Centro de Tecnologia da Informação Renato Archer

Manufatura Aditiva: da realidade da indústria aeroespacial ao potencial da bioimpressão de órgãos

Jorge Vicente Lopes da Silva - PhD
Divisão de Tecnologias Tridimensionais – DT3D/CTI

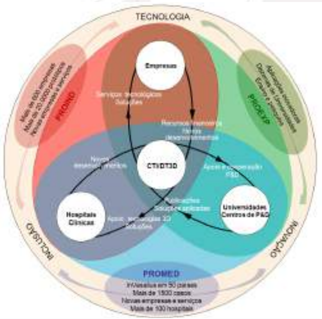
SINTPq 25 anos
SINDICATO DOS TRABALHADORES EM PESQUISA, CIÊNCIA E TECNOLOGIA-SP

Brazilian Science Technology and Innovation Ministry - MCTI

Three Dimensional Technologies Division – CTI/DT3D

Mission
To research, develop, utilize, and diffuse three dimensional technologies (virtual and physical) focusing in innovation and multidisciplinary applications driven by society

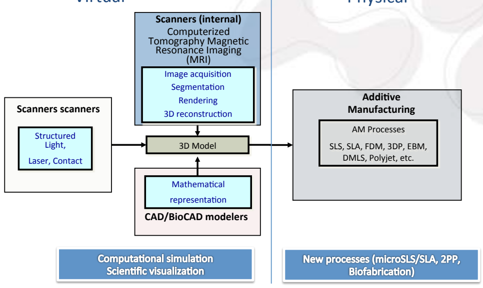
Partnership
Companies (ProIND)
Hospitals (ProMED)
Universities (ProEXP)



Topics

- Additive Manufacturing – AM (3D printing) main Concepts
- Applications of AM in
  - Engineering
  - Multidisciplinary research
  - Medicine / odontology
  - Architecture
- Expected impact of AM
- Conclusions

3D Technologies



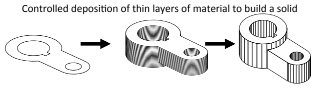
Additive Manufacturing (AM) concepts

Rapid prototyping, Solid Free-form fabrication, 3D printing

Rapid Prototyping

- Additive Processes – Additive Manufacturing – F42 Committee ASTM
- Conventional processes (e.g. HSC - *High Speed Cutting*)

Controlled deposition of thin layers of material to build a solid



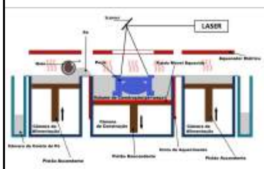
Originally a tool for product development

- Aeronautics industry
- Automobile industry
- Goods industry

Modeling and Process planning for RP

- Virtual model generation (CAD/Reverse engineering/MIP systems)
- Process planning
- Processing (RP process)
- Post processing

Selective Laser Sintering – SLS – 3D Systems



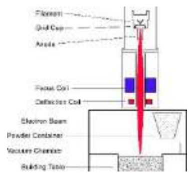
A CO2 Laser heats a plastic powder selectively
Wide range of materials. Polyamide is the most common
Many polymers and metal alloys

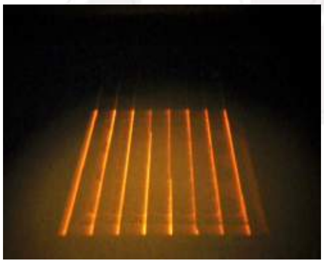
Laser Metal 3D Printing

A fiber laser melts down a metal bed

Thanks to Concept Laser and Techno-How for the availability of a Mlab at CTI

Electron Beam metal 3D Printing



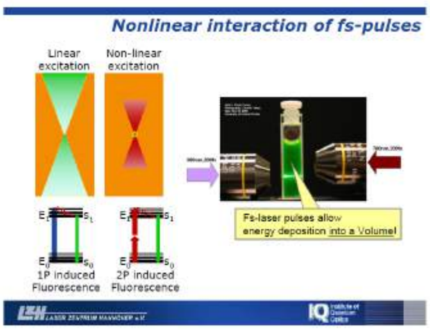


An electron beam, controlled by coils, melts down a metallic powder in a vacuum chamber. Electron Beam Melting - EBM

