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Erasmus+ Programme Key Action 2 Cooperation Partnerships for Higher Education (KA220-HED)

Agreement number 2023-1-RO01-KA220-HED-000155412

European Network for Additive Manufacturing in Industrial Design for Ukrainian Context

Staff Training (STTE) – Edibon International S.A., Madrid, Spain, 7-10 May 2024

Exploring Polymeric Materials: Innovations and Uses in 3D Printing

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Staff Training in VR and AR Programming EDIBON INTERNATIONAL S.A. Company, Madrid, Spain, 7-10.05.2024

National University of Science and Technology POLITEHNICA Bucharest

http://www.upb.ro/en/

POLITEHNICA Bucharest is the oldest and most prestigious engineering school in Romania, with a tradition of 200 years made possible by the efforts of some of the greatest Romanian professors, its specificity relies in creating knowledge through research and technological innovation, as well as through its implementation by means of education and professional training at a European level.

Politehnica Bucharest is formed by different faculties, classrooms and laboratories are distributed in 4 distinct residences:

Polizu – Strada Polizu, nr. 1-7, sector 1
Noul Local– Splaiul Independenței, nr 313, sector 6
Leu – Bulevardul Iuliu Maniu, nr. 1-3, sector 6
Pitesti Campus - Str. Targul din Vale, nr.1, 110040 Pitesti, Arges, Romania

National University of Science and Technology POLITEHNICA Bucharest

The main mission of POLITEHNICA Bucharest is to train an engineer capable of adapting to the requirements of market economy and new technologies, with an economic and managerial knowledge and promote the principles of sustainable development and environmental protection. To do this, he must be formed according to the modern principle of direct participation in choosing his formative trajectory and to be included in a learning process that will give him real chances to compete on the labour market.

POLITEHNICA Bucharest has the mission to bring together education, training and scientific research. The role of this intersection is to increase knowledge and innovation, two key concepts of knowledge-based economy and society.

APMG
Advanced Polymer Materials Group

ADVANCED POLYMER MATERIALS GROUP
POLITEHNICA BUCHAREST, ROMANIA
http://www.apmg.pub.ro/

4 main research labs:
Laboratory for polymer-based nanocomposites synthesis (and general polymer synthesis)
Laboratory for Advanced Chromatographic and Spectroscopic analysis (GPC, FTIR, FT Raman, Dispersive Raman, Confocal RAMAN, X-ray Photoelectron Spectroscopy)
Laboratory for thermal characterization (DSC, TGA, DETA, DMA, combined DSC-TGA-FT Raman)
Laboratory for polymer processing and mechanical characterization (FDM-DLP-SLA - Bioplotter 3D printing, tensile, compression, impact, hardness, rheometer, melt flow index, extruder, injection, AFM, nano-FTIR coupled with AFM) and collaborates with other labs in the University (SEM, TEM and XRD)

INOVABIOMED Project

11 teams from 6 faculties of POLITEHNICA Bucharest:

1. **Faculty of Chemical Engineering and Biotechnology**
    1. *Department of Bioresources and Polymer Science*
    2. *Advanced Polymer Materials Group – APMG*
    3. *Department of General Chemistry*
    4. *Department of Organic Chemistry "Costin D. Nenitescu"*
    5. *Department of Analytical Chemistry and Environmental Engineering*
2. **Faculty of Medical Engineering**
3. **Faculty of Energetics**
4. **Faculty of Applied Sciences**
    1. Department of Physics
    2. Center for Microscopy-Microanalysis and Information Processing
5. **Faculty of Science and Engineering of Materials**
6. **Faculty of Industrial Engineering and Robotics**

INOVABIOMED – 3 main topics

T1. Advanced methods for bio (fabrication) of biomaterials

4 labs

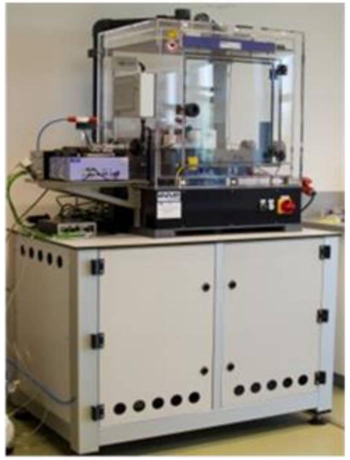
T2. Integral solutions for guiding of biomedical surfaces response **5 labs**

T3. New approaches in biomaterials characterization by coupling of micro and nano structural investigations

7 labs

3D-Bioscaffolder/ 3D-Bioplotter RegenHU

Liquid chromatograph (RHPLC) coupled with circular dicroism spectrometer JASCO



Electrospinning with controlled environment chamber IME Technologies

- ***3D - Bioplotter***
- ***NanoCT scanner***
- ***MicroCT scanner***
- ***Nanoindenter***
- ***Terahertz time-domain spectrometer***
- ***Complex system of microbalance with quartz crystal and elipsometer module***
- ***Electron beam litography – EBL***
- ***Liquid chromatograph coupled with circular dichroism***

POLYMERS / MACROMOLECULAR COMPOUNDS

Polymers are macromolecules formed by the chemical bonding of large numbers of smaller molecules, or repeating units, called monomers.

Monomers bonded together in two, three, and four are called dimers, trimers, and tetramers, respectively, and these short repeating units are further called oligomers.

The simplest form of polymer is one that is made up of only one type of monomer (a homopolymer).

Copolymers are composed of monomers that differ from one another. The degree to which they differ – either by structure or composition – and the quantities of each type of monomer relative to one another in the same polymer molecule ultimately determine that material's chemical and physical properties.

