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Additive Manufacturing Technologies
Técnicas de Fabrico Aditivo

Seminário Eng. Materiais

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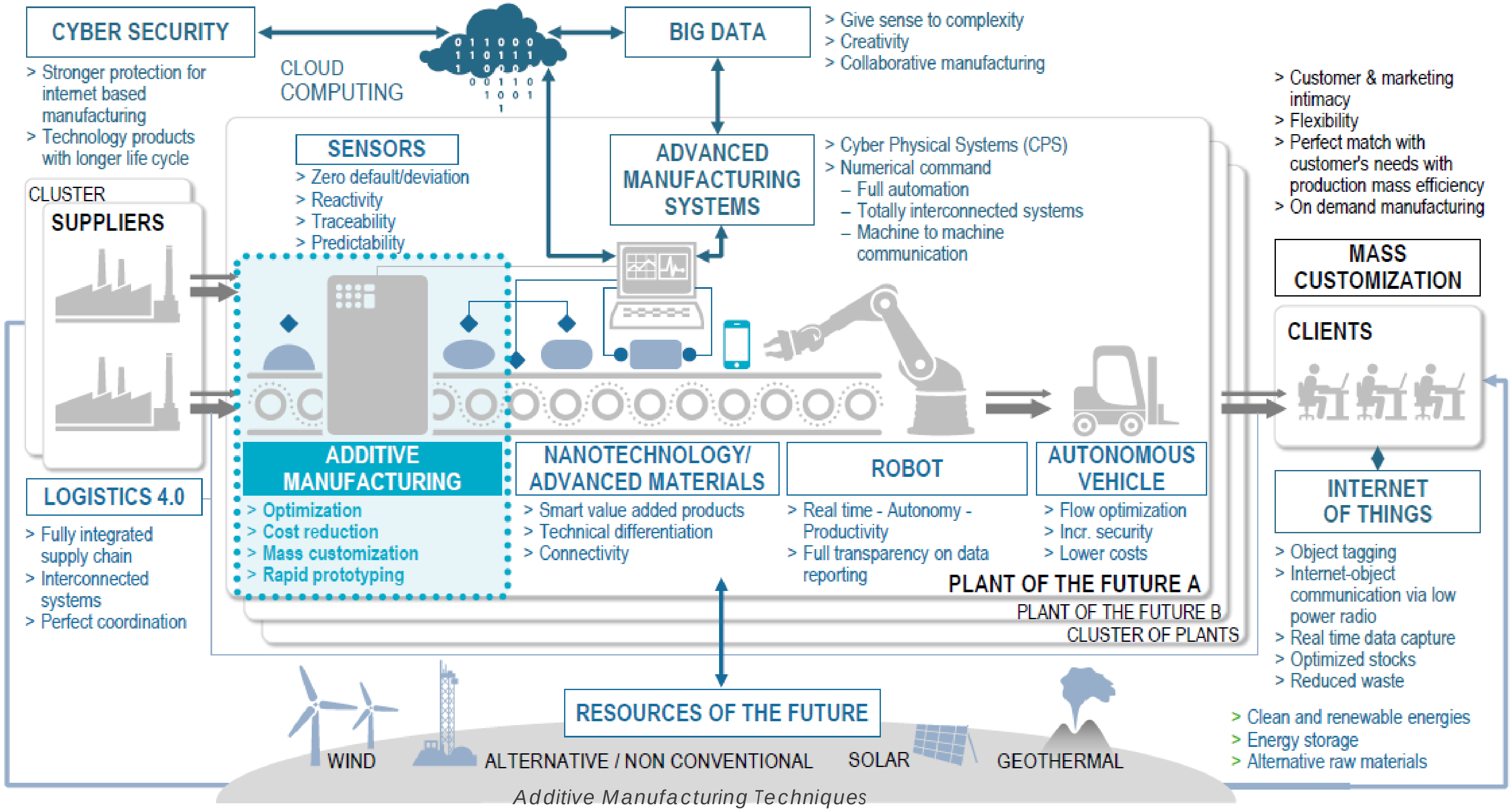
Additive Manufacturing

- This new technology evolved from rapid prototyping to a direct part manufacturing in the last years.
- It follows a direct digital manufacturing philosophy, from CAD to production.
- The concept is to build a part by adding layers upon layers in opposition to other subtractive or formative technologies.

Additive manufacturing is a core part of the Industry 4.0 technology ecosystem which is set to interconnect and disrupt business

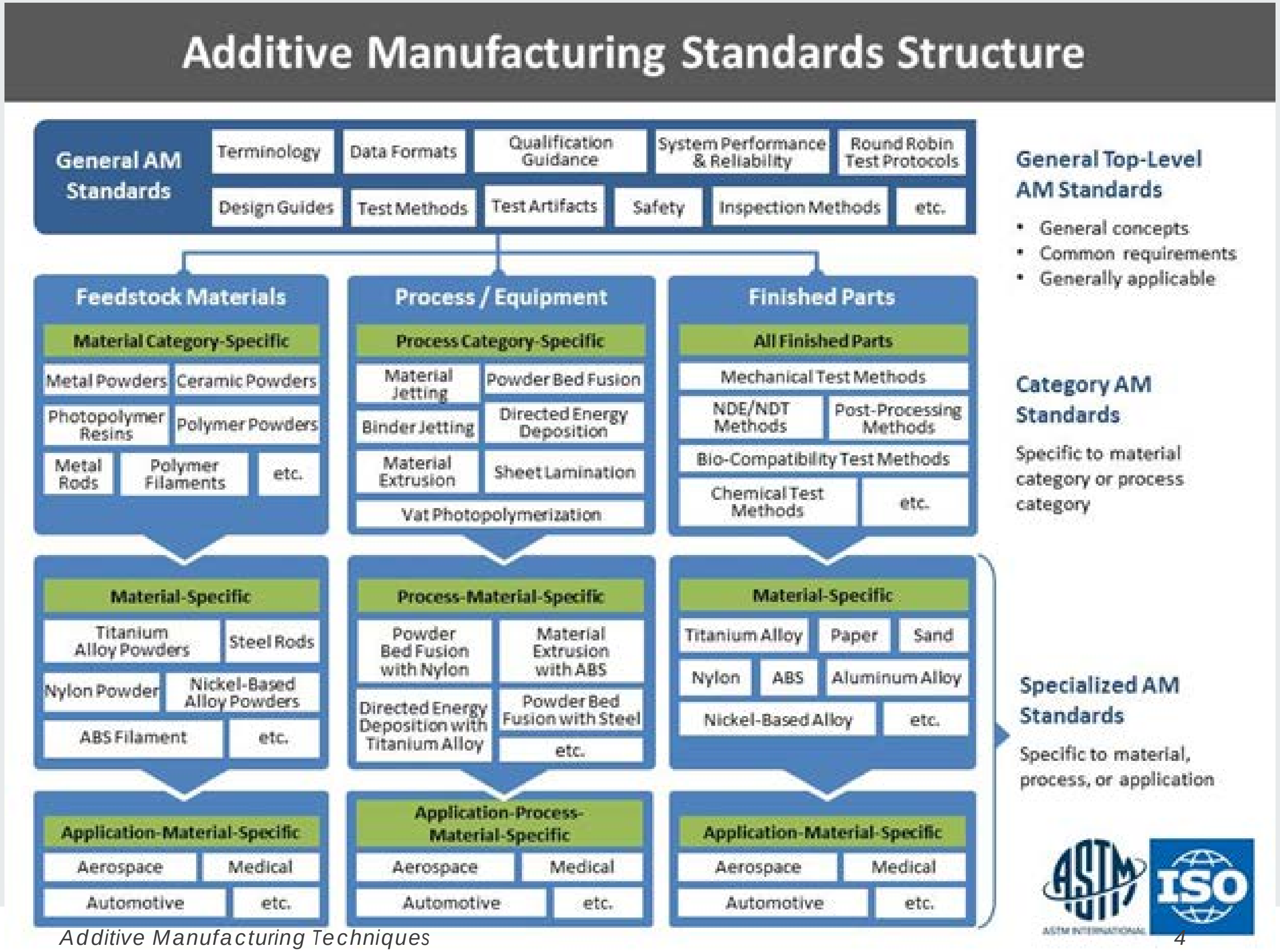
Industry 4.0 ecosystem

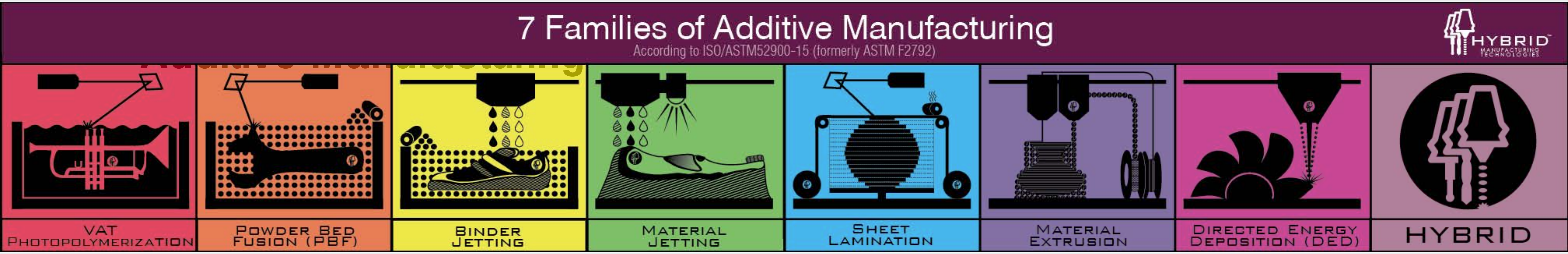


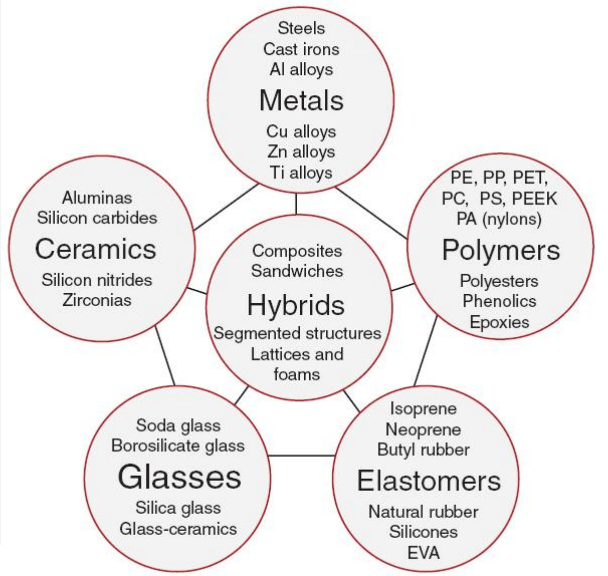
Source: Roland Berger

Additive Manufacturing

- ASTM and ISO started a common effort to develop standardization in this area.







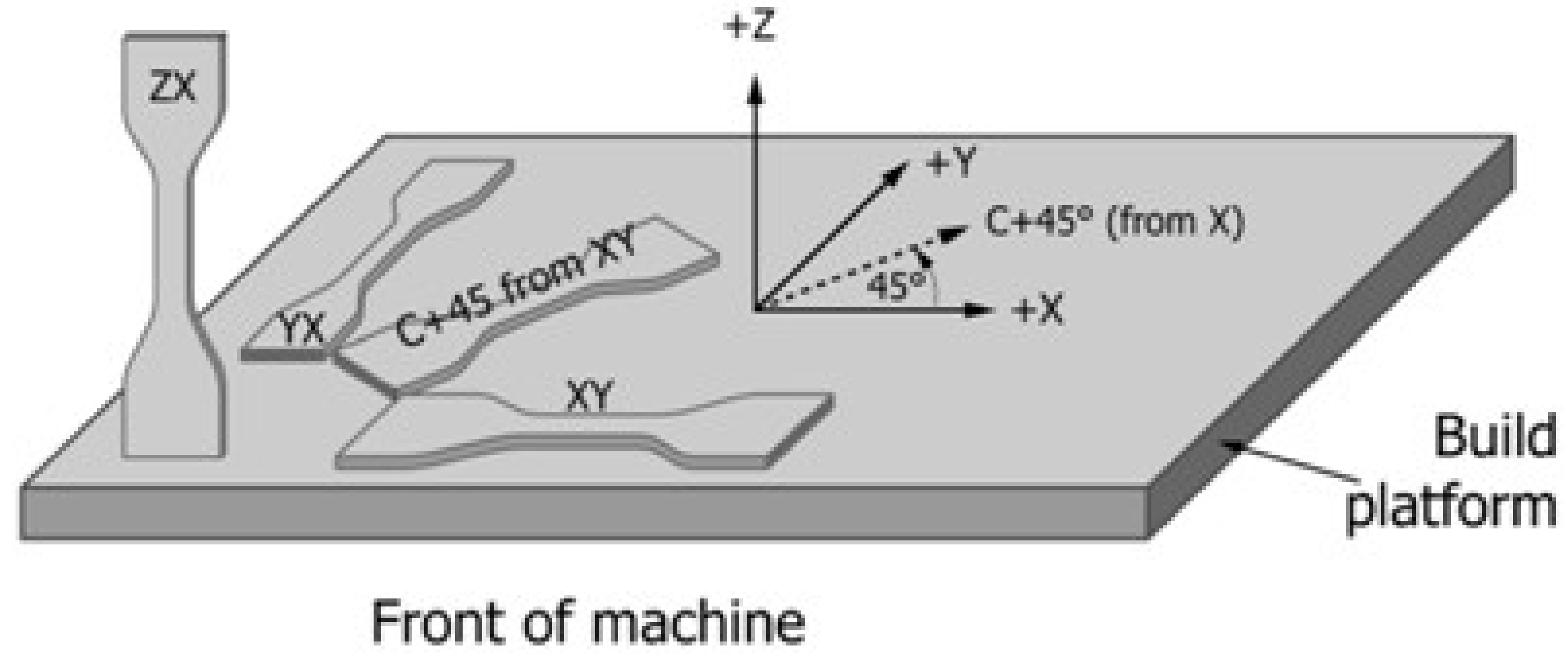
Powder

Wire

Sheet

Additive Manufacturing

- Orthotropic nature of layered deposition



Roadblocks

- “Lack of confidence in materials, processes and parts”
- “Redesign parts for 3D printing changes the game”
- “Quality control and quality assessment”
- “Post processing is complicated”
- “Nesting parts is important”

Advantages

- Complex parts for free
- Mass customization
- Integrated assembly
- Reverse engineering for maintenance
- Agility in product development

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Challenges and Opportunities

- AM technologies are established.
- Cost savings, time to market savings and weight savings are “normal”.
- Part redesign and part integration changes the game.
- Complexity is for free.
- Direct digital manufacturing with reduced manual intervention.
- Simulation is in the early stages (in composites).
- Still expensive (specially for universities).
- Post processing is a bottleneck.
- Highly specialized engineering.
- Improving the envelope of production (still small parts).

