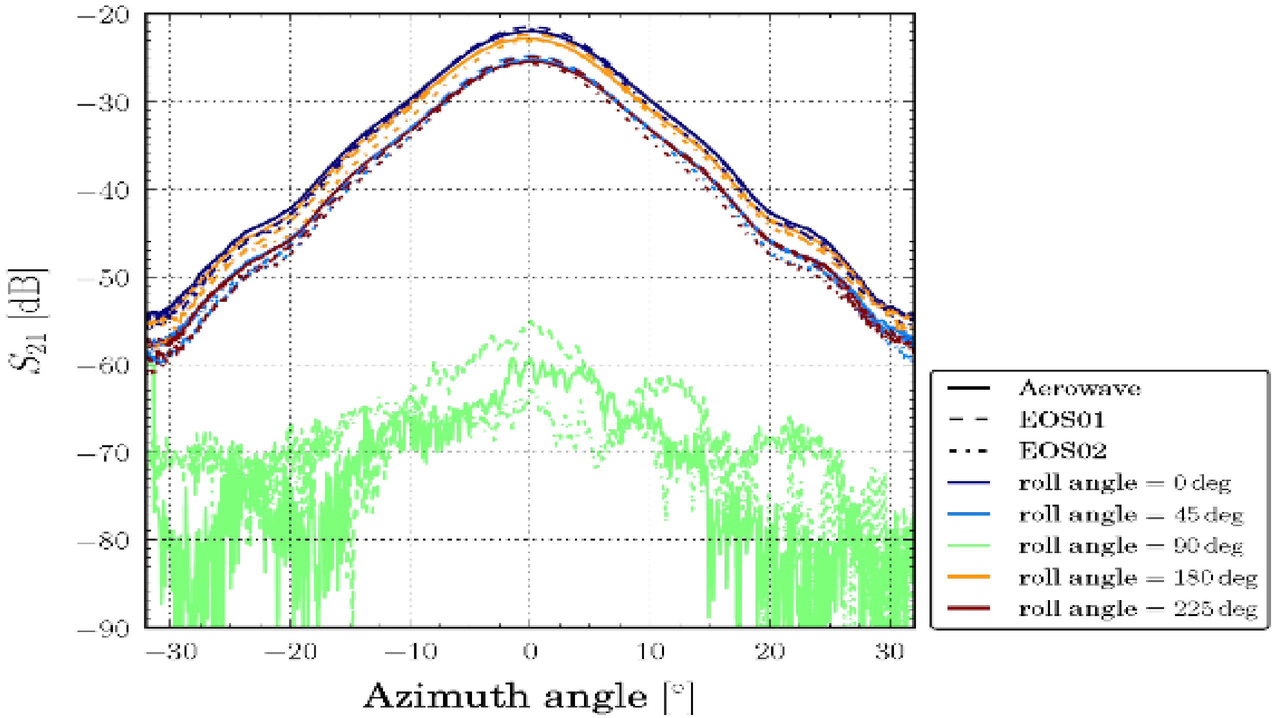
EOS

Reference

- **W-band (f=90 GHz, λ=3mm) antennas are widely used in radio-astronomy, communications,diagnostics.**
- **Usually made from copper and gold-plated. Expensive process, difficult to replicate in large arrays.**
- **We have optimized the production process for an aluminum antenna with the Sapienza EOS290.**
- **Surface roughness achieved <30μm before treatment**
- **Extensive performance measurements carried out with the VNA at the G31 lab.**
- **A commercial Cu antenna has been used as a reference for performance comparison.**

W-band Antenna Performance Tests





- **VNA measurements at 90 GHz of the beam pattern of the AM Al antennas, compared to the beam pattern of the reference antenna.**
- **Performance is nearly identical, at least for the main lobe and the first sidelobes.**
- **Far sidelobes being measured.**

The Sapienza ongoing experience with Additive Manufacturing
Conclusions

- **The multidisciplinary environment fosters all the research activities**

- **Collaboration with important players in aerospace sector: RUAG Space, Italian Air Force, Italian Space Agency**

- **All the projects are based on a system and systemic approach to the design for additive manufacturing**

- **Sapienza has shown an important capability in design and realization of components from different applications**