POLYMERS IN 3D PRINTING

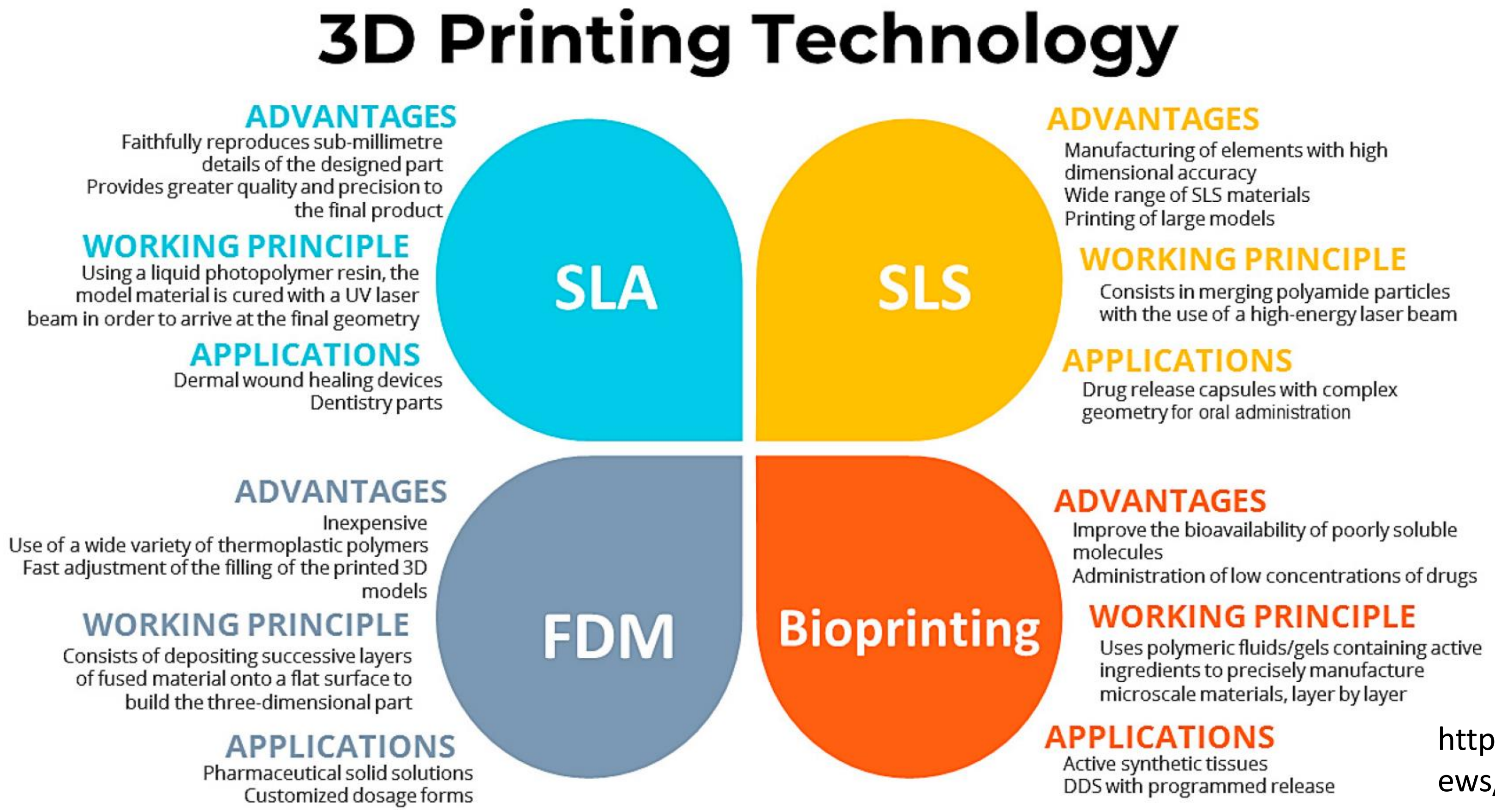
Polymer 3D printing has developed in recent years with many areas of research now translating to engineered products, especially in medical fields.

3D printing is a nice fabrication approach as it enables products with complex geometries and architectures that are not possible with conventional manufacturing processes.

Polymer printing is possible using extrusion, resin, and powder 3D printing processes.

Types of polymers: PLA, ABS, ASA, PP, PMMA, HIPS – common plastics; PC, PA, PET, TPU, TPE, TPC (thermoplastic co-polyesters), PETG – engineering plastics; PEI, PEEK, PEKK, PVDF, PPSU - high-performance plastics.

PEI – Polyethylenimine; PEEK - Polyether ether ketone; PEKK – Polyetherketoneketone; PVDF - Polyvinylidene fluoride; PPSU – Polyphenylsulfone.



https://www.pharmaexcipients.com/news/3d-printing-techniques/

THE FIRST INDUSTRIAL REVOLUTION

The first industrial revolution started in Britain in the late 18th century with the mechanisation of the textile industry. The Industrial Revolution factory system introduced principles that remain vital in contemporary manufacturing practices: centralized production, efficiency and specialization.

https://history.howstuffworks.com/historical-events/industrial-revolution-factory.htm

Centralized Production: concentration of manufacturing processes in a single location or a few centralized locations. This allows for better coordination, management, and utilization of resources. However, modern technology and logistics have also enabled decentralized production models, especially in industries where customization and agility are valued.

Efficiency: This has always been important in the manufacturing practices, and the Industrial Revolution greatly emphasized this through mechanization and standardization of processes. In actual manufacturing, efficiency is still a key objective, but it's often achieved through advanced technologies such as automation, robotics, data analytics, and lean manufacturing principles.

Specialization: The Industrial Revolution introduced the concept of dividing labor into specialized tasks, leading to increased productivity and output. This specialization allowed workers to become highly skilled in specific tasks, contributing to overall efficiency. In modern manufacturing, specialization is even more pronounced, with highly specialized roles and advanced training programs to develop expertise in specific areas.

THE SECOND INDUSTRIAL REVOLUTION

The second industrial revolution came in the early 20th century, when Henry Ford mastered the moving assembly line and ushered in the age of mass production.

https://industrialrevolutiontwo.weebly.com/automobiles
planes.html

Technological Advancements: new technologies such as electricity, the internal combustion engine, and steel production techniques. These innovations revolutionized industries such as transportation, manufacturing, and communication, leading to increased efficiency and productivity.

Mass Production: Building upon the principles established in the First Industrial Revolution, the Second Industrial Revolution further refined methods of mass production – assembly lines.

Expansion of Industry: New industries emerged (beside textile and iron), including chemicals, petroleum, automobiles, and telecommunications. This diversification of industries led to economic growth and urbanization.

Globalization: Advances in transportation and communication, such as the steamship and telegraph, facilitated global trade and interconnected economies. The Second Industrial Revolution accelerated globalization by enabling the movement of goods, people, and information across vast distances more quickly and efficiently.

Impact on Society: industrial capitalism, the growth of urban centers, and major changes in labor practices. While it generated wealth and innovation, it also started debates about working conditions, income inequality, and the role of government in regulating industry.

The Third Industrial Revolution (late 20th century)

Referred to as the **Digital Revolution**, the third industrial revolution was driven by the widespread adoption of digital technology, encompassing personal computers, the internet, telecommunications, and automation. During this era, there was a notable shift towards the digitization of information and the automation of diverse processes across multiple industries.

The third industrial revolution revolutionized communication, commerce, and information sharing, leading to the emergence of the digital economy and knowledge-based industries. It facilitated globalization on an unprecedented scale and brought about significant changes in employment patterns, skills requirements, and social interactions.