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In conclusion,

- Additive manufacturing technologies will become conventional.
- They will not substitute all other technologies.
- How to integrate AM in organizations is a challenge for every organization.
- One needs technical and economic models and highly specialized engineering

Additive Manufacturing Technologies
Técnicas de Fabrico Aditivo

Historical review – from rapid prototyping to AM

Relógio Ribeiro
Marco Leite

Introduction

- Additive Manufacturing (AM) technology came about as a result of developments in a variety of different technology sectors
- As a matter of fact, additive techniques appeared before written history
  – Placing a stone over another to build something is and additive process

Introduction

- Modern AM come into being as a result of the availability of tools that made the dream of physical embodiment of idealized objects possible
- This possibility, in turn, opened new avenues for the idealization of new objects (design)
- Initially conceived for prototyping, Am is increasingly becoming an end-product manufacturing technology

Setting up the stage

- Like many other technologies, AM came about as a result of the development of computers as serviceable tools due to:
  - Processing power
  - Graphics capability
  - Machine control
- Also, hardware was useless to AM until software also developed:
  - CAD
  - CAM
  - Machine control
- Mostly, the need to obtain a prototype in a short time was the initial main driver

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Setting up the stage

- Lasers:
  - high intensity and highly collimated beam of energy that can be moved very quickly in a controlled manner
- Printing Technologies
  - droplet deposition can now be used to print photocurable and molten resins as well as binders for powder systems
- Programmable Logic Controllers
  - Designing and building industrial machinery, like AM machines, is much easier using building blocks based around modern PLCs for coordinating and controlling the various steps in the machine process

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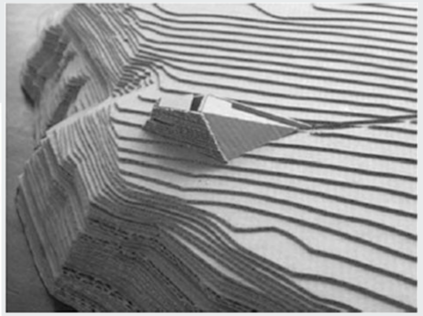
Setting up the stage

- Materials
  - Materials have been tuned to suit more closely the operating parameters of the different processes and to provide better output parts
- The Use of Layers
  - Almost every AM technology builds parts using layers of material added together



The 3 ages of AM

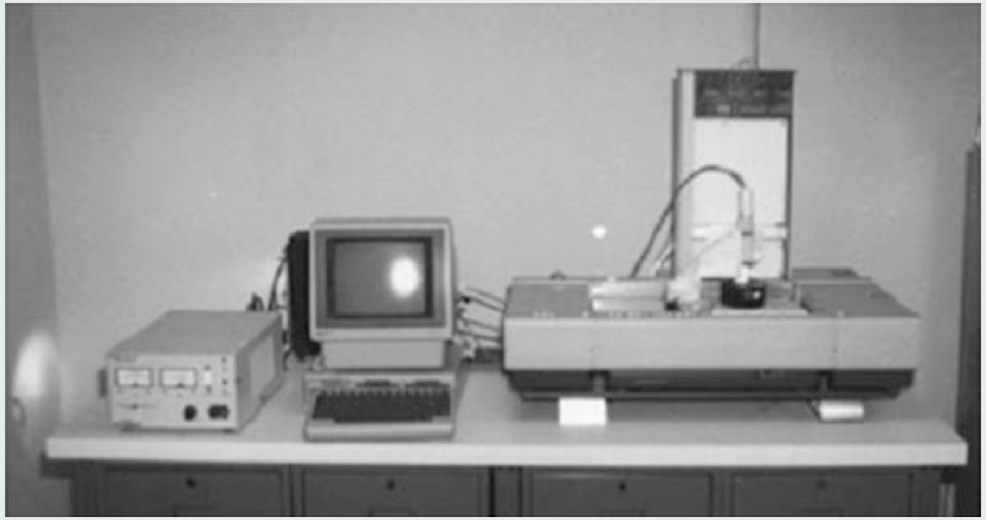
- The Infancy Stage: 1981 to 1999
- The Adolescence Stage: 1999 to 2010
- The Adult Stage: 2011 to the present day

The conception

- 1974: **David Edward Hugh Jones**, in the UK and under the pen name of **Daedalus**, laid out the concept in the Ariadne pages in New Scientist magazine, a section that commented on the lighter side of science and technology where plausible but impractical and humorous inventions were presented.
- 1980-81: **Kodama** in Japan, invented two additive methods for fabricating three-dimensional plastic models with photo-hardening thermoset polymer. Patents refused due to failure to file the full patent requirements on time
- **Murutani** in Japan, **Le Méhauté, de Witte & André**, in France and **Masters** and **Hull**, in the USA, filled patents, all in the same year, for variants of the stereolithography concept

The first machine

– **Hull** had its patent accepted in 1986 and founded the 3D Systems company, the first to commercialize AM apparatus. He also set the STL (STereoLithography) file format, now widely used in automated manufacture



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Further developments, new companies, new processes

- 1986 filled patents:
  - **Deckard & Beaman** invented and developed SLS - Selective Laser Sintering and founded DTM (1987-2001, merged with 3D Systems)
- 1989 patents:
  - **Crump** patented the FDM process, forming the Stratasys Company
  - **Sachs et al**, a group at MIT, patented the 3D Printing (3DP) process developed it up to 1993 and licensed the technology to different companies
- 1994:
  - **Sanders** developed the ink-jet technology and Object Company used this technique form in 2001

Some past failures later succeeded... and some not

- **Feygin** patented LOM - Laminated Object Manufacture developed by Helisys (1991 – 2000, failed)
  - 5 companies are using it nowadays
- **Pomerantz et al** patented SGC - Solid Ground Curing developed by Cubital (1991 – 2000, failed)
  - No one uses it presently
- **Masters** patent for BPM - Ballistic Particle Manufacturing used a 5-axis mechanism to direct wax droplets onto a substrate
  - Although no company currently uses such an approach for polymers, similar 5-axis deposition schemes are being used for depositing metal and composites

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The world of AM after the patents

- Explosion of material extrusion vendors and systems since the first FDM patents expired in the early 2010s

- Patents in the stereolithography, laser sintering, and LOM areas are expiring (or have already expired) and may lead to a proliferation of technologies, processes, machines, and companies

Forecasting AM: Rapid Prototyping Develops into Direct Digital Manufacturing

- A dream: to forget constrains about how to manufacture and focus on functionality

- Customization: a product tailored for each customer

- Home manufacturing of final consumer products

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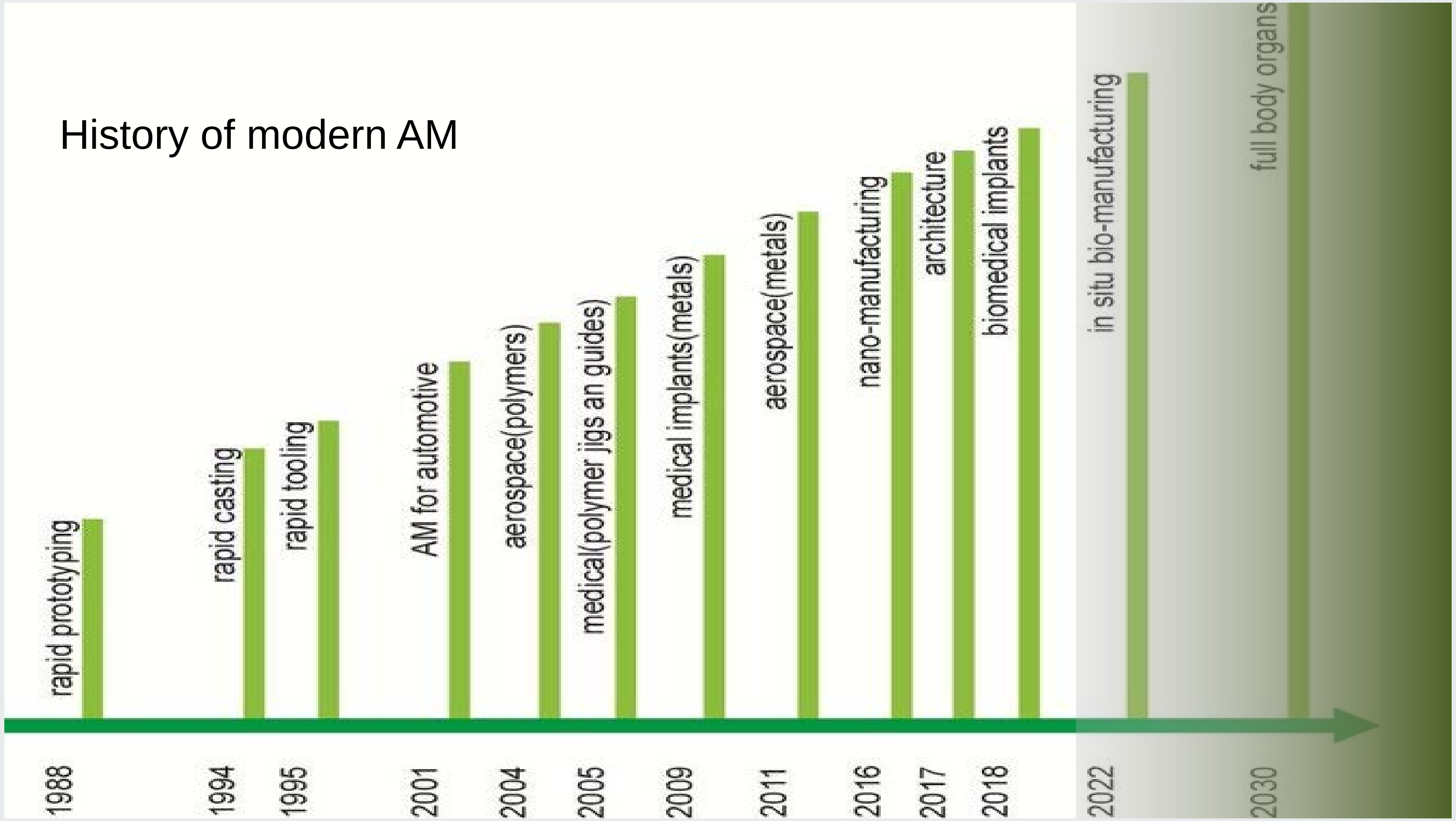
Timeline

Pre-history of modern AM

Development of computers as serviceable tools for real-time tasks



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How it works

Relógio Ribeiro
Marco Leite

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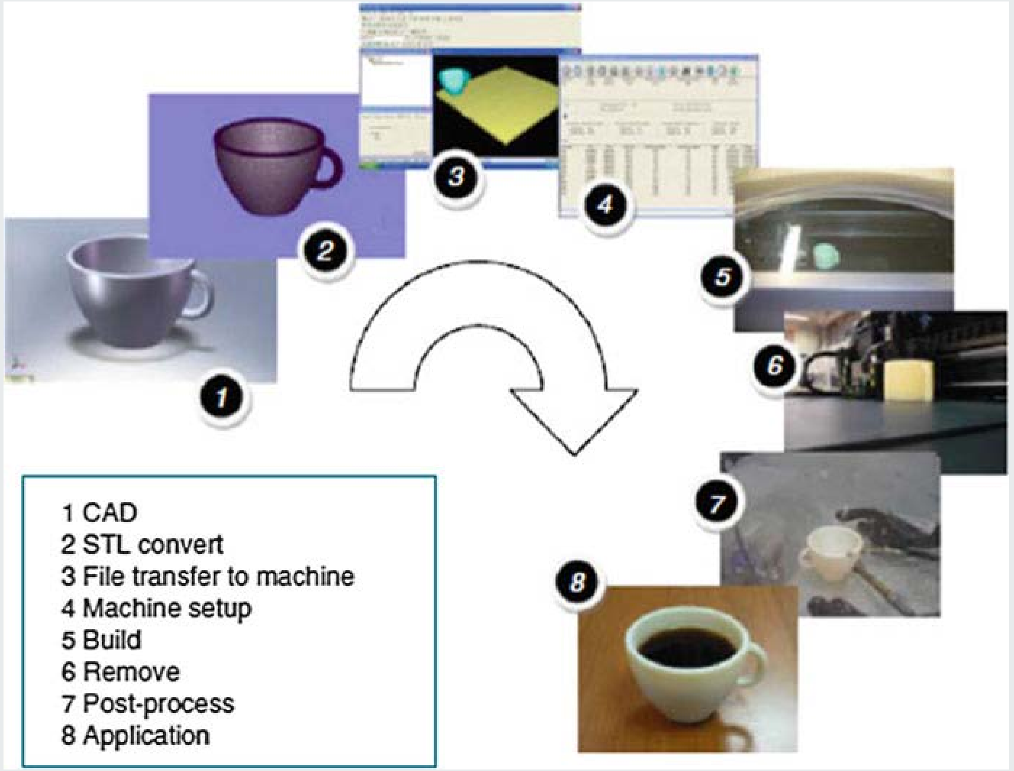
Introduction

- The key to how AM works is that parts are made by adding material
  - All currently available techniques add material in layers
    - In the future, this may cease to be true
  - each layer is a thin cross-section of the part derived from the original CAD data
  - each layer must have a finite thickness
  - the resulting part will be an approximation of the original data