Courtesy Arcam

Complex shape and optimized cellular material

Two Photon Polimerization – 2PP



Courtesy of Prof. Boris Chichikov - LZH

Two Photon Polimerization – 2PP

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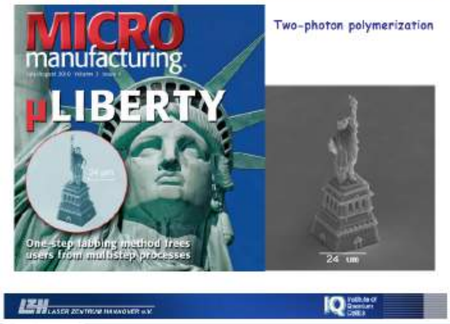
Courtesy of Prof. Boris Chichikov - LZH

Two Photon Polimerization – 2PP



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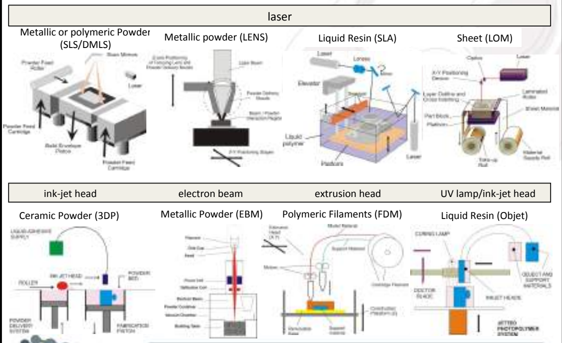
Courtesy of Prof. Boris Chichikov - LZH

Additive Manufacturing myriad of processes



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AM Trends

Functional materials and dimensions

(1) Lockheed Martin
(2) University of California
(3) Some applications at CTI Renato Archer
(4) Laser Zentrun Hannover
(5) Karlsruhe Institute of Technology
(6) 2D National Geographic cover (11x14 microns) IBM - Almaden Research Center

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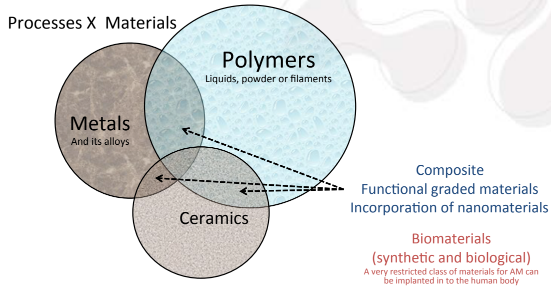
Materials for AM



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10 principles of AM

1) Manufacturing complexity is free
   - Complexity ↑
   - Costs →
2) Variety is free
   - Variety ↑
   - Costs →
3) No assembling required
   - Movable parts ↑
   - Costs →
4) Zero lead-time
   - Inventory ↓
   - Flexibility and local production ↑
5) Unlimited design space
   - Design complexity and natural shapes ↑
   - Costs →
6) Zero skill manufacturing
   - Skill needed (artisans / setup) ↓
   - Costs →
7) Compact / portable manufacturing
   - Compactness and portability ↑
   - Costs →
8) Less waste by product (metal)
   - Recycling needs ↓
   - Energy needs ↓
9) Infinite materials composition
   - Combination of raw materials ↑
   - Costs →
10) Precise physical replication
   - Cycle of scan-print-scan ↑
   - Costs →

↑High →Average ↓Low

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Adapted from: Fabricator – Hod Lipson and Melba Kurman (2013)

Mass production
Economy of scale

Customization/variety ↓
Number of same product ↑
Automation ↑
Price per product (profit) ↓

Convergence

Artisan production
Expensive

Customization/variety ↑
Number of same product ↓
Automation ↓
Price per product (profit) ↑

Additive Manufacturing
Average costs

Customization/variety ↑
Number of same product →
Automation ↑
Price per (identical or different) product (profit) →

↑High →Average ↓Low

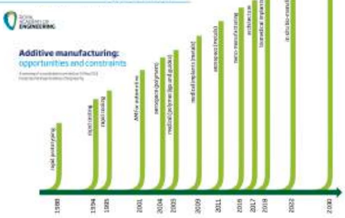
AM Trends and Market

AM and 3D printing industry (products and services) worldwide projected value

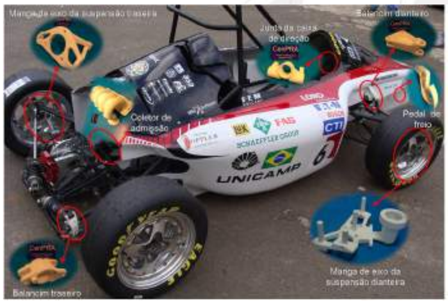
2015	$4 billion
2017	$6 billion
2021	$10.8 billion

AM applications timeline
This timeline lays out past, present and potential future AM developments and applications.