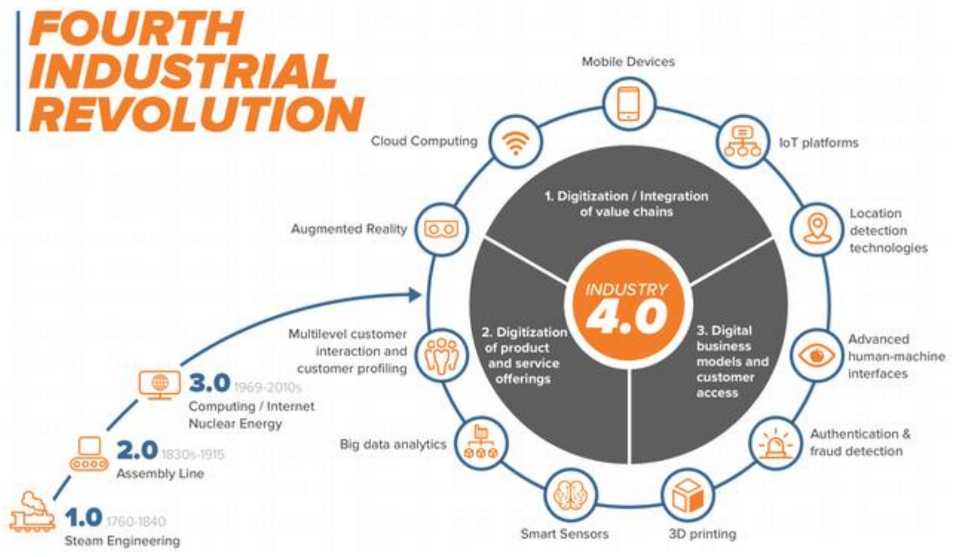
https://www.trendlog.dk/the-story-about-the-third-industrial-revolution/

THE FOURTH INDUSTRIAL REVOLUTION

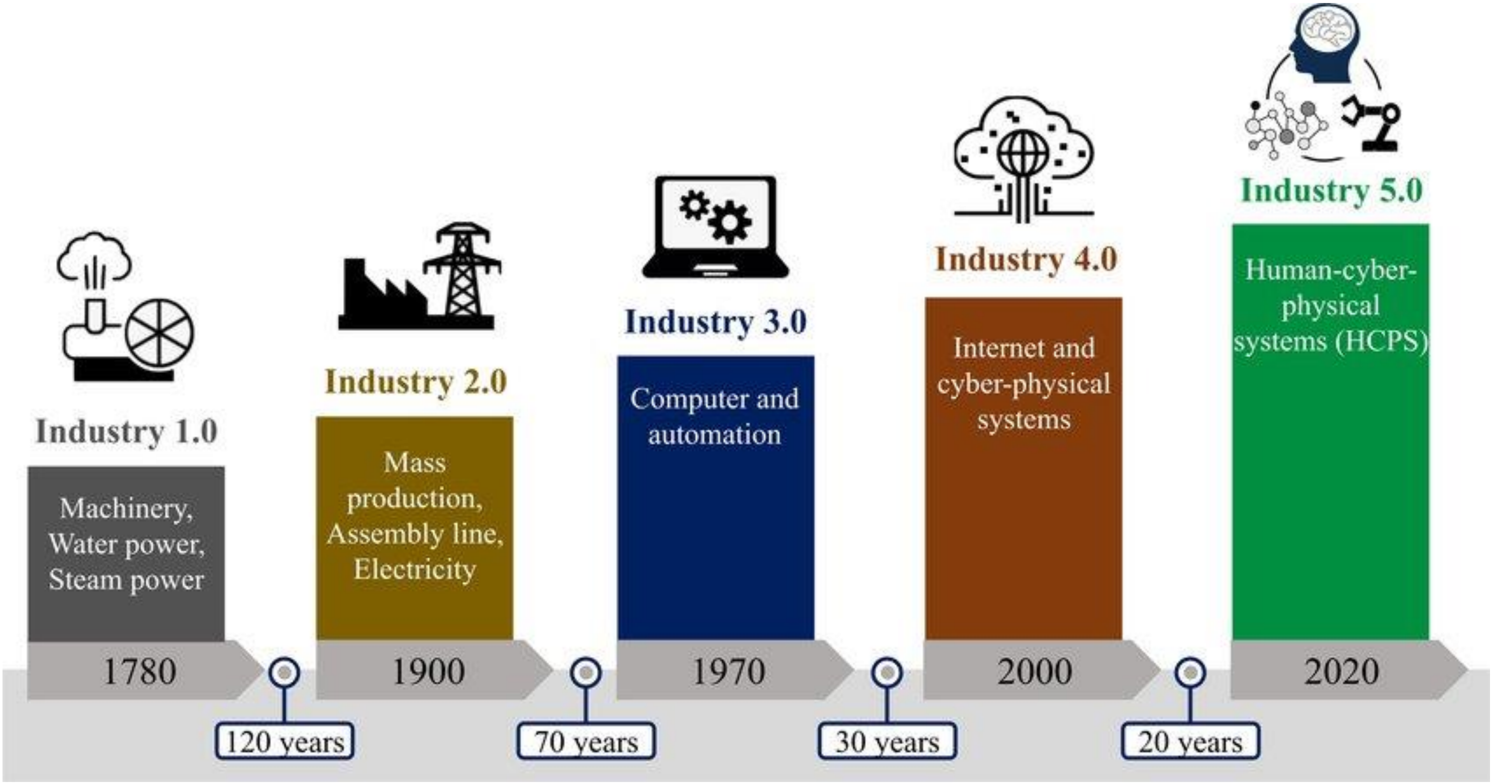
This is characterized by the application of information and communication technologies to industry and is also known as "Industry 4.0".

We can speak about advancements in artificial intelligence, robotics, 3D printing, and biotechnology, which are reshaping industries and economies in the 21st century.

Driverless cars, autonomous drones, gene editing, **3D printing**, artificial intelligence (AI), smart robots and synthetic biology are some of the new developments.



https://www.ictworks.org/problems-fourth-industrial-revolution/



Sustainability 2021, 13(2), 561;
https://doi.org/10.3390/su13020561

3D printing, AI (Artificial Intelligence), VR (Virtual Reality), and AR (Augmented Reality) are rapidly advancing technologies, each having unique applications and interactions with each other.