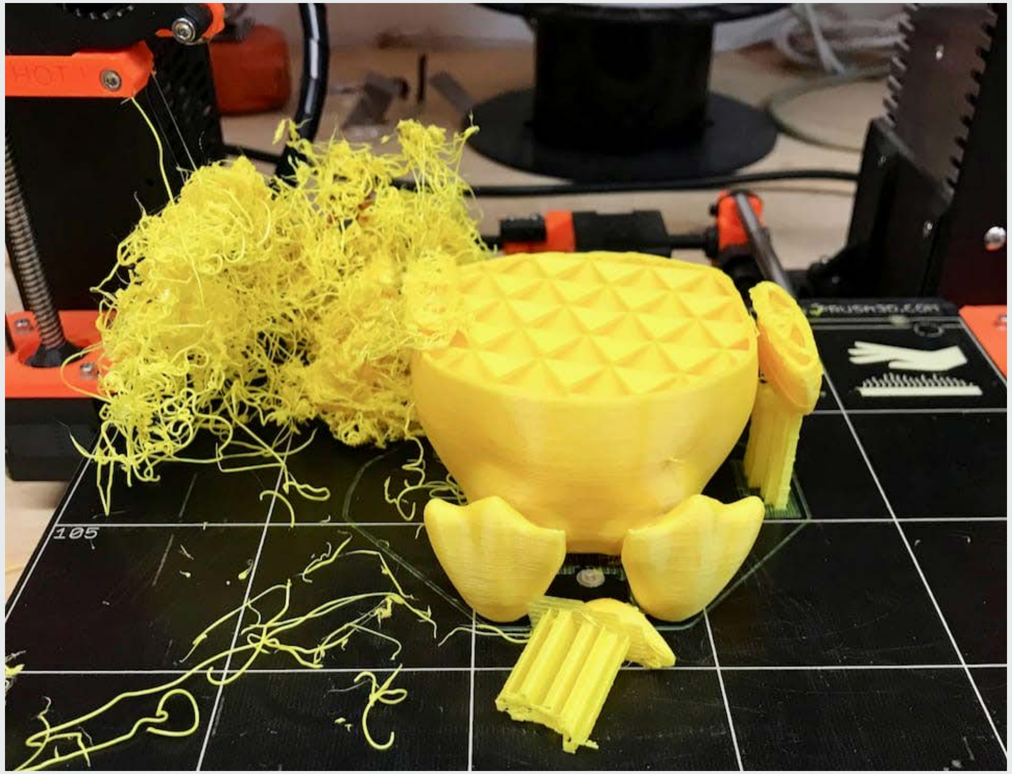
AM steps

- Step 1: CAD
- Step 2: Conversion to STL
- Step 3: Transfer to AM Machine and STL File Manipulation
- Step 4: Machine Setup
- Step 5: **Build**
- Step 6: Removal
- Step 7: Post-processing
- Step 8: Application



Build

- Building the part is mainly an automated process and the machine can largely carry on without supervision
- But its success is very dependent on:
  - The previous steps
  - The material health
  - The environment (temperature, vibrations, etc.)



Building processes: classification

- There are several ways to classify AM technologies, such as:
  - Baseline technology
    - Lasers
    - Printer technology
    - Extrusion technology
    - etc.
  - Type of raw material
    - Liquid Polymer
    - Discrete Particle Systems
    - Molten Material Systems
    - Solid Sheet Systems

Joint ISO TC/261 - ASTM F 42 Group

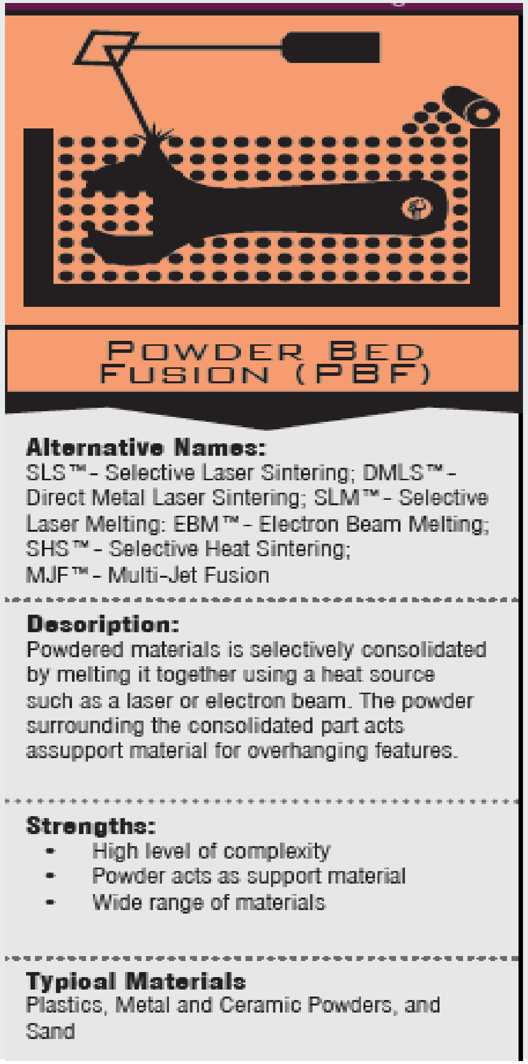
- Vat photopolymerization
- Powder bed fusion
- Binder jetting
- Material jetting
- Sheet lamination
- Material extrusion
- Directed energy deposition
- Hybrid

Vat photopolymerization

- Processes that utilize a liquid photopolymer that is contained in a vat and processed by selectively delivering energy to cure specific regions of a part cross-section.

Powder bed fusion

- Processes that utilize a container filled with powder that is processed selectively using an energy source, most commonly a scanning laser or electron beam.

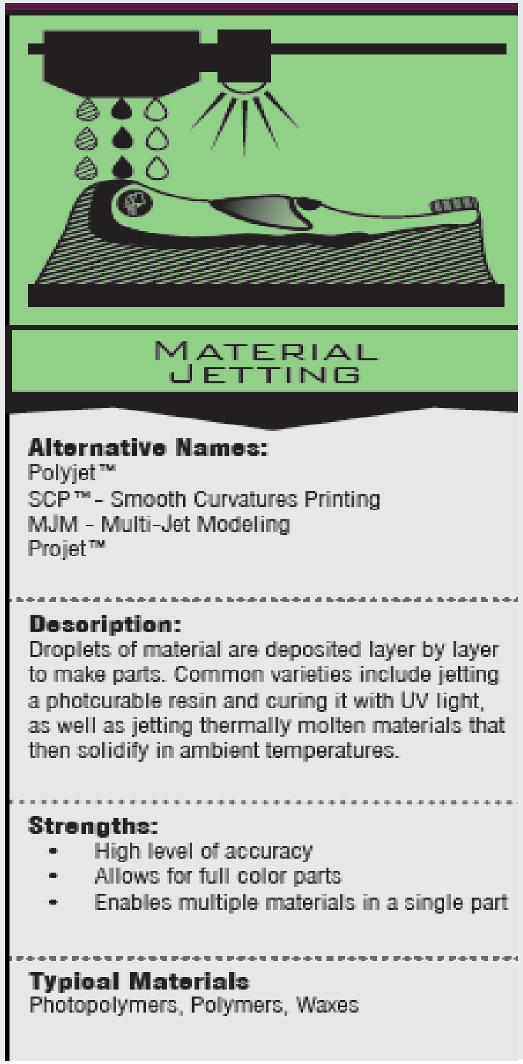


Binder jetting

- Processes where a binder is printed into a powder bed in order to form part cross-sections.

Material jetting

- Ink-jet printing processes.

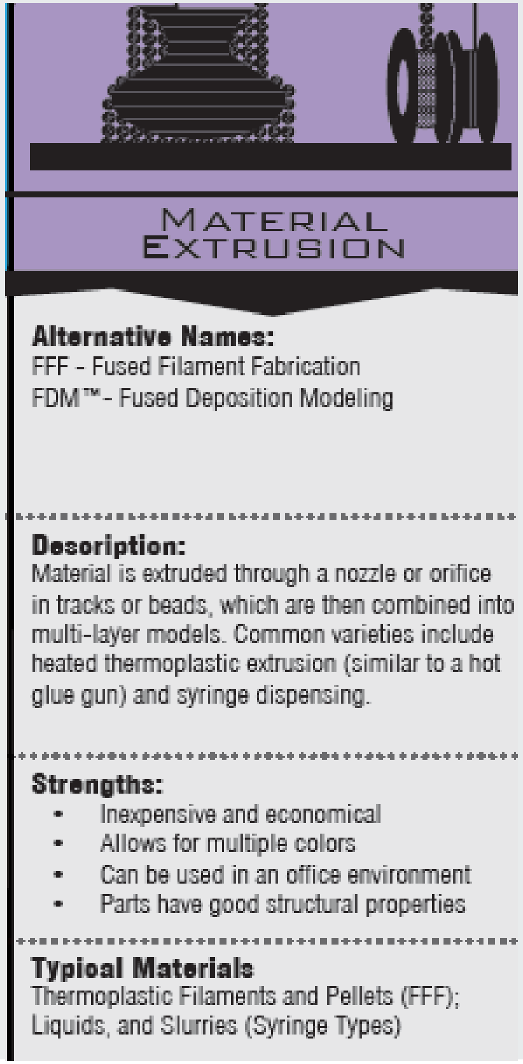


Sheet lamination

- Processes that deposit a layer of material at a time, where the material is in sheet form.

Material extrusion

- Processes that deposit a material by extruding it through a nozzle, typically while scanning the nozzle in a pattern that produces a part cross-section.



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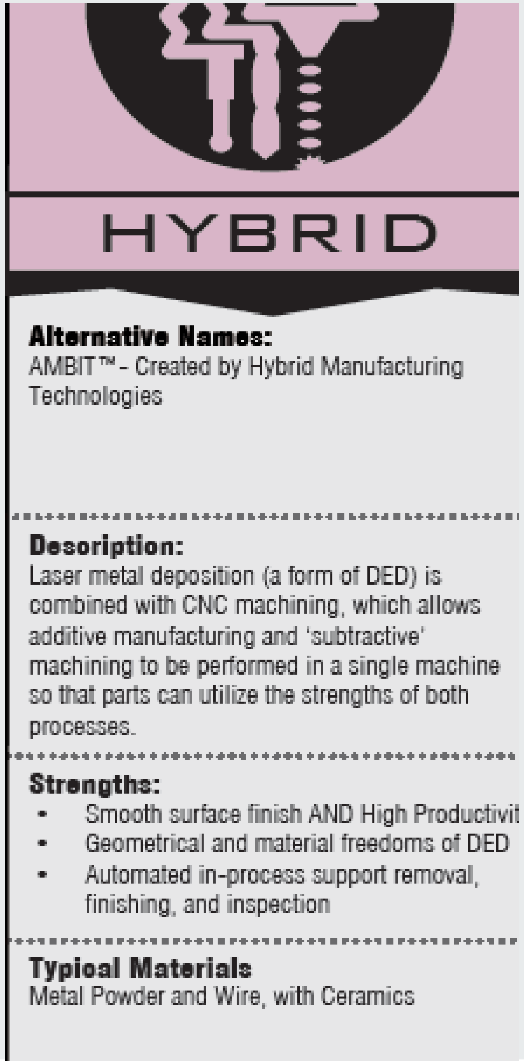
Directed energy deposition

- Processes that simultaneously deposit a material (usually powder or wire) and provide energy to process that material through a single deposition device.

Hybrid

- Processes that include additive and subtractive phases.
- Both additive and subtractive phases occur in the same machine
- Usually requires 5 axis machines



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Técnicas de Fabrico Aditivo

Reverse engineering, 3D scanning and 3D printing

Relógio Ribeiro
Marco Leite

Reverse engineering

- Parts of this handout was retrieved from FORMLABS WHITE PAPER.
  - https://formlabs.com/eu/blog/how-to-use-3d-scanning-and-3d-printing-for-reverse-engineering/

How Does 3D Scanning Complement 3D Printing?

- A 3D scanner expands the capabilities of a 3D printer, allowing you to replicate the shape of almost any object.
- Together, the two technologies create a powerful, digital workflow that can simplify and sophisticate processes in a range of industries.
- The output from a 3D scanner is a mesh of triangles representing the surface of an object at a real-world scale.
- In some cases, the scan can be used directly to replicate objects without any CAD work.