1988-1994	rapid prototyping
1994	rapid casting
1995	rapid tooling
2001	AM for automotive
2004	aerospace (polymers)
2005	medical (polymer jigs and guides)
2009	medical implants (metals)
2011	aerospace (metals)
2013-2016	nano-manufacturing
2013-2017	architecture
2013-2018	biomedical implants
2013-2022	in situ bio-manufacturing
2013-2032	full body organs



Experimental Vehicles



Research - Small series

BDA - *Brazilian Decimetric Array*

INPE Cachoeira Paulista

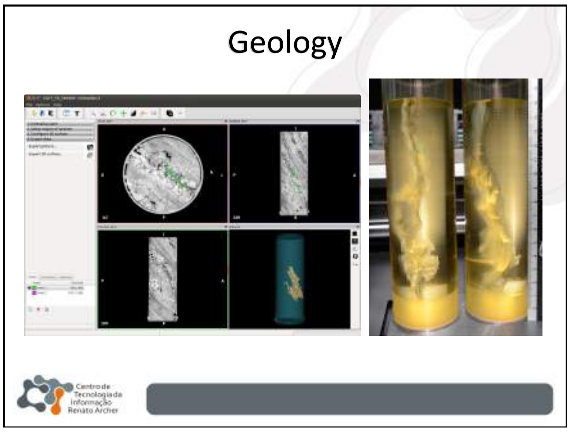
Restricted environment - Aerospace

Maia et al (2008) Maia, I.A., M.F. Oliveira, P.Y. Noritomi, J.V.L. Silva. Application of Rapid Manufacturing to build artifacts for using in microgravity environment. An International Space Station case. Virtual and Rapid Manufacturing. (Bártolo (Ed)), 559-562, Taylor and Francis Group, London.

Paleontology

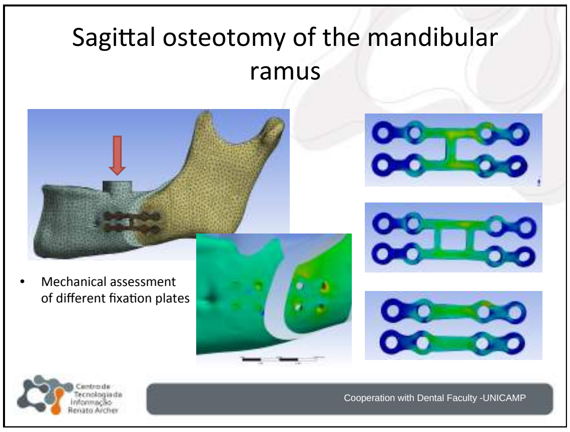
Montealto Suchus – 90 million years old

Cooperation with Monte Alto Museum and University of Campinas - UNICAMP

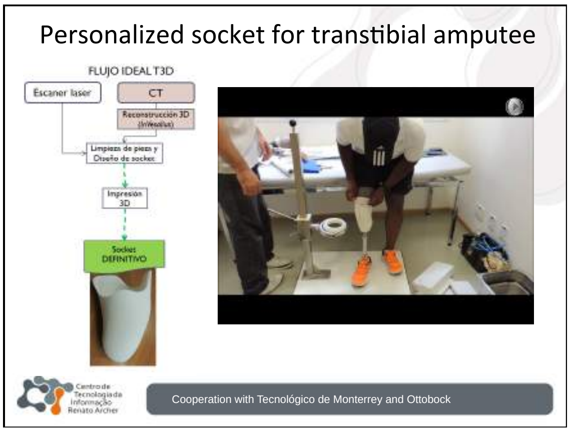

Geology


Egyptology
Forensic 3D Facial Approximation From a CT Scan Video of a Mummified Egyptian-Roman Child
Leiria, Portugal - 2013


Forensic Reconstruction – Saint Anthony of Padova
FANTÁSTICO
Designer brasileiro reconstrói face de Santo Antônio
MANUAL DE RECONSTRUÇÃO FACIAL 3D
http://www.ciceromoraes.com.br/ebook/


Sagittal osteotomy of the mandibular ramus
• Mechanical assessment of different fixation plates
Cooperation with Dental Faculty -UNICAMP