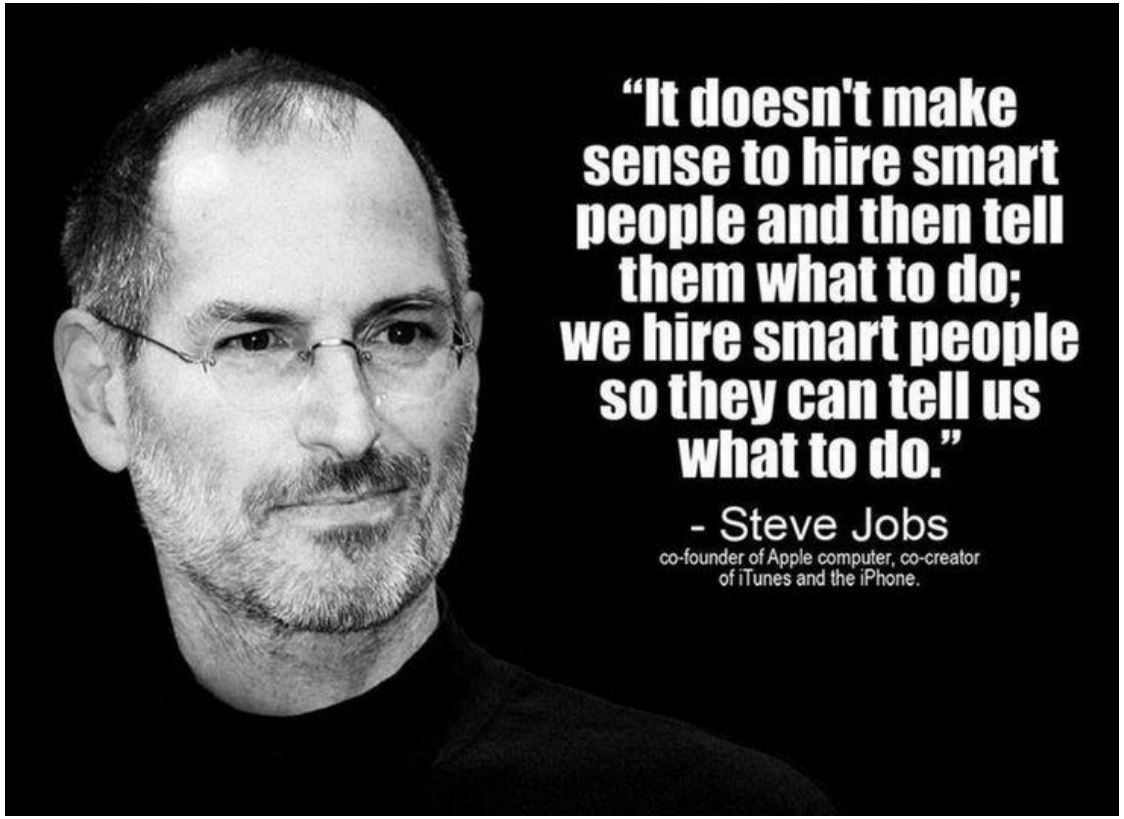
VR and AR can assist in the 3D printing process by providing more intuitive design interfaces and enabling virtual prototypes. Designers can use VR to immerse themselves in the design process or use AR for overlaying design modifications on a physical prototype to see how changes would look.

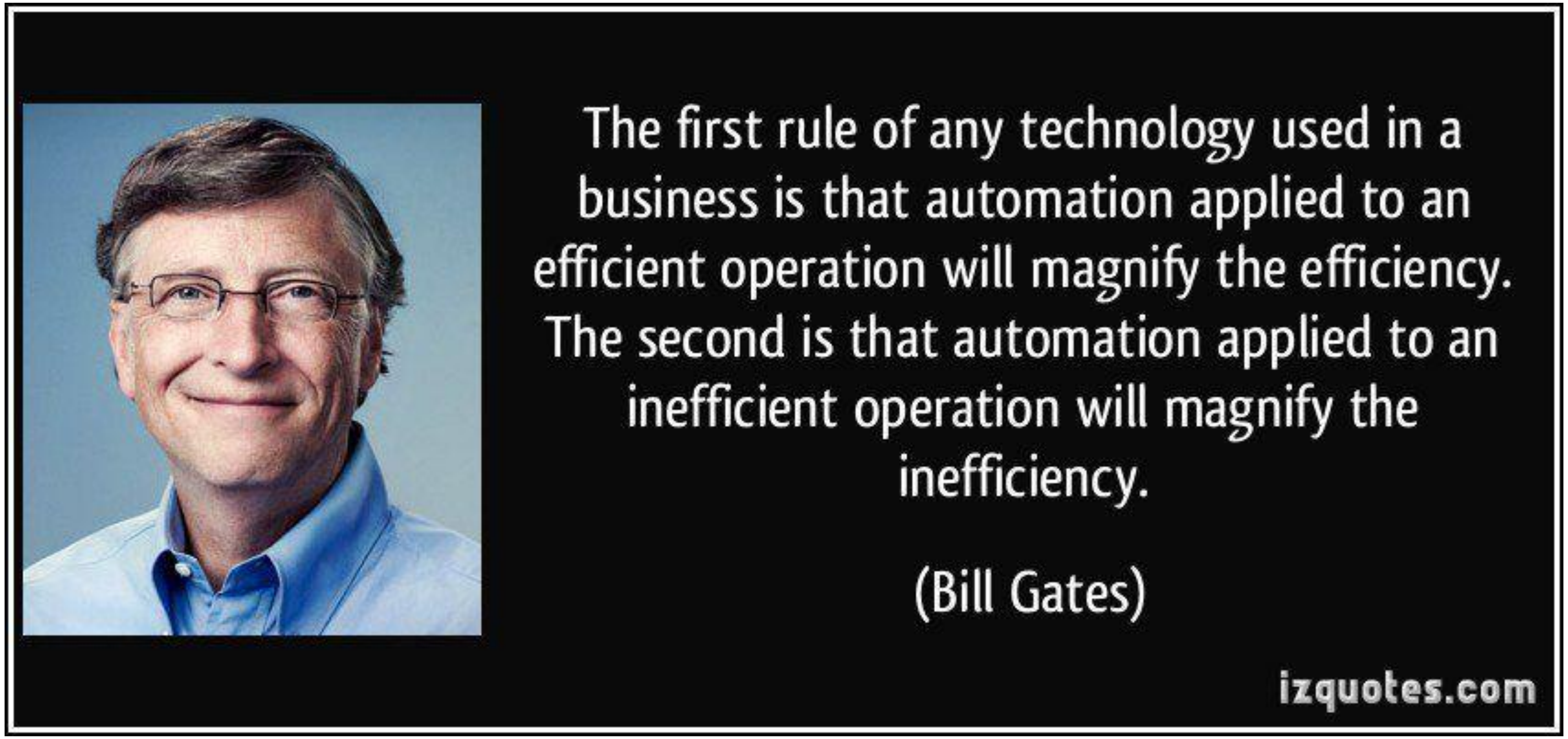
AI enhances 3D printing in several ways, including predictive maintenance, quality control, and design optimization. AI algorithms can predict failures, adjust parameters in real-time to improve the quality of prints, and even aid in complex design processes by suggesting optimization procedures.