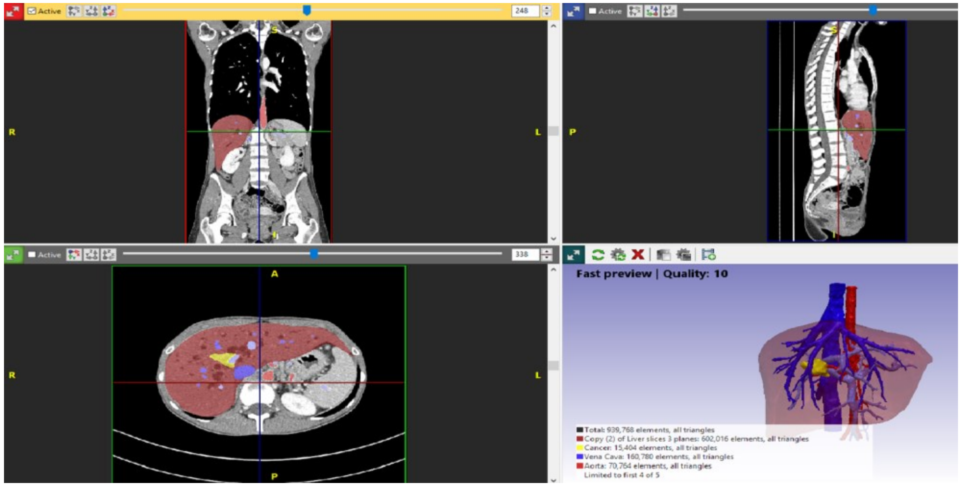
- **And an extra on bio-engineering…**

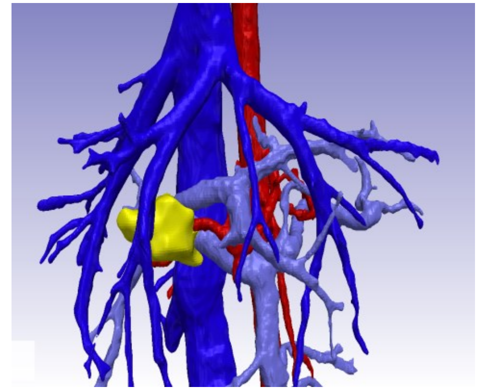
7. Additive Manufacturing for bio-engineering

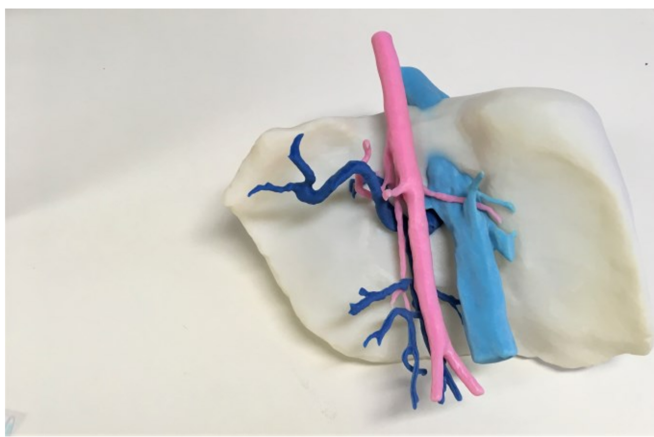
Dip. di Chirurgia Generale, Specialistica e Trapianti d'organo “Paride Stefanini”

AM for bio-engineering

Our Experience [I] : Process to create 3D model of liver, portal vein, aorta, vena cava and tumor from a CT scan







- 3D scaffold created by selecting liver boundary in 3 planes
- Veins and arteries were segmented using the specific Hounsfield units range for each area of interest
- Manually segmented on each individual slice to create a 3D structure
- Clear colours were assigned to the liver, portal vein, aorta, vena cava and tumor models

AM for bio-engineering

Our Experience [I] : Process to create 3D printed model of a human colon from a CT scan

Pre-Processing
1. DICOM elaboration
2. Section stack-up
3. 3D points filtering/smoothing
4. 3D surface tesselation
5. *Check and Healing*
6. Insert details

CAM
1. Select no. of parts and slicing directions
2. Define supports and filling
3. Define process parameters
4. *Check*
5. Print

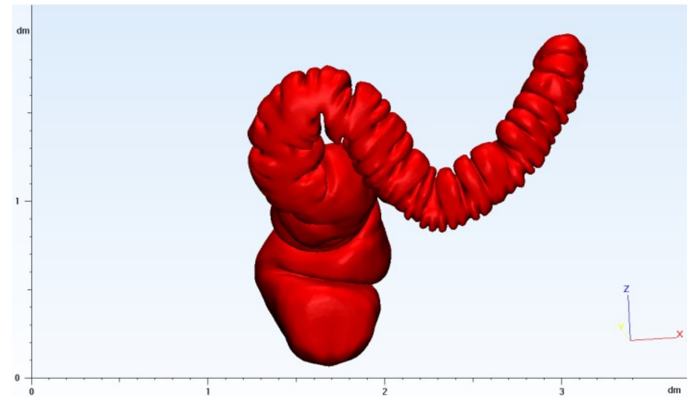
Post-Processing
1. Remove from basement
2. Remove supports
3. Smooth surfaces and glue

Source of Error

- DICOM segmentation
- Filtering/Smoothing

- Staircase effect due to slicing
- Shape variations due to cooling and support/filling
- Local defects due to process parameters