Personalized Assistive Technology
3D map and Braille
Braille and visible letters
Customized devices
Customized Orthosis


Personalized socket for transtibial amputee
FLUJO IDEAL T3D
Escaner laser
CT
Reconstrucción 3D (InVesalius)
Limpieza de piezas y Diseño de socket
Impresión 3D
Socket DEFINITIVO
Cooperation with Tecnológico de Monterrey and Ottobock

Protein model 3D Printing

GFP - Green Fluorescent Protein

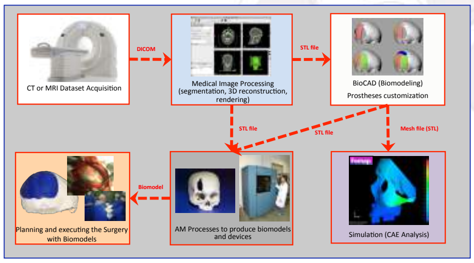
Xyllela Fastidiosa (amarelinho)

Astronomy – Eta Carinae

Source: http://revistapesquisa.fapesp.br/2014/07/15/nebulosa-em-3d-2/
http://www.etacarinae.iag.usp.br/pressrelease.html
Email Prof. Augusto Damineli (USP)

Multiscale visualization

MIP/CAD/CAE/AM



InVesalius

Volume rendering Transparency

Volume cropping

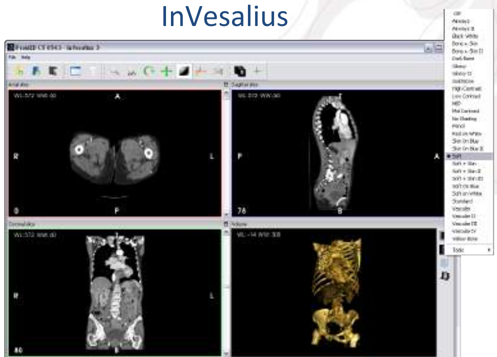
Volume segmentation and planes

Advanced Visualization Tumor with contrast

Volume rendering of multiple tissues

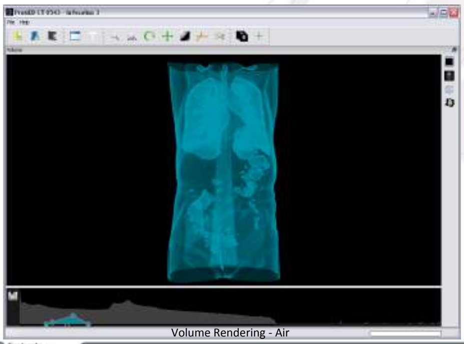
3D measurements heart

InVesalius



Volume Rendering - Presets

InVesalius



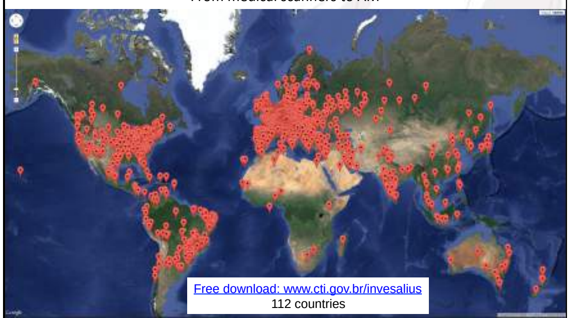
InVesalius

Visualization / Analysis

Plateau Fracture

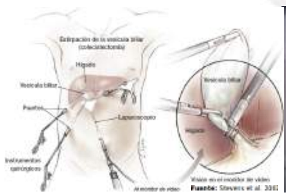
InVesalius

From medical scanners to AM



Simulação de cirurgia laparoscópica

- Propõe ferramentas computacionais e de realidade virtual para o treinamento de cirurgiões em procedimentos de laparoscopia.



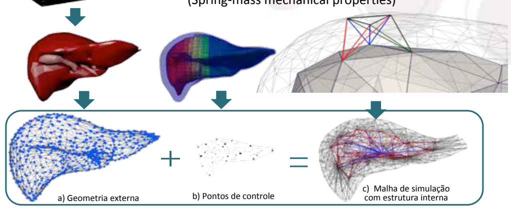
a) Colecistectomia laparoscópica

b) Treinamento de cirurgiões em procedimentos de laparoscopia

Simulação de cirurgia laparoscópica

Usando InVesalius, as estruturas anatômicas do paciente podem ser segmentadas, gerando uma malha para simular o comportamento do órgão.