In recent years, there has been a significant growth in medical research focused on Virtual Reality (VR) technologies, particularly for uses in education and training, patient engagement, physician communication, and anatomy visualization.

This surge in research, along with advancements in hardware and reductions in costs, has contributed to the broader adoption and expansion of VR applications within the medical field.

https://www.makepartsfast.com/interactive-vr-models-complement-3d-printing/


“It doesn't make sense to hire smart people and then tell them what to do; we hire smart people so they can tell us what to do.”
- Steve Jobs
co-founder of Apple computer, co-creator of iTunes and the iPhone.


The first rule of any technology used in a business is that automation applied to an efficient operation will magnify the efficiency. The second is that automation applied to an inefficient operation will magnify the inefficiency.
(Bill Gates)
izquotes.com

BRIEF HISTORY OF 3D PRINTING

1860 – The photosculpture method of *François Willème* captures an object in 3 dimensions using cameras surrounding the subject. A subject or object was placed in a circular room and simultaneously photographed by 24 cameras placed equally about the circumference of the room. An artisan then carved a 1/24th cylindrical portion of the figure using a silhouette of each photograph. *François Willème was granted U.S. patent 43,822 for Photographing Sculpture in 1864, and this is one of the first attempts to obtain 3D printed objects*.

1892 – *J.E. Blanther* suggested a layered method for making a mold for topographical relief maps for which he was granted the US patent 473,901.

1940 – *Perera* proposed a method for making a relief map by cutting contour lines on sheets (cardboard) and then stacking and pasting these sheets to form a three-dimensional map.

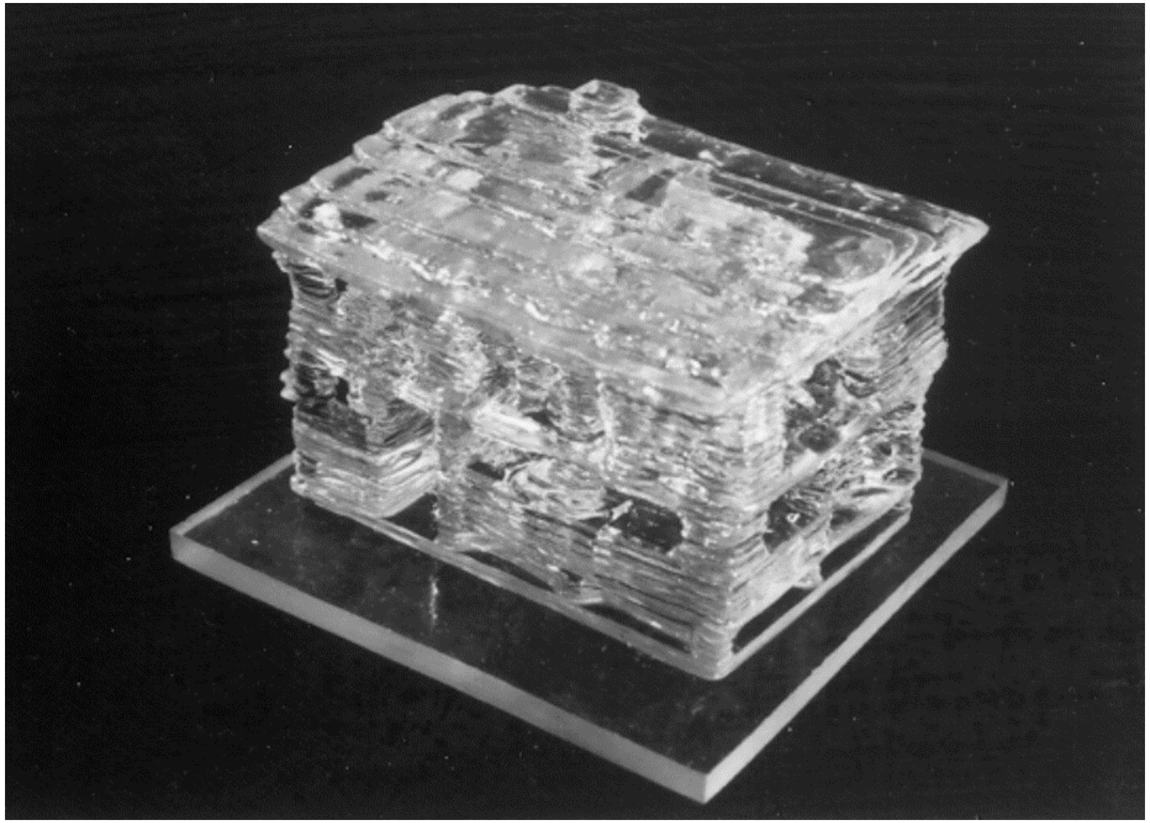
Munz developed some techniques in 1951 that resemble the SLA used today.

Photoscultpture in 1860 and solid reproduction from Willème's photosulpture

1968 - Swainson was also a pioneer in early freeform fabrication by proposing a method to produce plastic models by 3D polymerization of photosensitive polymers at the intersection of two laser beams (1968, Photochemical machining).

1972 – Division Matsubara of Mitsubishi motors proposes that photo-hardened materials (photopolymers) are used to produce layered parts.

The first 3D printing attempts are granted to ***Dr. Hideo Kodama*** for his development of a rapid prototyping technique (photopolymerization of polymeric resins in 1980). He created a product that used ultraviolet lights to harden polymers and create solid objects. This is a stepping-stone to stereolithography (SLA). At the same time, but independently *Herbert* tried the same process at 3M Company. Unfortunately, the patent of Dr. Kodama was abandoned after one year and he did not finance it furthermore.



Kodama’s model part

Jean-Claude André, Olivier de Witte, and Alain le Méhauté were French inventors working at Alcatel and the French National Center for Scientific Research trying to apply the rapid prototyping technique for producing parts. Sadly, their companies were not interested in this topic, and the idea was abandoned.

1984 – **Charles Hull** (founder of 3D systems) invents stereolithography (SLA) – which is patented in 1987. The technology allows you to take a 3D model and use a laser to etch it into a special liquid (photopolymer). The object is printed layer by layer, rinsed with a solvent, and hardened with an ultraviolet light. The process uses computer-aided designs (CAD) to create the 3D model.

Hull's company, 3D Systems Corporation, released the world's first stereolithographic apparatus (SLA) machine, the SLA-1, in 1987. Hull has more than 60 patents around the technology, becoming the godfather of the rapid prototyping movement and inventing the STL file format that's still in use today.