- Local inacurracy due to residues
- Joint with glue

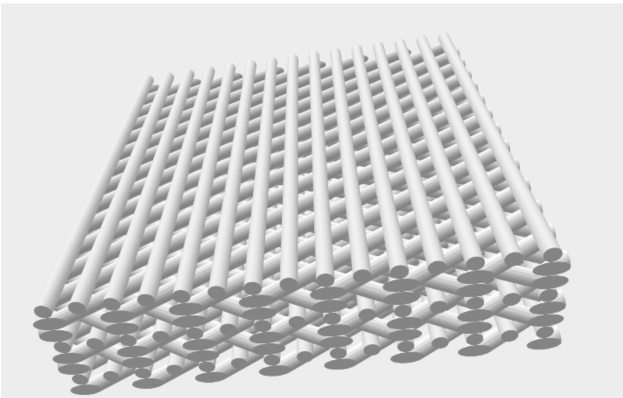


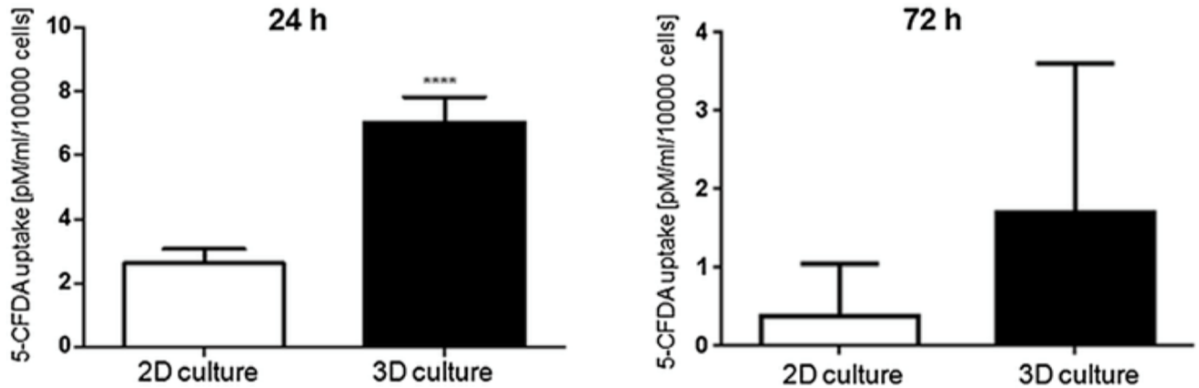
Main Issues:
- To guarantee compliance with the human associated to the CT scan (tumor structures)
- Surfaces accuracy
- Dimension and shape accuracy

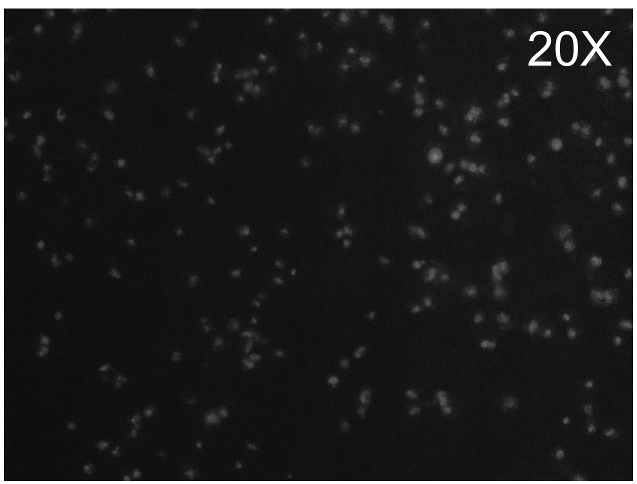
Digital Design of Medical Replicas via Desktop Systems: shape evaluation of colon parts
Journal of Healthcare Eng. by Gaudenzi et Alii

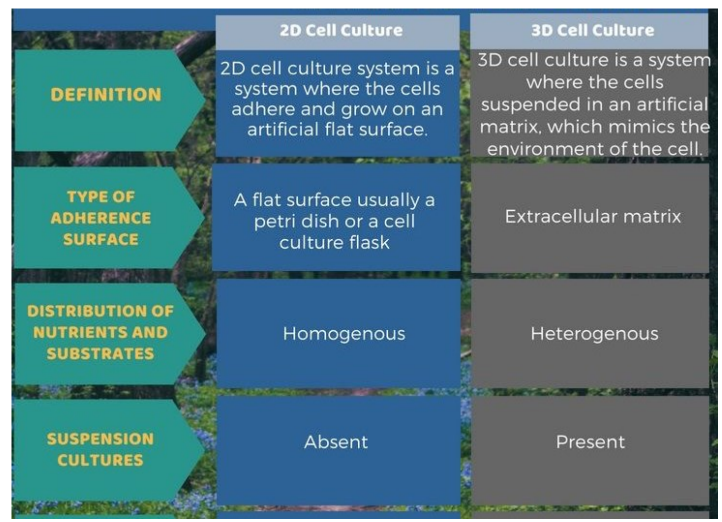
AM for bio-engineering

Our Experience [II]: Design and Print Polycarprolactone (PCL) scaffolds for Primary Hepatocyte cells.









	2D Cell Culture	3D Cell Culture
DEFINITION	2D cell culture system is a system where the cells adhere and grow on an artificial flat surface.	3D cell culture is a system where the cells suspended in an artificial matrix, which mimics the environment of the cell.
TYPE OF ADHERENCE SURFACE	A flat surface usually a petri dish or a cell culture flask	Extracellular matrix
DISTRIBUTION OF NUTRIENTS AND SUBSTRATES	Homogenous	Heterogenous
SUSPENSION CULTURES	Absent	Present

CONTATTI

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