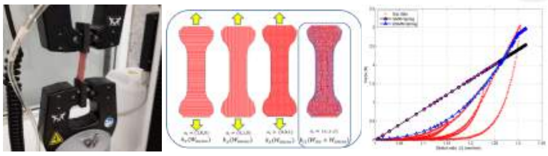
(Spring-mass mechanical properties)



Simulação de cirurgia laparoscópica

Para simular o comportamento do tecido no ambiente virtual, utilizou-se um modelo matemático calibrado com dados experimentais de ensaios de tração uniaxial de amostras do parênquima hepático suíno (a).

O modelo foi implementado computacionalmente para calcular o comportamento de tecidos em tempo real (b), e avaliando os resultados com os dados experimentais (c).



Simulação de cirurgia laparoscópica

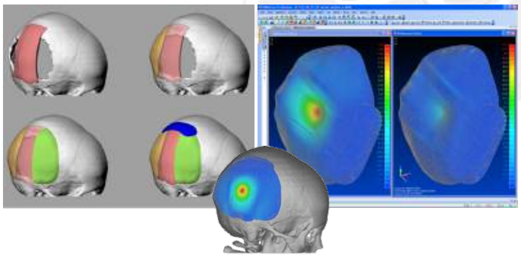
Com esta implementação, foi gerado um ambiente virtual para simulação do comportamento de tecidos (a), junto com um dispositivo de interação, para permitir o treinamento de cirurgiões.

a) Ambiente virtual

b) Dispositivo de interação

Adaptive Prostheses

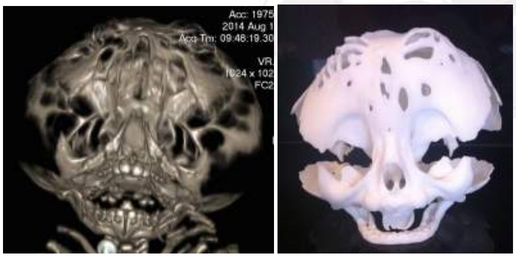
- Cranioplasty prosthesis for growing age patient



Clinica Roland

Complex craniosynostosis Surgeries

Kleeblattschädel syndrome (cloverleaf skull syndrome)



The Craniofacial Plastic Surgery Unit (NPA- Advanced Plastic Center) and Paediatric Neurosurgery Unit (CENEPE - www.cenepe.com.br) of the Beneficência Portuguesa Hospital in Sao Paulo, Brazil.

5/4/15

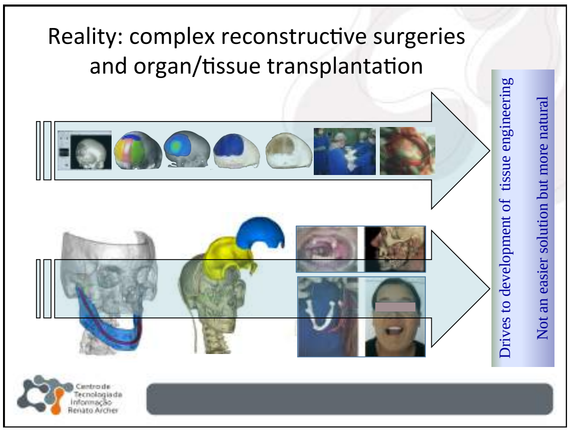
Hospitals

ProMed program – 3D Technologies for healthcare (Sw+AM) / 4000+ cases / 130 Hospitals in 2014