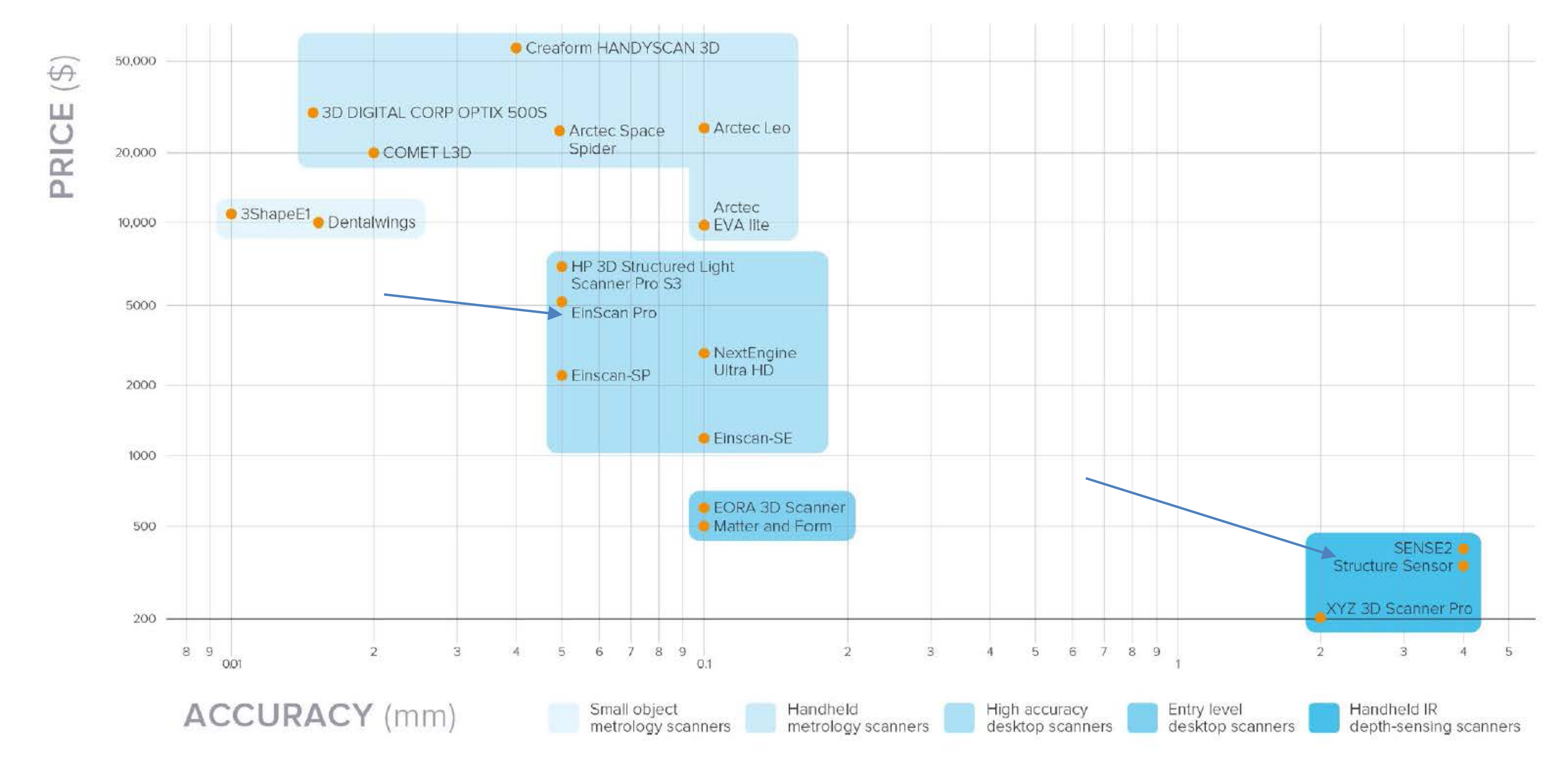
3D scanning for ergonomics and prosthetics

- A hybrid workflow can also be powerful, where solid CAD models are combined with scanned models.
- Customized ergonomics capture a physical imprint of a part of the human body, and integrate them with a mechanical design.

3D scanning for metrology

- 3D scanners are also valuable tools for measuring the accuracy of manufactured objects.
- Many factors affect 3D print accuracy, and metrology-grade 3D scanners provide a clear picture of how a material performs for demanding applications.

What scanner to select



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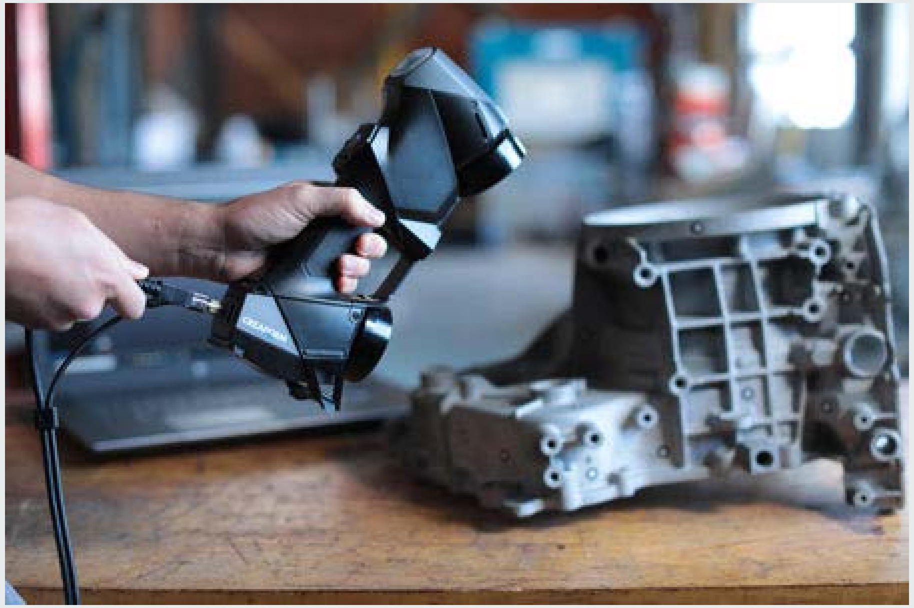
Examples of high end and low cost systems

- Handyscan 3D

EinScan Pro

DIY



Combination with your 3D printer

- With accuracy in the range of 0.1 mm or better, laser and structured light scanners are a good fit alongside high resolution 3D printers.

- You do not need the best, unless your printer is also the best.

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Combination with your 3D printer

- Both structured light and laser scanners use projected light and an offset camera to triangulate points on a scan object.
- A laser scanner projects laser lines on the object, while structured light projects a focused grid from a digital projector.
- Structured light can achieve higher accuracy than laser scanning due to the noise caused by laser speckle patterns.

About resolution

- Besides the accuracy between measured points and their actual location, scanners also vary in terms of resolution, which is the distance between captured points at a given scan distance.
- In general, structured light scanning provides the best resolution and accuracy, typically slightly higher than laser scanning.
- For some artistic use cases for 3D scanning you may need a lot of detail, while overall accuracy is less important—especially if you don't require your part to fit precisely with other parts in an assembly.
- In these cases photogrammetry is an excellent low-cost option to explore.

Photogrammetry

- **Photogrammetry** uses a large set of photographs that are automatically analysed to create a 3D model. Under ideal conditions, object detail captured by photogrammetry can rival a laser scanner.
- Overall, geometric accuracy is usually worse due to the lack of fixed reference points for the camera's position.
- Nonetheless, photogrammetry does not require any equipment besides a digital camera and software, which makes it an attractive option.

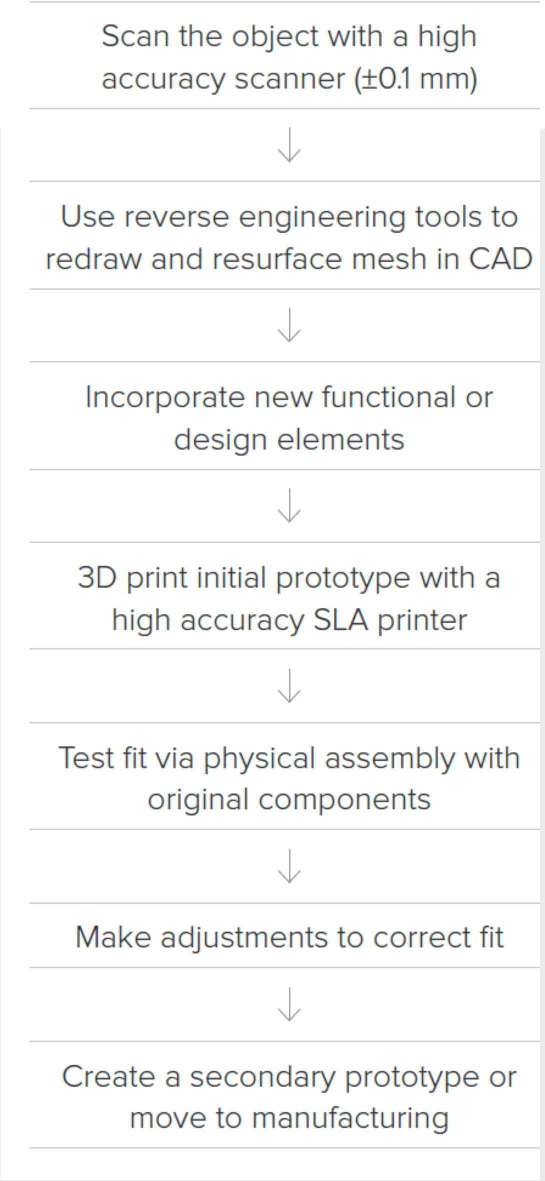
Reverse engineering and 3D printing

- Reverse engineering is a method of reconstructing a design from an existing object, so that the design can be modified or adapted. In practice, this means measuring an object (usually with a 3D scanner) and converting the 3D scan into a solid format that is compatible with CAD modeling tools.

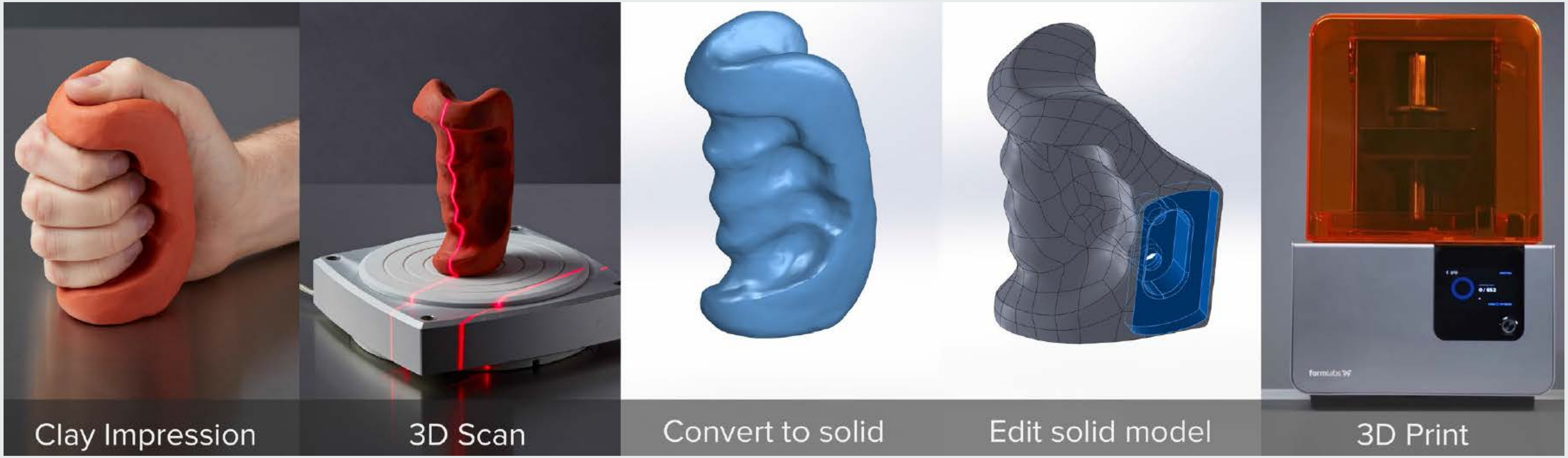
- For 3D printing, reverse engineering is a method to increase confidence in your design and can be an intermediate step when creating custom organic shapes.

Reverse engineering and 3D printing

- Workflow



Reverse engineering and 3D printing for ergonomics



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Técnicas de Fabrico Aditivo

Current research at IST

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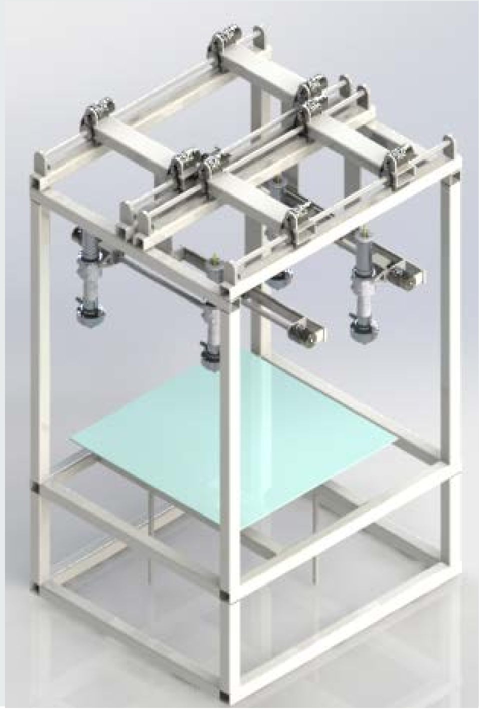
Marco Leite

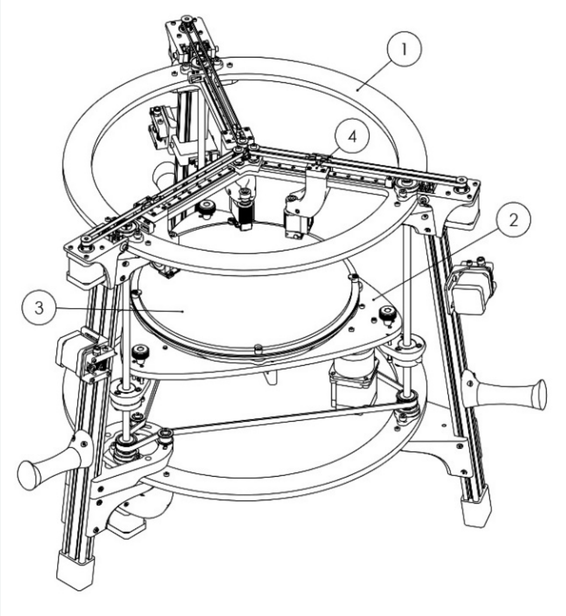
New equipment for AM

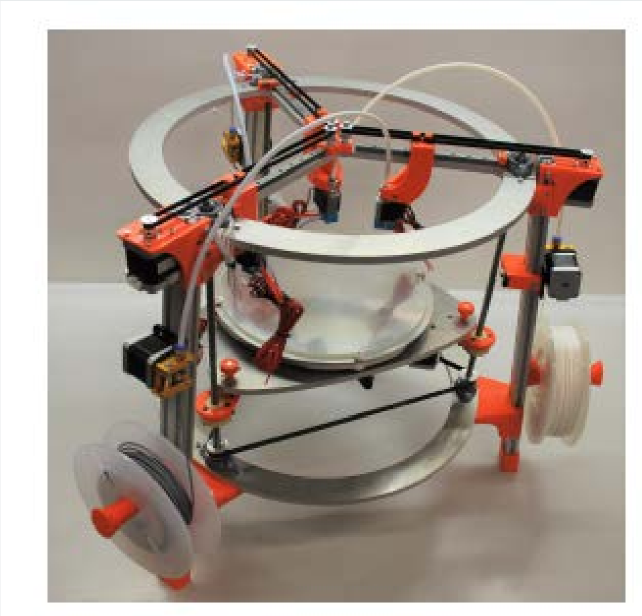
- Impressora 3D para fabrico de peças de grandes dimensões em metal., João Miguel Henriques Silva