1991 – Stratasys produces the world's first FDM (fused deposition modelling, **Scott Crump**) machine. This technology uses plastic and an extruder to deposit layers on a print bed. FDM was patented in 1989 by **Scott Crump** just before he launched the Stratasys company with his wife, *Lisa Crump*.

1992 – 3D systems produce the first SLA 3D Printer machine.

1992 – DTM produces first SLS (selective laser sintering) machine. This machine is similar to SLA technology but uses a powder (and laser) instead of a liquid. SLS uses a laser to fuse the powder together, layer by layer, into more complex shapes than SLA is capable of creating.

The term 3D printing was coined in 1992 by **Prof. Emanuel Sachs from MIT** replacing somehow the initial term rapid prototyping. He has more than 40 patents from 1988-2002 and is a pioneer in the 3D printing field. Due to the work of Prof. Sachs, 3D printing technology has been used in many applications like metal end-use parts, ceramic parts for electronic applications, ceramic parts for machining, ceramic molds for metal casting, and for medical applications including polymeric materials for tissue engineering and drug delivery systems.

1999 – Scientists manage to grow organs from patient’s cells and use a 3D printed scaffold to support them.

2002 – A 3D printed miniature kidney is manufactured. Scientists aim to produce full-sized, working organs.

2008 – The first 3D prosthetic leg is produced.

2009 – The first 3D printed blood vessel is produced by Organovo.

2010 – The first 3D printed car (Urbee, Kor Ecologic). In 2014 we had the first fully functional 3D printed car STRATI by Local Motors.

2013 – Cody Wilson of Defense Distributed is asked to remove designs for the world’s first 3D printed gun and the domain is seized.

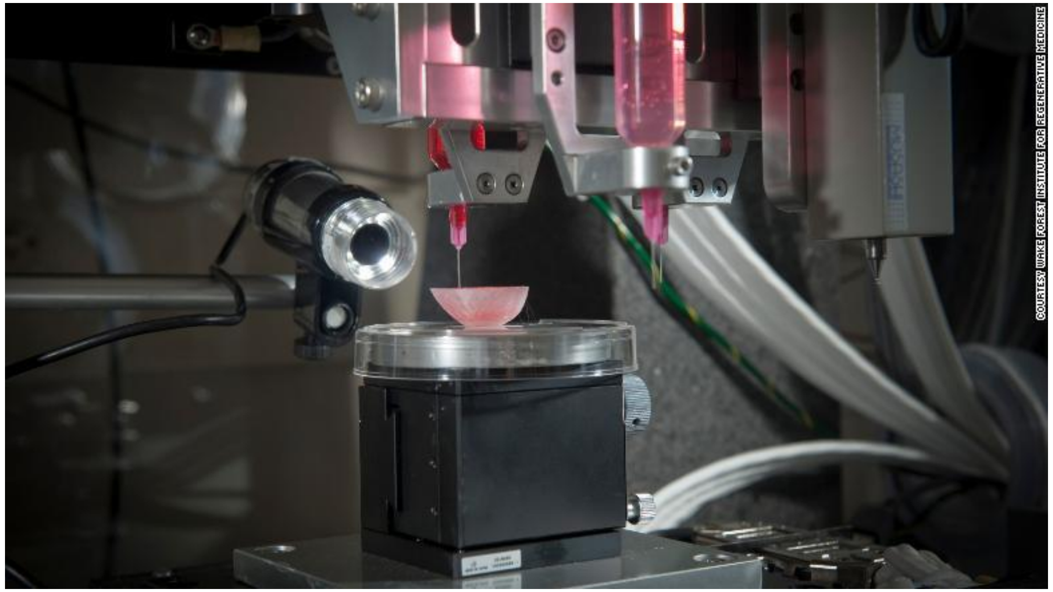
A breakthrough was in 2014 when NASA brought a printer in space on the International Space Station. The next breakthrough is related to 2015 when the first commercial bioink for 3D printing of body tissue was on the market. In one year, scientists were able to print human bone and cartilage. Bioprinting is an emerging technology in producing functional tissue scaffolds based on natural/synthetic polymers to replace injured or diseased tissues.

URBEE

STRATI

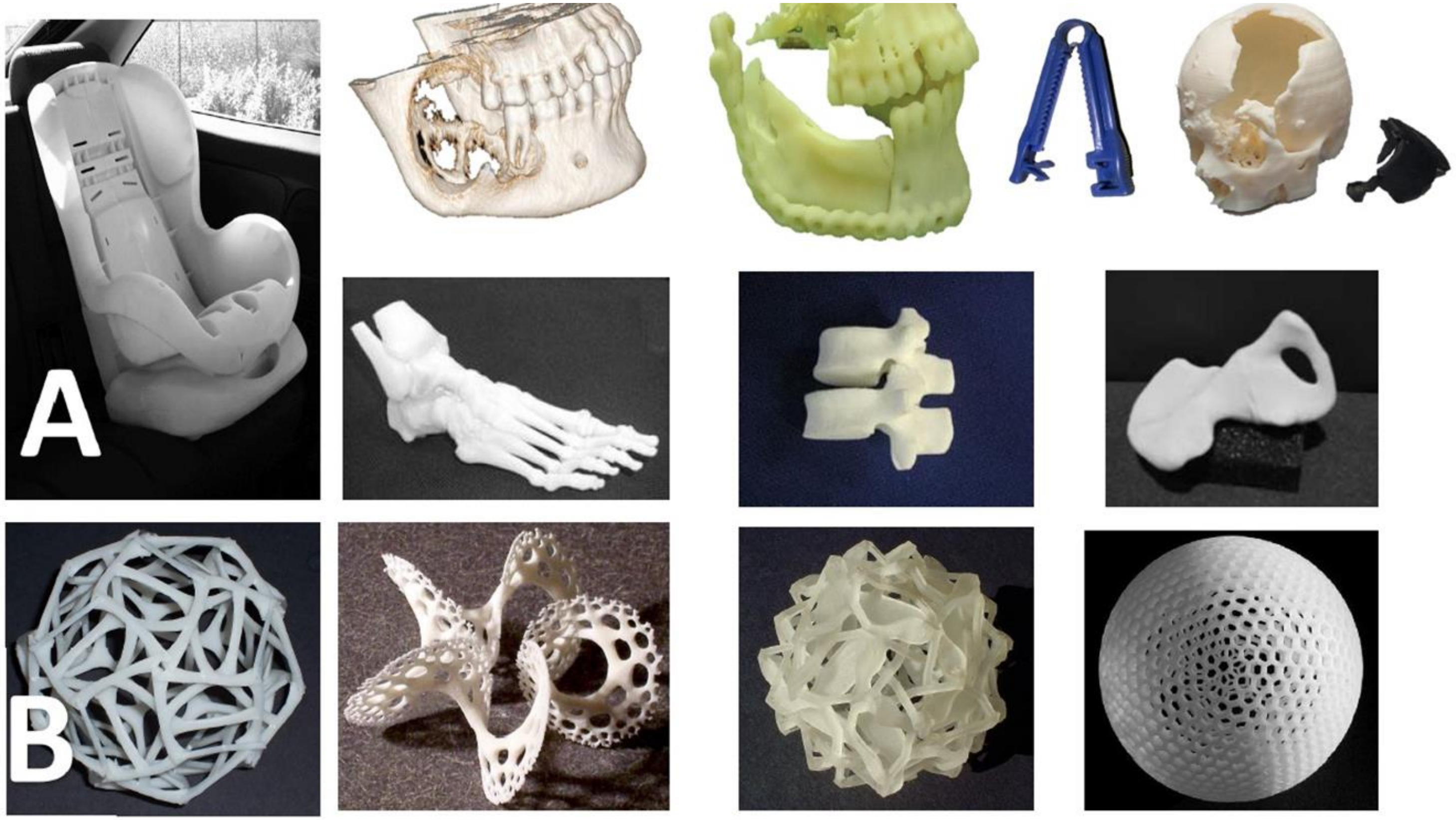
https://newatlas.com/local-motors-strati-imts/33846/ - 44h