Thanks to Brazilian Ministry of Health for the financial support

Reducing subjectivity

PUC-RS surgical team


Reality: complex reconstructive surgeries and organ/tissue transplantation
Drives to development of tissue engineering
Not an easier solution but more natural
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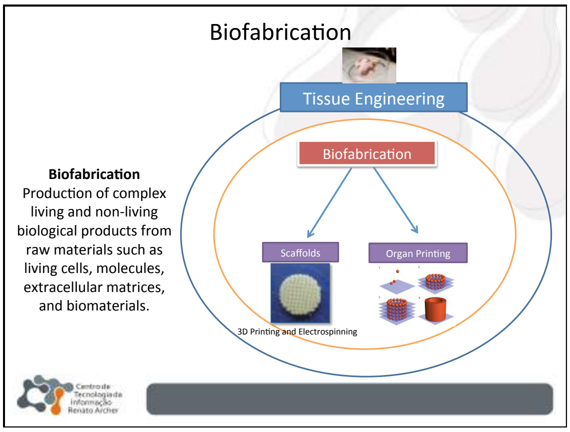
Biofabrication
Biofabrication
Production of complex living and non-living biological products from raw materials such as living cells, molecules, extracellular matrices, and biomaterials.
Tissue Engineering
Biofabrication
Scaffolds
Organ Printing
3D Printing and Electrospinning
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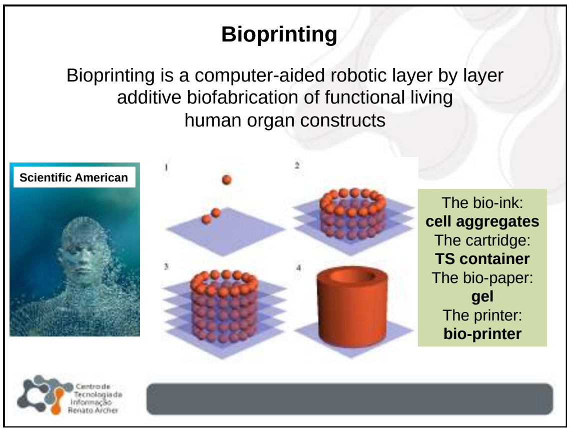
Bioprinting
Bioprinting is a computer-aided robotic layer by layer additive biofabrication of functional living human organ constructs
Scientific American
1
2
3
4
The bio-ink: cell aggregates
The cartridge: TS container
The bio-paper: gel
The printer: bio-printer
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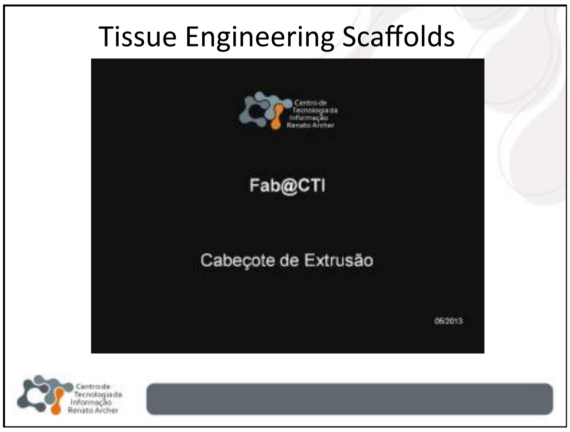
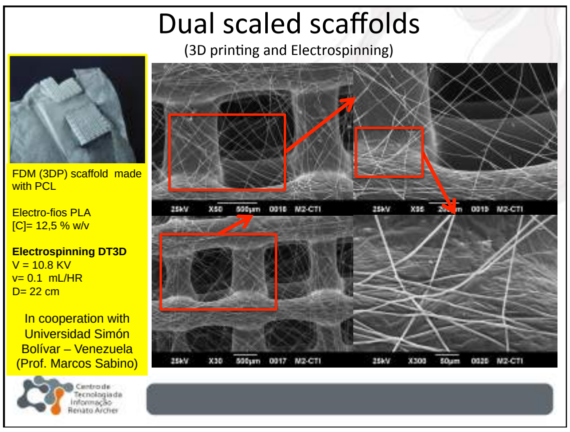

Tissue Engineering Scaffolds
Centro de Tecnologia da Informação Renato Archer
Fab@CTI
Cabeçote de Extrusão
05/2013
Centro de Tecnologia da Informação Renato Archer