New equipment for AM

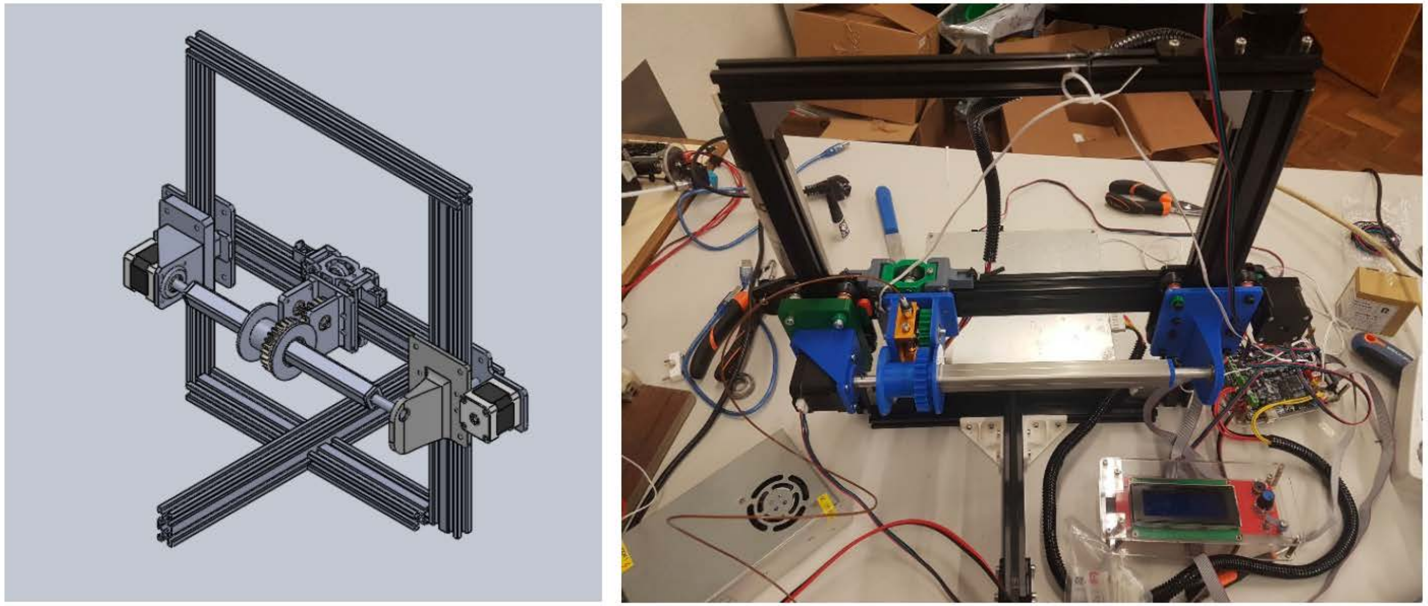
- Impressora 3D para fabrico de peças de grandes dimensões em metal, Diogo Pereira de Brito Líbano Monteiro





New equipment for AM

- Concepção e desenvolvimento de um sistema de alimentação para máquinas FDM, Miguel de Abreu Paramos de Carvalho



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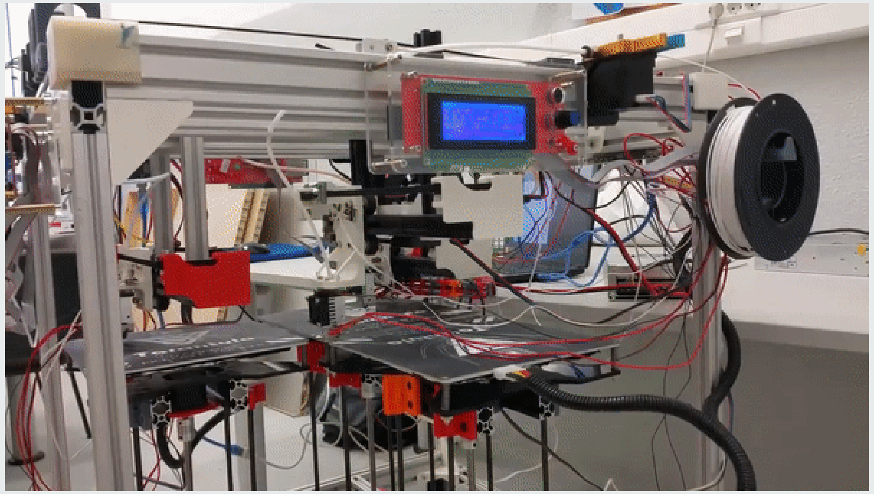
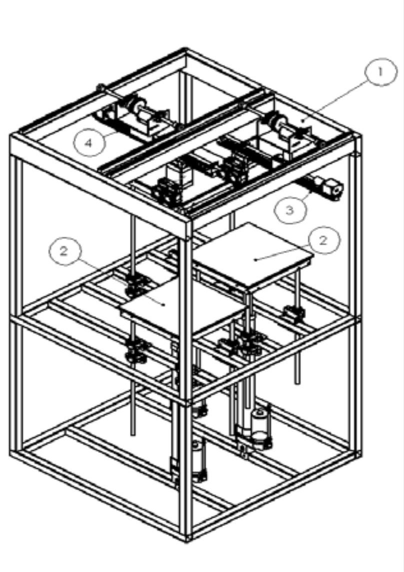
New equipment for AM

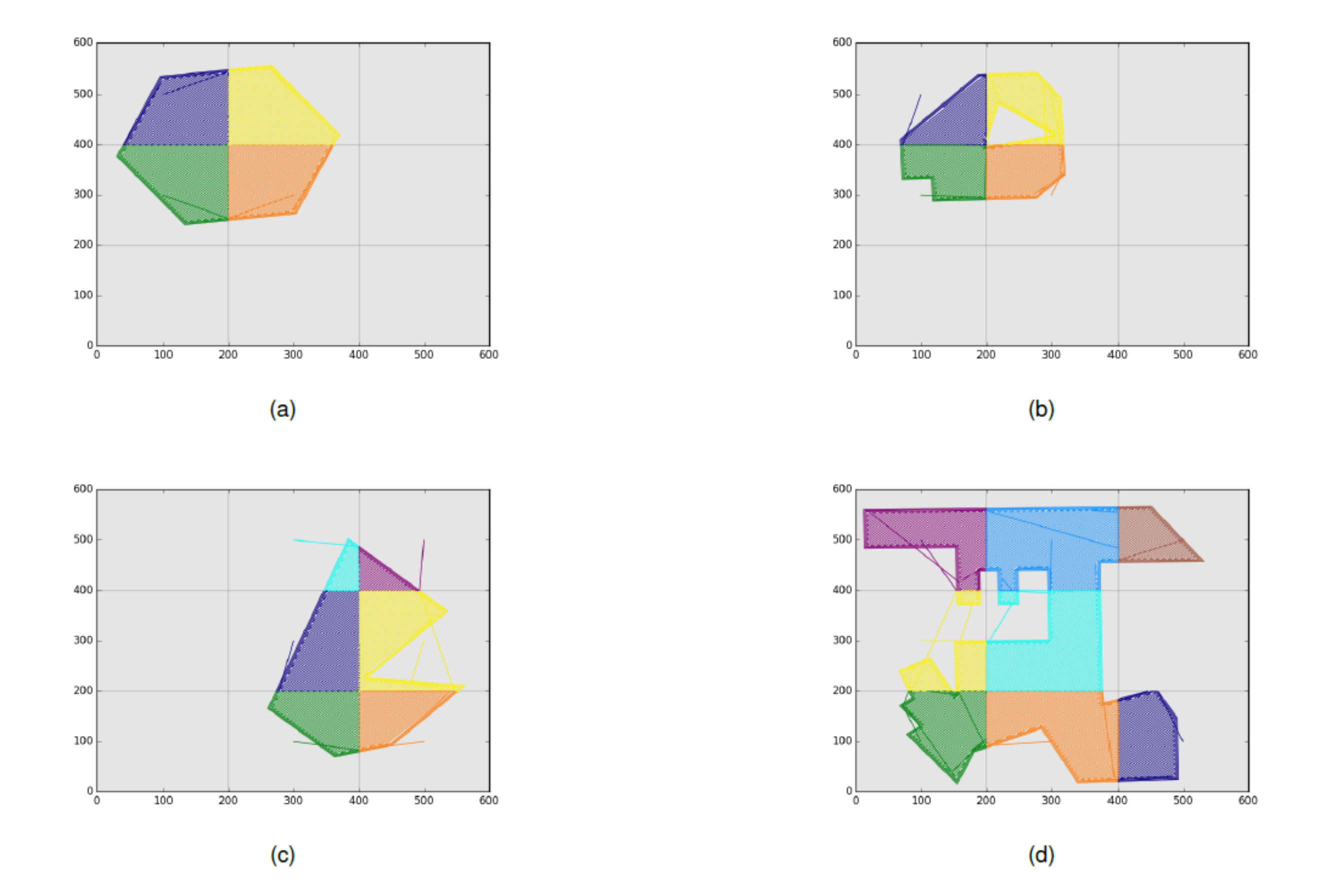
- Concepção, desenvolvimento e projecto de um sistema modular de fabrico aditivo, João Francisco de Aragão Barros e Alvim Boto
- Design and development of a modular fused deposition modelling apparatus, Manuel de Figueiredo Cravo Relvas Sardinha





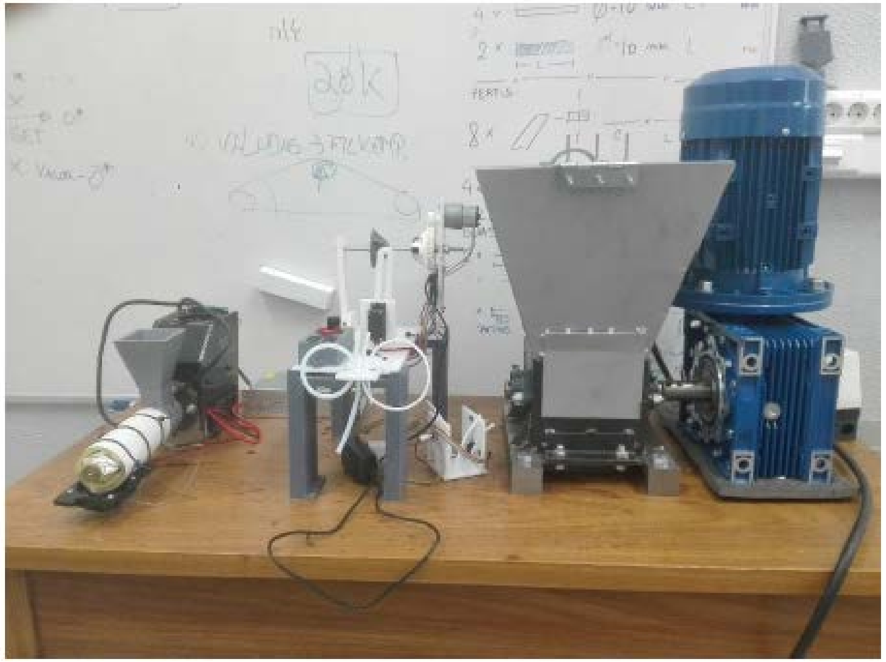
New equipment for AM

- Tool-path Generation for a Multiple Independent Print Head System for Fused Deposition Modeling, Nuno André Mateus de Marques Frutuoso



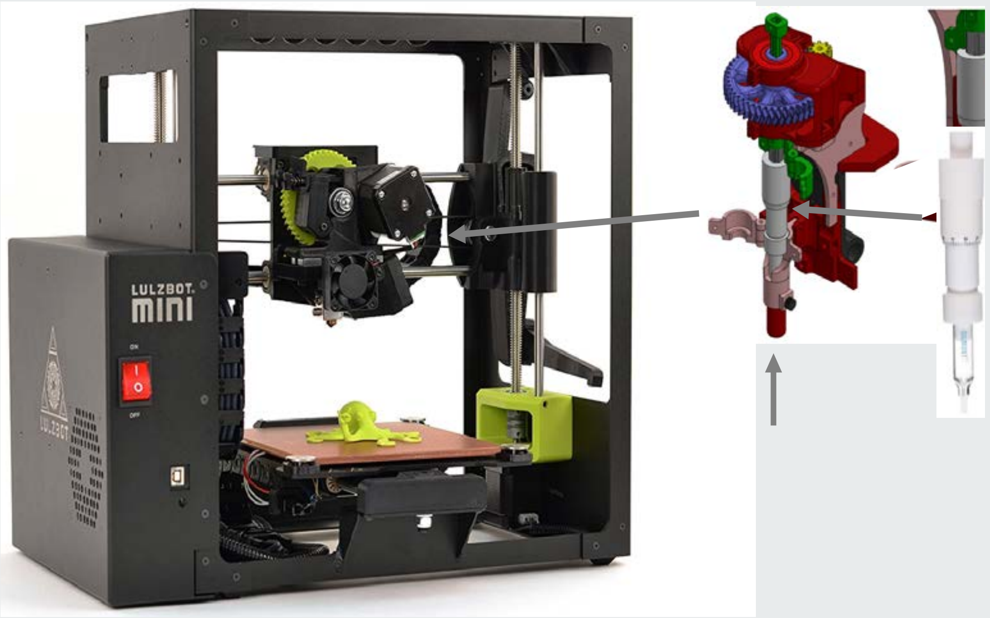
New equipment for AM

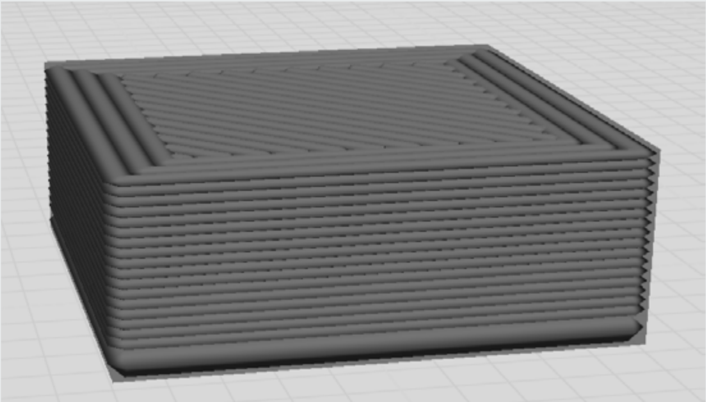
- Reciclador de polímeros utilizados em impressoras 3D, Diogo Miguel Valeriano de Oliveira