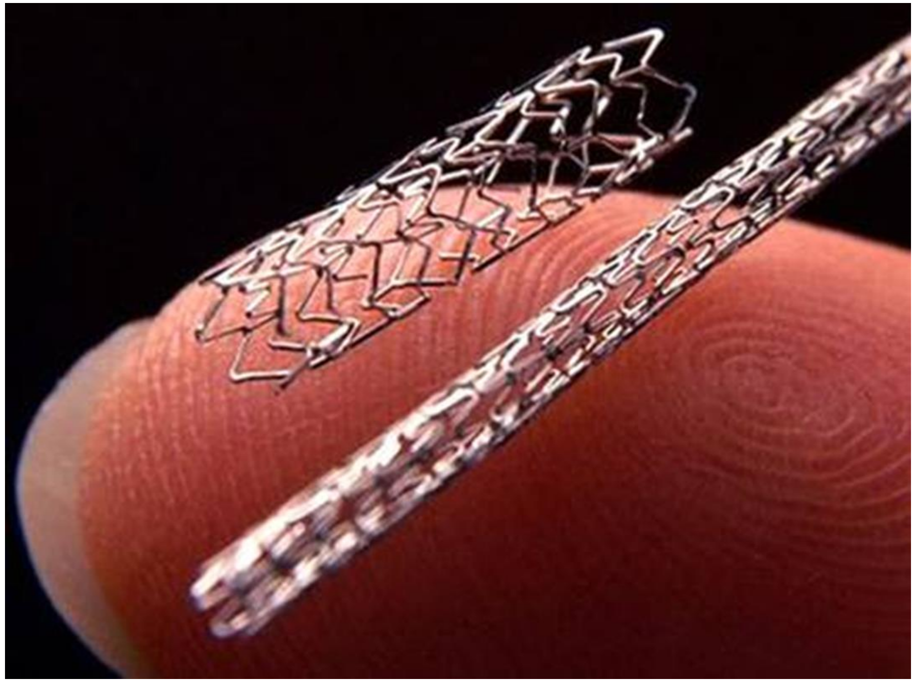
The first 3D-printed kidney, ear and finger (scaffolds).
https://globalnews.ca/news/8872292/3d-printers-building-a-better-world/



https://edition.cnn.com/2022/06/10/health/3d-printed-organs-bioprinting-life-itself-wellness-scn/index.html

This 3D printer seeds various types of cells onto a kidney scaffold at the *Wake Forest Institute for Regenerative Medicine,* Winston-Salem, North Carolina, United States.

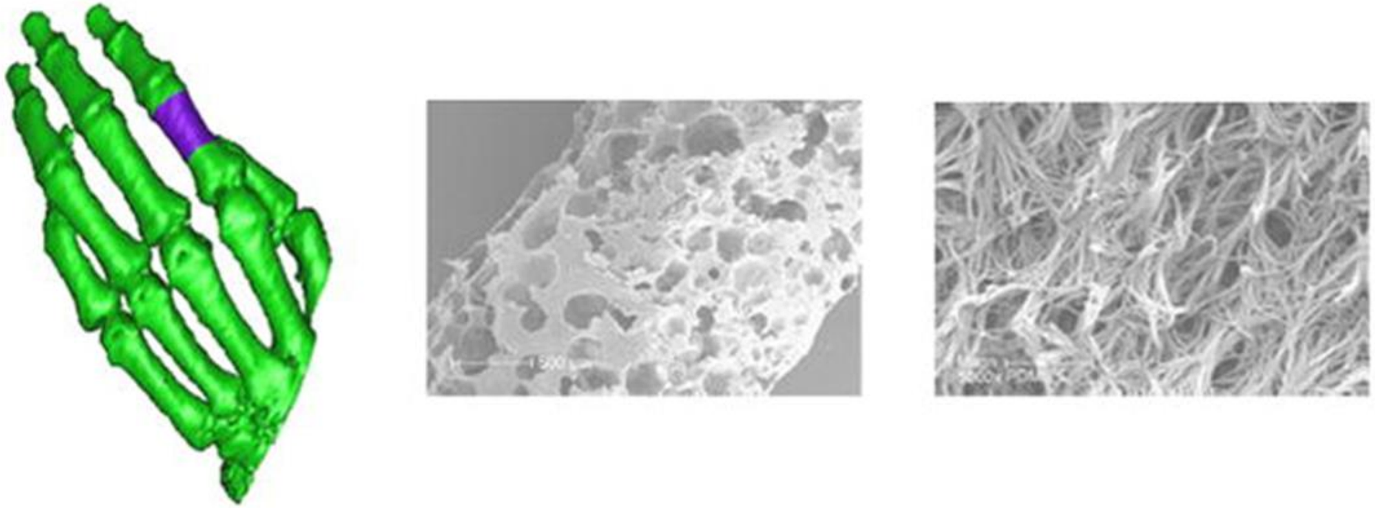

A
B



Dr. Peter Ma's group produced some very exciting research on the design of PLLA-based patient specific scaffolds.

A CT image of a digit was converted to a 3-D structured wax mold through layer-by-layer printing.