Dual scaled scaffolds
(3D printing and Electrospinning)
FDM (3DP) scaffold made with PCL
Electro-fios PLA
[C]= 12,5 % w/v
Electrospinning DT3D
V = 10.8 KV
v= 0.1 mL/HR
D= 22 cm
In cooperation with Universidad Simón Bolívar – Venezuela (Prof. Marcos Sabino)
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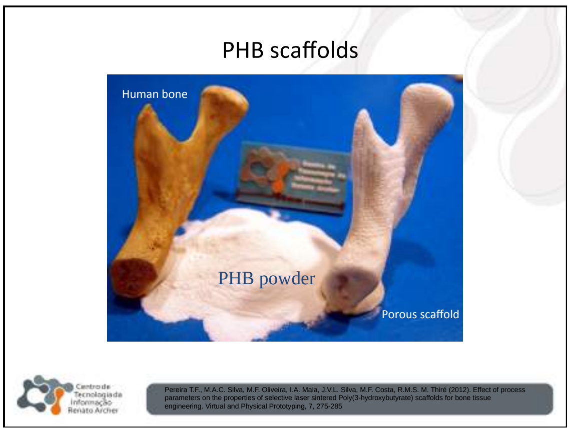
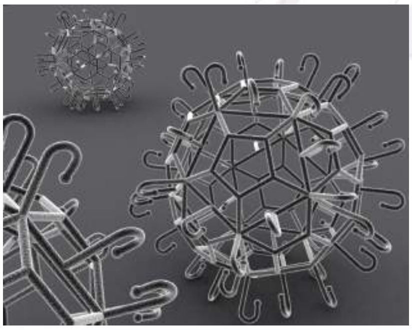

PHB scaffolds
Human bone
PHB powder
Porous scaffold
Centro de Tecnologia da Informação Renato Archer
Pereira T.F., M.A.C. Silva, M.F. Oliveira, I.A. Maia, J.V.L. Silva, M.F. Costa, R.M.S. M. Thiré (2012). Effect of process parameters on the properties of selective laser sintered Poly(3-hydroxybutyrate) scaffolds for bone tissue engineering. Virtual and Physical Prototyping, 7, 275-285

Lockyballs



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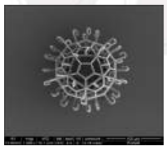
Lockyballs

Interlockable Microscaffold or Simply 'Lockyballs' Fabricated by Two Photon Polymerization Technology

Light microscopy

Confocal



SEM

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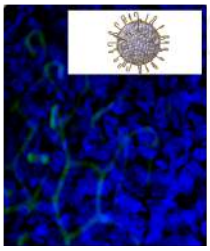
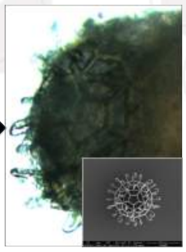
Rezende, R.A., F.D.A.S. Pereira, V. Kasyanov, A. Ovsianikov, J. Torgensen, P. Gruber, J. Stampfl, K. Brakke, J.A. Nogueira, V. Mironov, J.V.L. Silva (2012). Design, physical prototyping and initial characterisation of Lockyballs. Virtual and Phys. Prototyping,7, 287-301

Lockyballs

Cell Seeded Lockyballs



DAPI Staining for nuclei



Light microscopy

(Lockyballs hooks are indicated by arrows)

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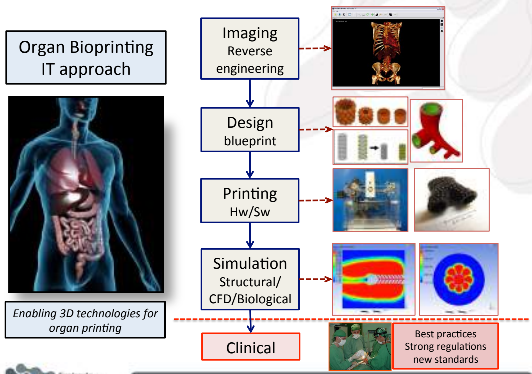

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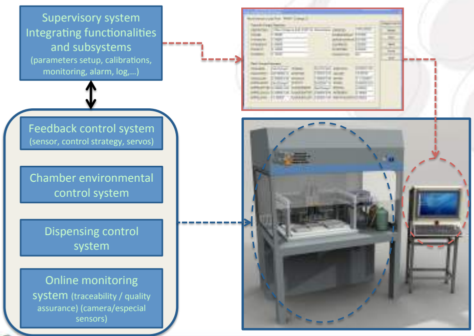
Integrated Bioprinter



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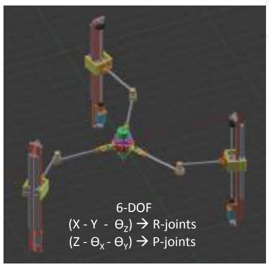
Personal Bioprinter

Basic Sketch



Design, implement and share an open source 6-DOF robotic platform capable of automatic tool changing, aiming at a flexible "personal biofabricator"

- Higher payload capacity
- Low inertia → higher acceleration
- Better structural rigidity
- Low sensibility to errors → better accuracy
- *U-Joints* e *S-Joints* → no shear nor torsion moment
- **Inverse Kinematics** is much simpler when compared to a serial robot
- **Inverse kinematic** has an **unique** solution.