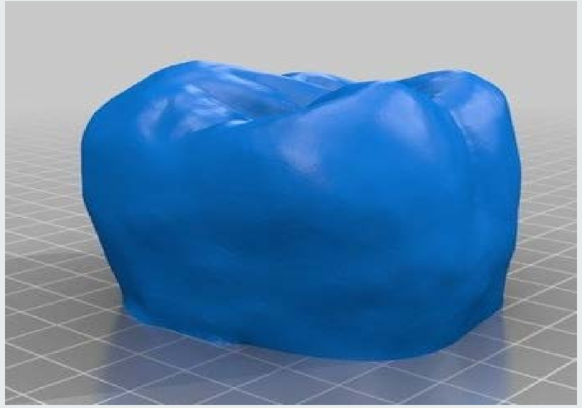


New equipment for AM

- 3D printing system for ceramic materials: design and testing of an experimental rig., Armand Yahnn Fabrice Chefdor

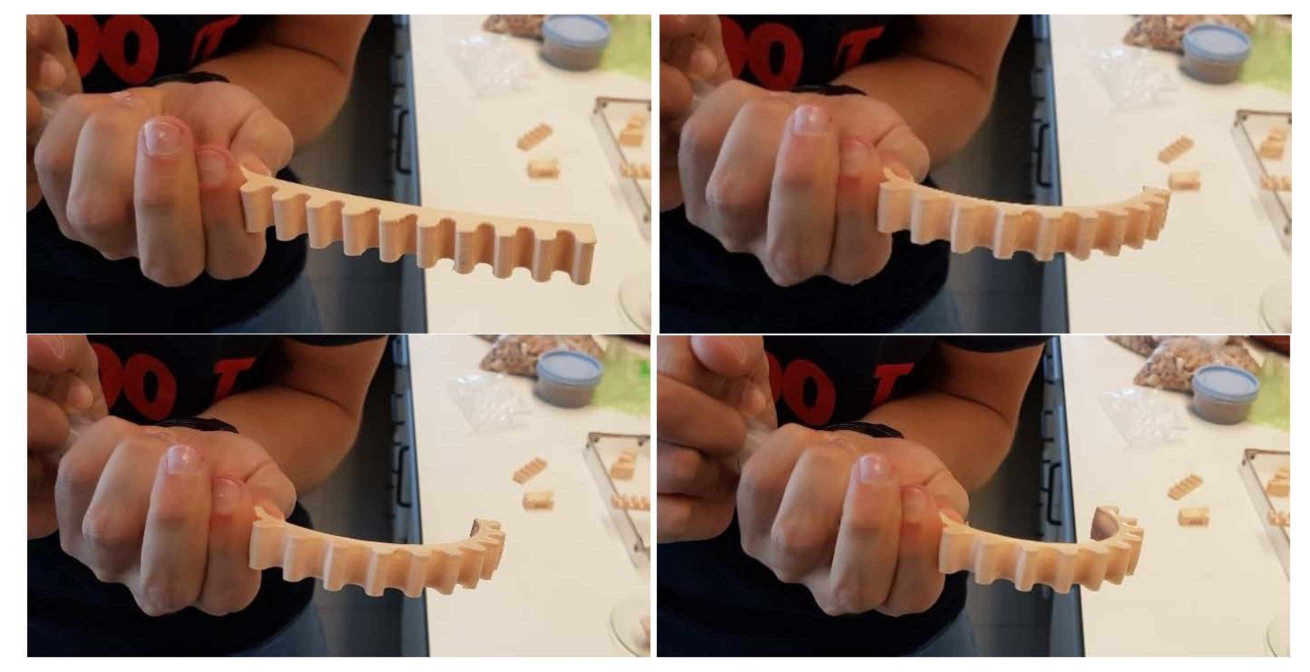






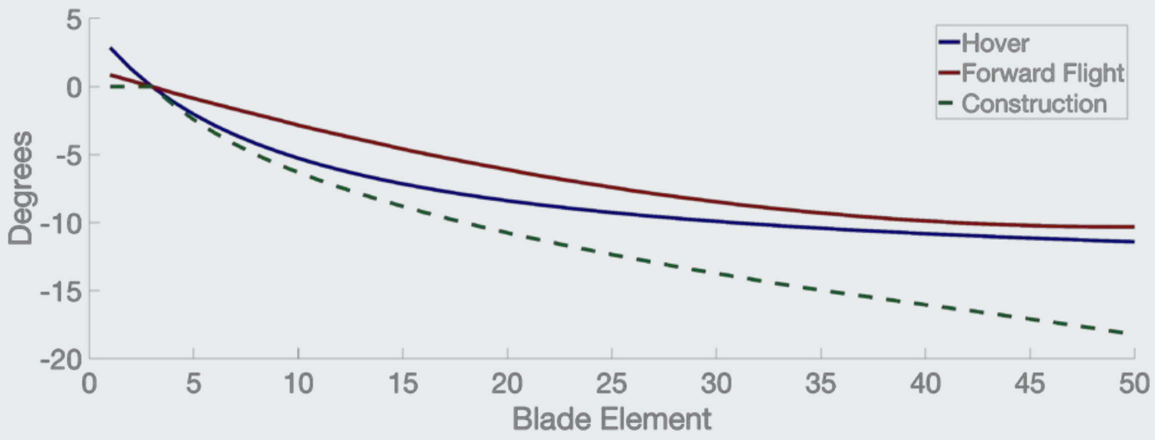
New applications for AM

- Actuador Pneumático para Manipulação Humana por Fabrico Aditivo , Miguel Oliveira Meirinho Lopes Nabais



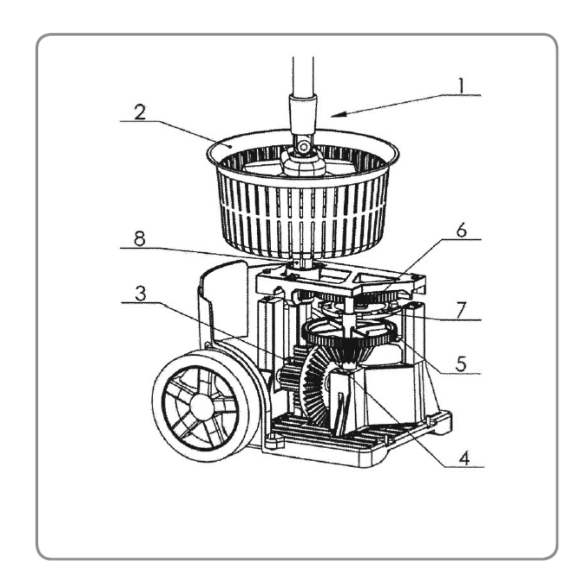
New applications for AM

- Smart structure design using additive manufacturing to emulate a functionally graded material, Diogo Rui Alves da Costa Vasconcelos Nascimento



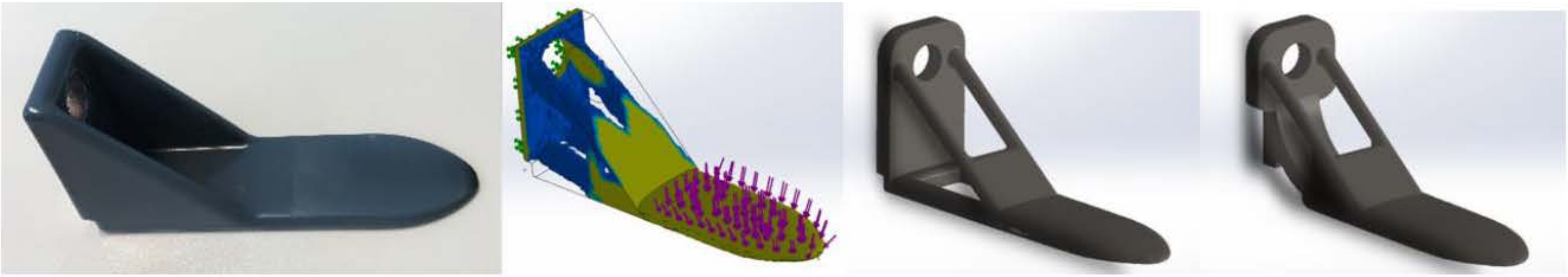
Prototyping new products

- Desenvolvimento de sistema de secagem automático para esfregonas – Fapil , Diogo Lopes Viana Nunes
- Desenvolvimento de uma mochila multifuncional, Manuel Sá Teixeira de Freitas Bastos



AM in Maintenance, repair and overhaul

- Aplicação de técnicas de fabrico aditivo em componentes de substituição – Caso de estudo Navigator , Catarina Alexandra da Costa Moiçó



AM for biomedical applications

- Design and Development of an Upper Limb Prosthesis (inglês), Vanessa Mariana Alves Carvalho Lopes

AM for biomedical applications

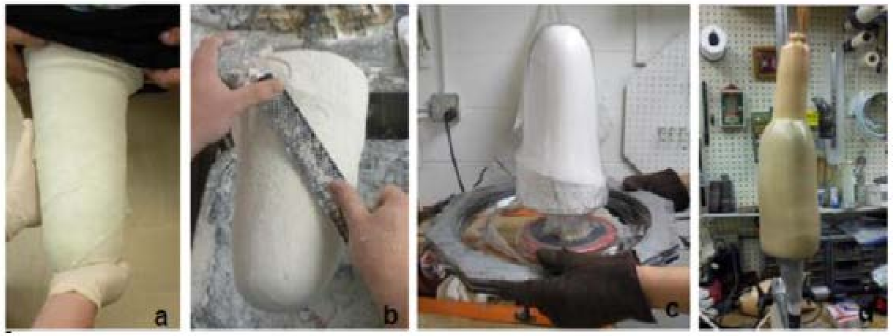
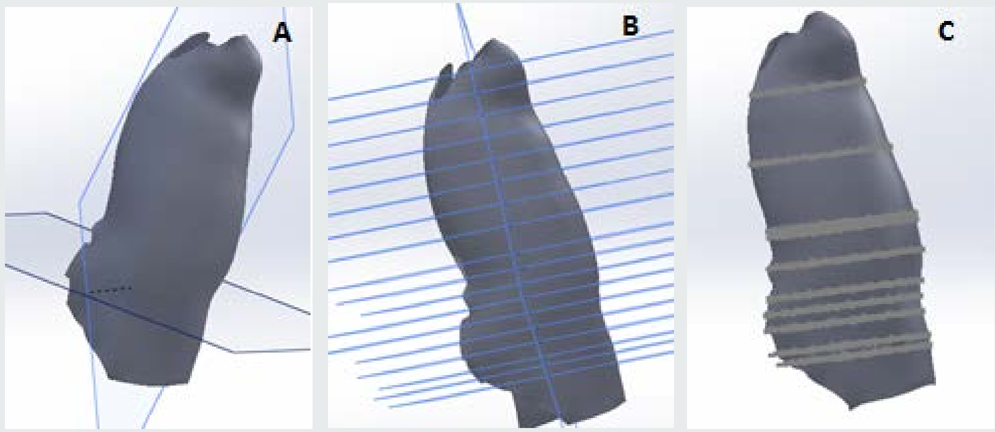


Figure 1 - Fabrication process for fitting a transfemoral prosthesis: a) negative mold b) positive mold, c) testing model, d) final part. Pictures taken at a rehabilitation hospital.

Figure 4 – Right forearm X-Ray of the patient



AM for biomedical applications

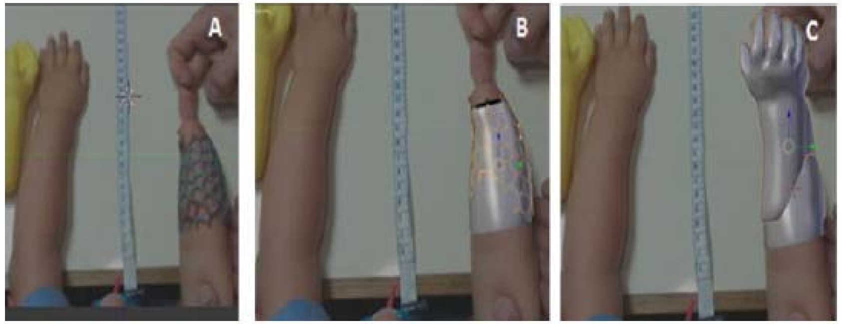


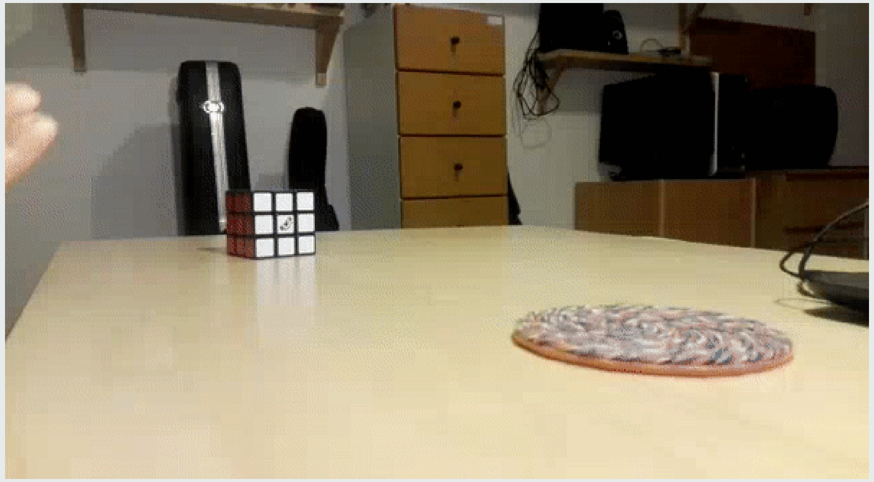
Figure 6 - Geometry alignment procedures: A: Photography importation. B: Voronoi and stump geometries alignment. C: Hand alignment.

Figure 8 – Final print FilaFlex™

Figure 9 – A, B and C: Patient with the PLA cosmetic prosthesis in different activities.D: Patiernt with the NinjaFlex cosmetic prosthesis.

AM for biomedical applications

- Desenvolvimento de uma Prótese Funcional para o Membro Superior, Francisco Correia Botelho Dias Pinheiro



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AM for biomedical applications

- Desenvolvimento de novos produtos para Medicina de Reabilitação com Recurso à Fabricação Aditiva: Design Customizado de uma Ortótese de Posicionamento de joelho, Sara Prata Bagulho Santos
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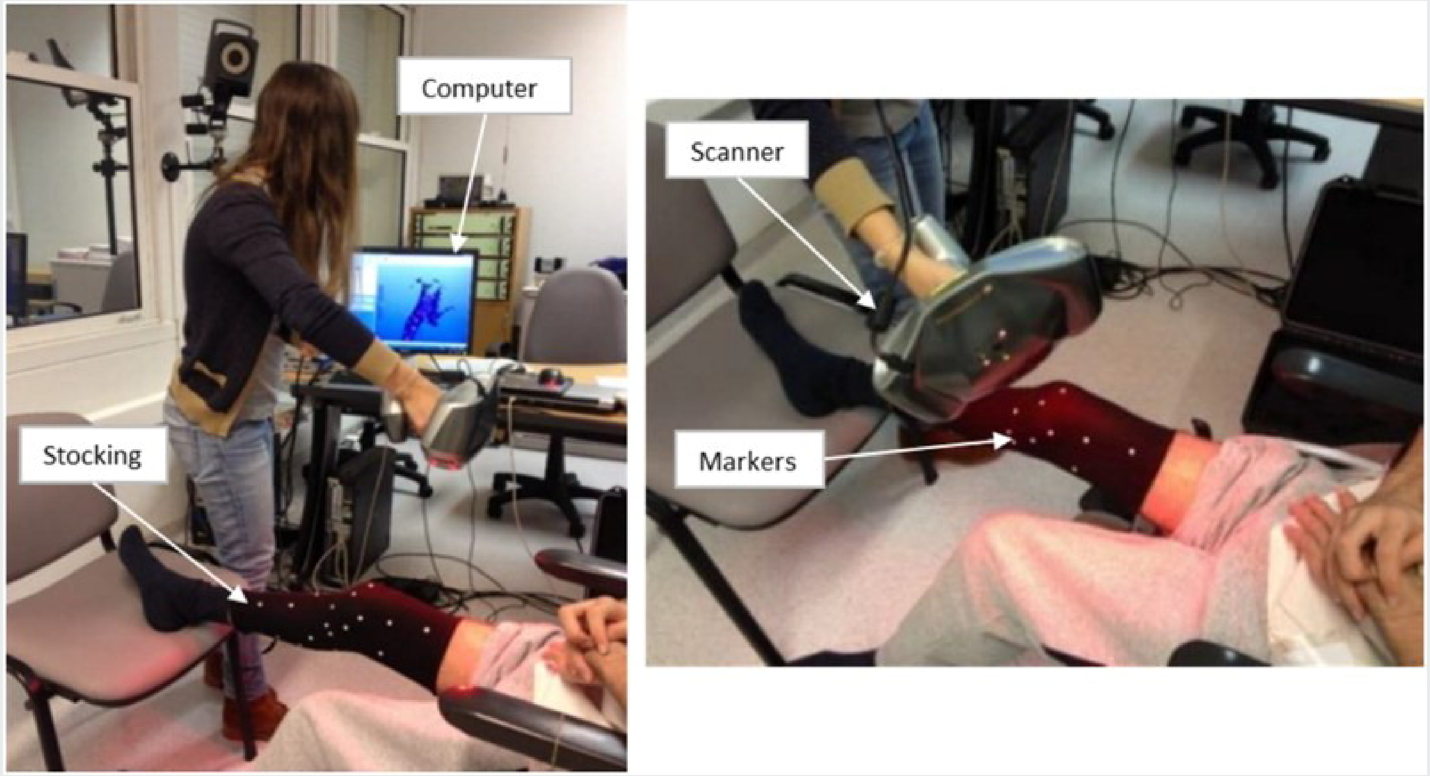
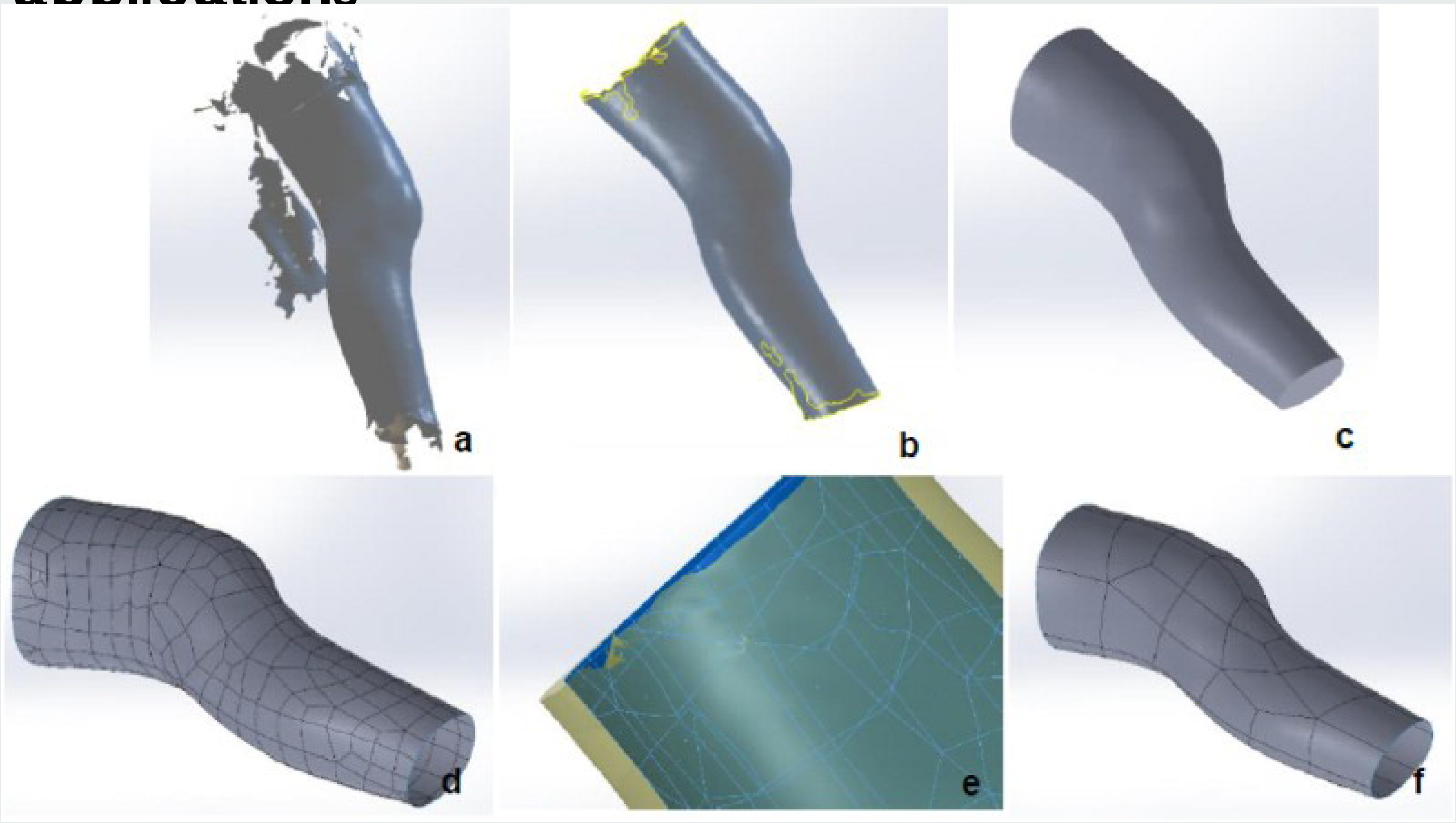
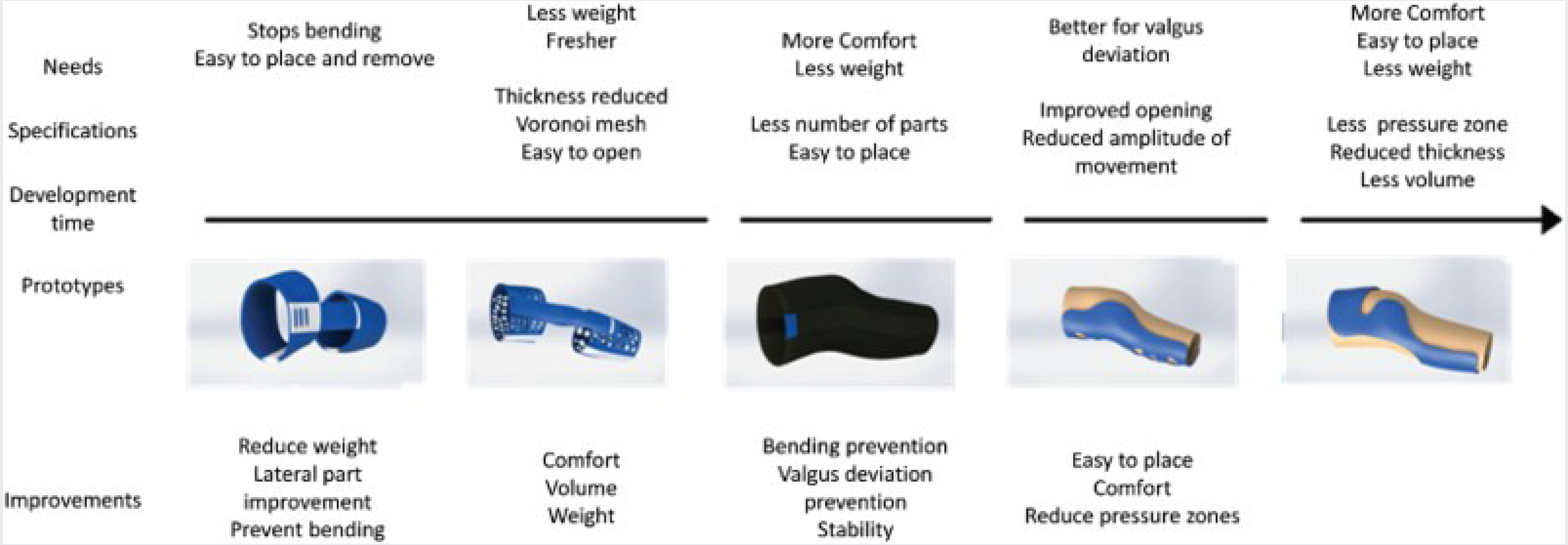


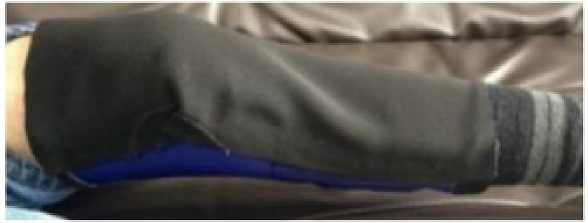
AM for biomedical applications



AM for biomedical applications



AM for biomedical applicatio

Concept	3D Printed concepts	Concept testing
1a)		Not tested.
1b)		
2		
3		
4		

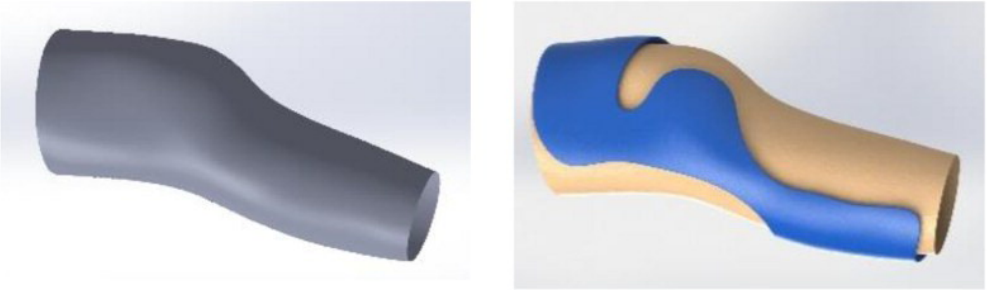
AM for biomedical applications

3D scanning

Acquiring the image of the anatomical member

3D modelling

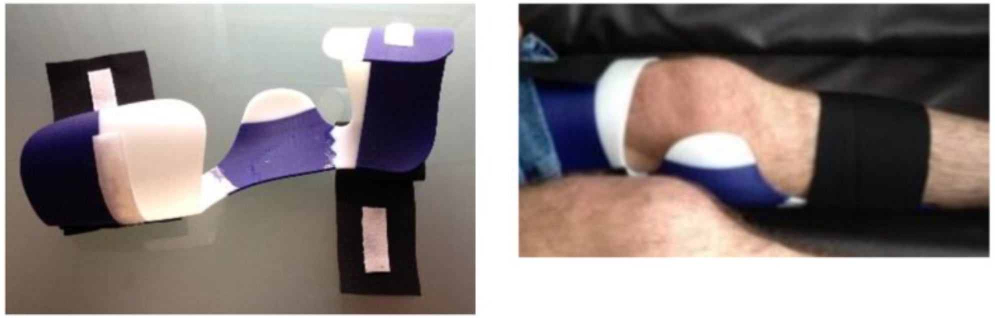
Design of the orthosis



3D printing

Fabrication of the orthosis

Concept testing



AM for biomedical applications

- Inês Ferreira

Figure 6-1: Double-amputee test subject (left) and her prosthesis (right).