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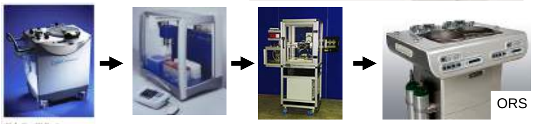
Organ Biofabrication Line



Cell sorter → Robotic tissue spheroids biofabricator → Robotic bioprinter → Perfusion bioreactor

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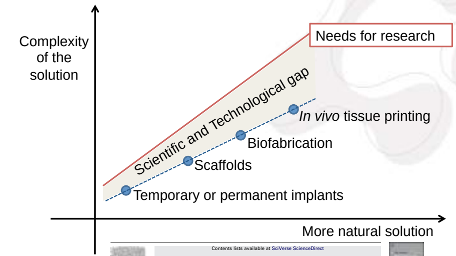
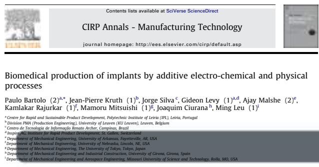




New revolution in the Horizon

- **FDM/SLA/SLS and other main AM patents are expiring 2013/14**
- SME companies are benefited
- FABLabs (universities)
- Big ones entering this low-end market (AutoDesk, 3D systems …)

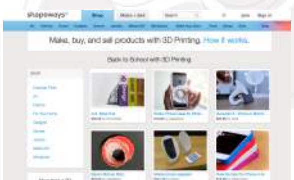
Rally Fighter (Local Motors)

Open design

Created by an open design community with a functional prototype in 14 weeks

You can assembly yourself (DIY) in 15 days

New business models



Stratasys, UPS Team up to Bring 3DP to 100 Stores in the US

The Engineer posted on September 30, 2014 | Comment | 1633 views

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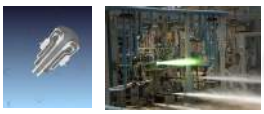
Aerospace - NASA



Subscale rocket injectors

Temperatures over 3,315 ºC
part built in less than three weeks with 60% costs reduction
Stand-up for 1 minute with the same performance of the injectors traditionally produced

Moon dust simulant sinterized

Aerospace -Boeing

"We have approximately 300 different part numbers on 10 different aircraft production programs, which amounts to more than 20,000 non-metallic additive manufactured parts that are on vehicles that we have delivered to our customers,"

"The F/A-18 Super Hornet has approximately 150 parts in the forward fuselage area that have been produced through selective laser sintering."

Nathan Hulings (Boeing Spokesman)

Aerospace -GE

19 nozzle per LEAP engine
100K nozzle produced around 2020

…The 3D-printed LEAP fuel nozzle, for example, is five times more durable than the previous model, and 25 percent lighter. Additive manufacturing allowed engineers to reduce the number of individual pieces that were brazed and welded together from 20 to just one part, and achieve the best fuel flow geometry. "These tools unleash incredible creativity," Morris says…

Source: http://www.gereports.com/

4D Printing: Programmable materials

"Programmable Materials consist of material compositions that are designed to become highly dynamic in form and function, yet they are as cost-effective as traditional materials, easily fabricated and capable of flat-pack shipping and self-assembly"

"programmable carbon fiber material that can fold, curl, twist and respond to a variety of activation energies. By printing various materials within the flexible carbon fiber grain, we are able to promote local curvature when subject to heat, light or moisture"

"4D Printing entails multi-material prints provided by the Connex Technology with the added capability of embedded transformation from one shape to another, directly off the print-bed"

Source: http://www.selfassemblylab.net/ProgrammableMaterials.php

Conclusions

- Strategic area;
- CEPAL/UNIDO proposition;
- AM is multiuse and taking-off as a serious manufacturing process;
- New regulations and testing for processes and materials;
- Energy optimization;
- Mass customization;
- Highly flexible / less investments (SME);
- Reduce supply chain (from jus-in-time logistics to just-in-place manufacturing);
- New developments (materials, processes, and management);
- To be cheaper, faster and higher quality;
- Quality control "on-the-fly";
- Pay by weight - complexity is for free;
- Open-source software -> open-source hardware -> open design;
- Disconnection between software and hardware.

Centro de Tecnologia da Informação Renato Archer

Obrigado pela atenção!
Thank you for your kind attention!

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