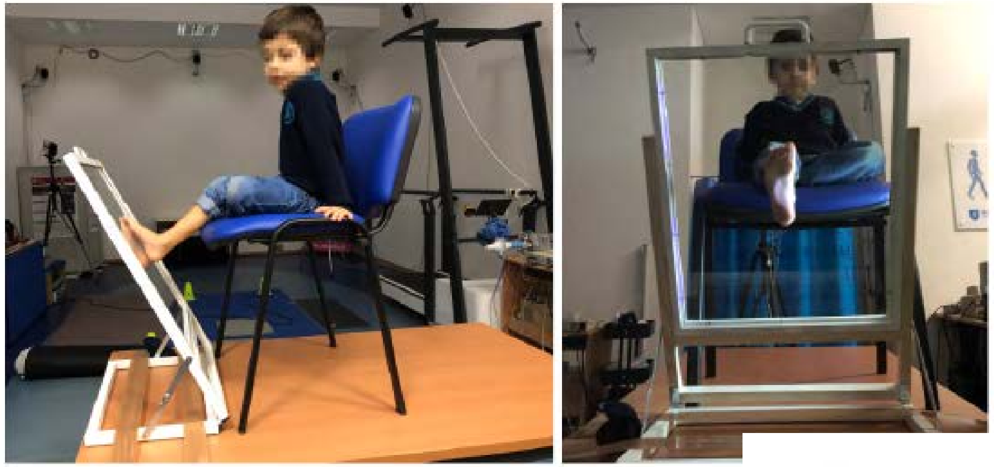
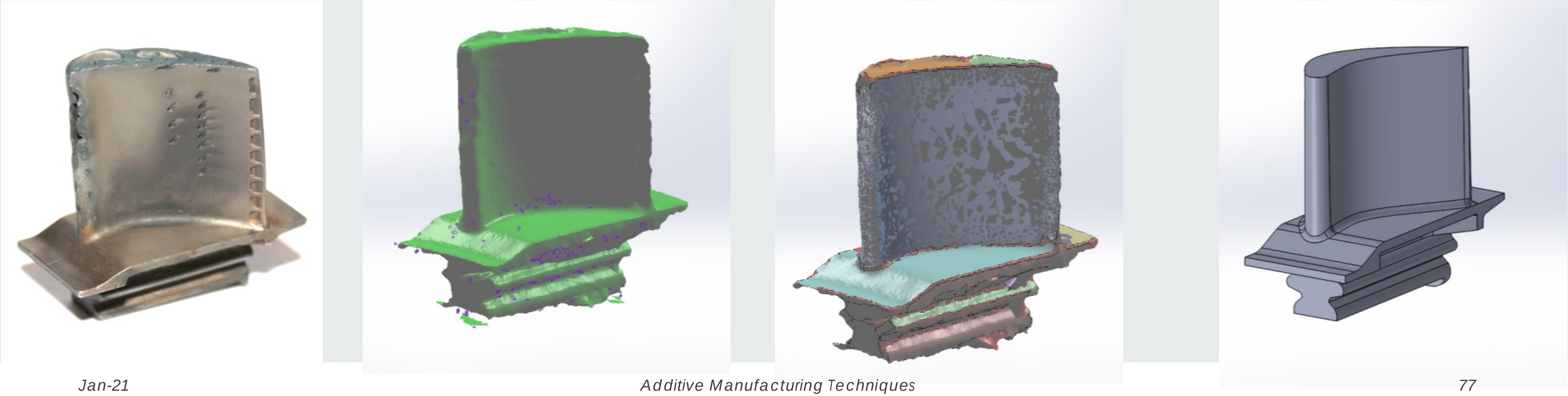


Figure 5-1: Child's posture during 3D scan proce

Figure 5-4: Measures taken on the CRF8 child foot.

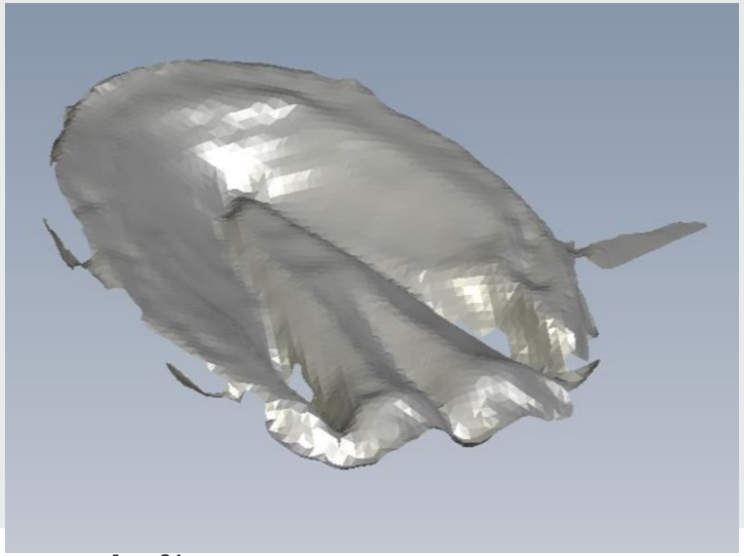
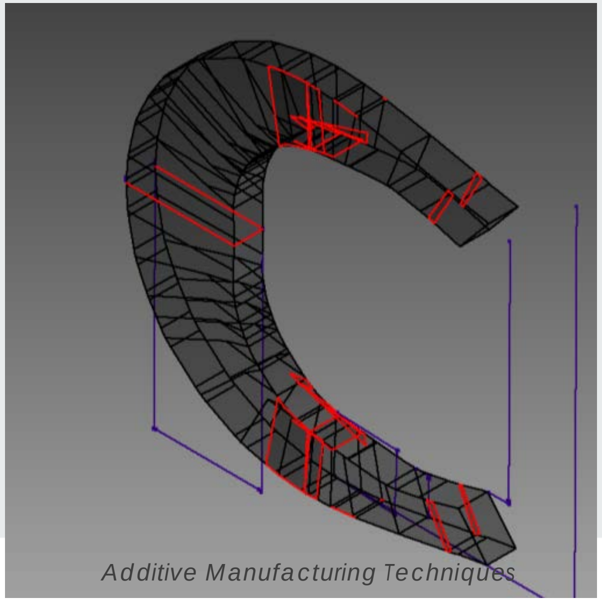
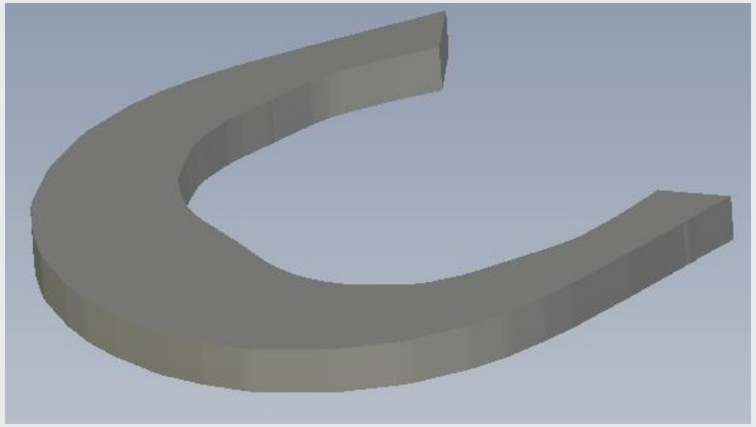
Tese Mestrado – Paulo Brandão – IST MEC

- Reverse engineering
- Prof. Augusto Moita de Deus.



Tese Mestrado – Gabriel Sartori Fernandes – Fac. Veterinária

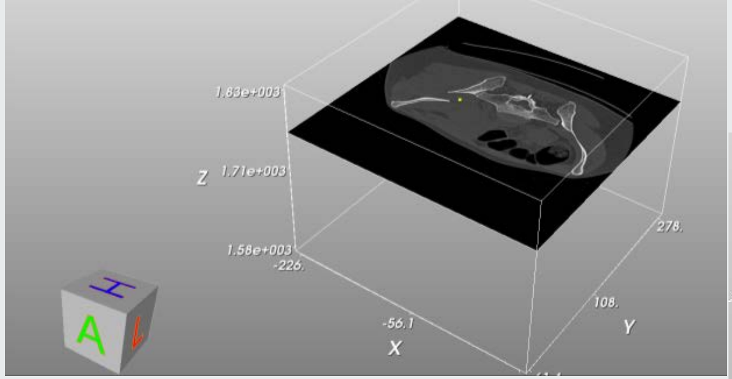
– Horse gait correction
– Prof. Fátima Vaz, Prof. Marco Leite, Eng. Vet. Nuno

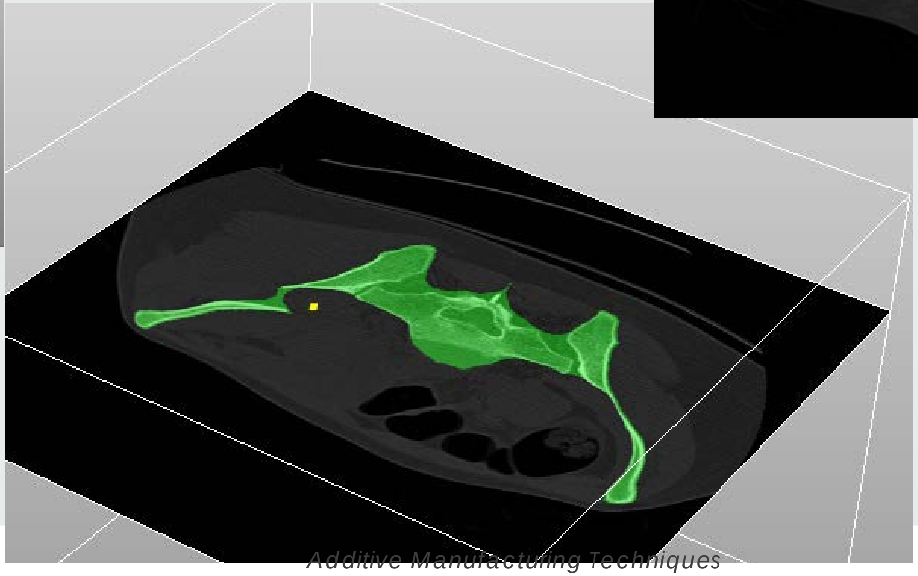




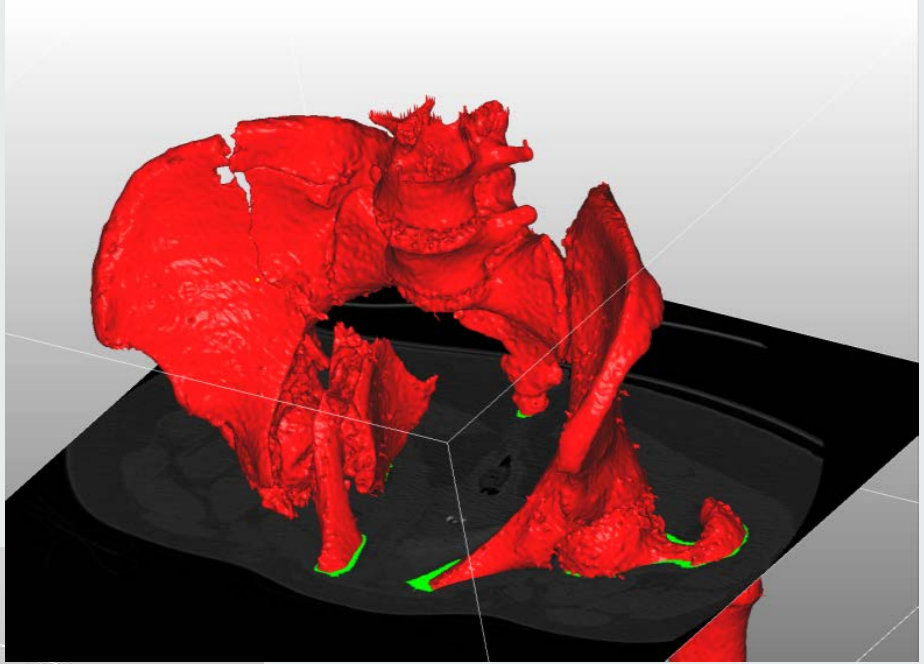
Reading CAT scans and 3D printing

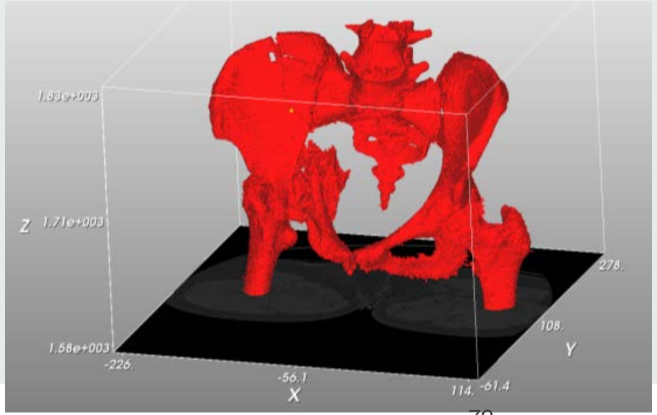
Reading CAT scans and 3D printing

- Prof. Marco Leite









AM material properties

- Design and development of cellular structures for additive manufacturing, Biranchi Narayan Panda
- Efeito de produtos protectores nas propriedades mecânicas e de absorção de água em peças fabricadas por fused deposition modelling (FDM)/ additive manufacturing, Miguel Ângelo Pinheiro Miguel
- Estudo da Influência de Parâmetros de Impressão 3D nas Propriedades Mecânicas do PLA, João Francisco Miranda Fernandes
- Influência dos parâmetros de fabrico nas propriedades mecânicas de peças obtidas por impressão 3D com um único material, Tomás Sousa Martins
- Caracterização e avaliação dos parâmetros de fabrico nas propriedades mecânicas de um material compósito obtido por impressão 3D, Pedro Miguel Rijo Diogo
- Comportamento Eléctrico de um Polímero Condutor sob Tensão, Rita Maria Figueiredo

Additional internet references

- https://3dinsider.com/3d-printing-history/
- https://wohlersassociates.com/Mar01TCT.htm
- ... and, of course, https://en.wikipedia.org/wiki/3D_printing#History

What to expect from IST students

- To take advantage of this and other technologies to provide solutions that solve problems that are important for society.

Additive Manufacturing Technologies
Técnicas de Fabrico Aditivo

Seminário Eng. Materiais

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