By utilizing a solvent-extraction process and paraffin spheres, a 3-D PLLA scaffold that matched the structure of the digit was manufactured.



Conversion of CT images into micro- and nanostructure-controlled PLA scaffolds. A CT image of a hand (left) with a non-traditional defect (shown in purple) is converted into a wax mold which can be filled with PLA to create a scaffold with controllable pore size on the micro scale (center) and fiber size on the nano scale (right).

Bret D. Ulery, Lakshmi S. Nair and Cato T. Laurencin, Biomedical Applications of Biodegradable Polymers, J Polym Sci B Polym Phys. 2011 Jun 15; 49(12): 832–864. doi: 10.1002/polb.22259

2020 - The Fibonacci House in Proctor, the Canada’s first fully 3D-printed home.

The Fibonacci House is located in the Kootenay Lake Village community at Procter, British Columbia in Canada, and could be rented.

The Fibonacci House was printed using a concrete printer designed and sold by Twente Additive Manufacturing.

2021 - Virginia family received the keys to their new 3D-printed home for Christmas. The 1,200-square-foot home has three bedrooms, two full baths and was built from concrete. The technology allowed the home to be built in 12 hours, which saves about four weeks of construction time for a typical home.

2021 - Elize Lutz, 70, and Harrie Dekkers, 67, retired shopkeepers from the Netherlands, received their digital key for a 3D-printed house – an application allowing them to open the front door of their two-bedroom bungalow.

Harrie Dekkers and Elize Lutz outside their 3D-printed house in Eindhoven, the Netherlands. Photograph: Judith Jockel/The Guardian

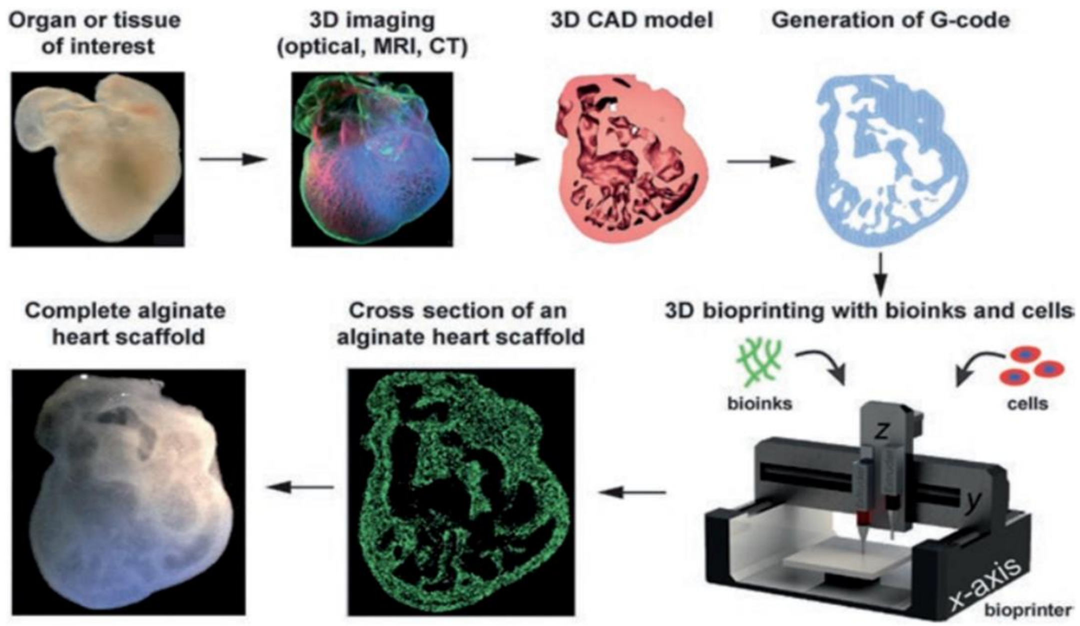
3D BIOPRINTING

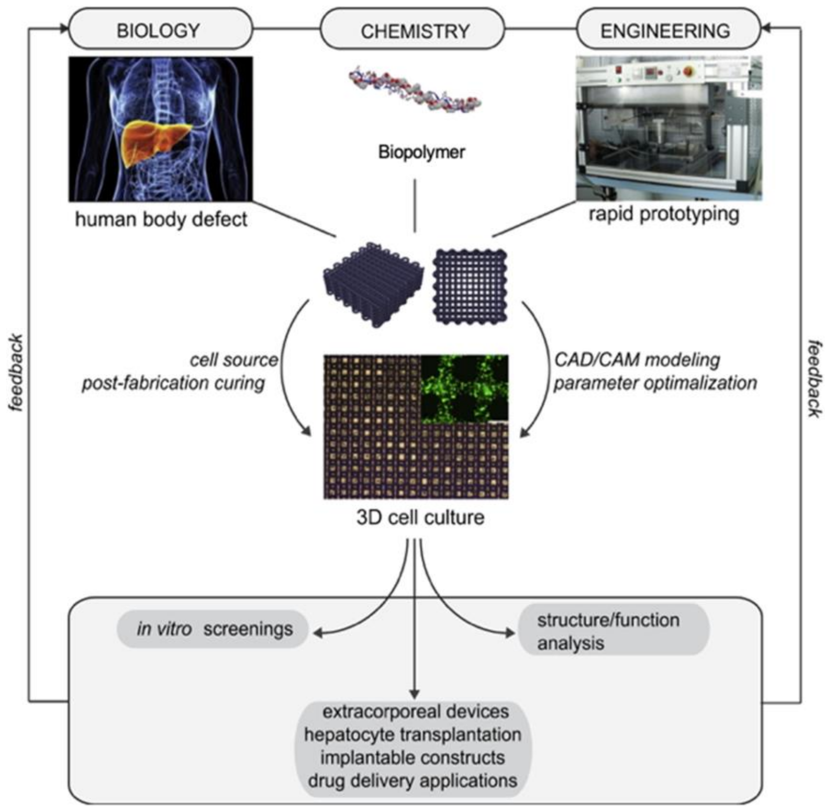
Bioprinting can produce living tissue, bone, blood vessels and whole organs for use in medical procedures, training and testing.

Bioprinting could generate patient-specific tissue for the development of accurate, targeted and completely personalised treatments.

“Biofabrication can be defined as the production of complex living and non-living biological products from raw materials such as living cells, molecules, extracellular matrices, and biomaterials” – Mironov 2015.

Ramiah P, du Toit LC, Choonara YE, Kondiah PPD and Pillay V (2020) Hydrogel-Based Bioinks for 3D Bioprinting in Tissue Regeneration. Front. Mater. 7:76. doi: 10.3389/fmats.2020.00076

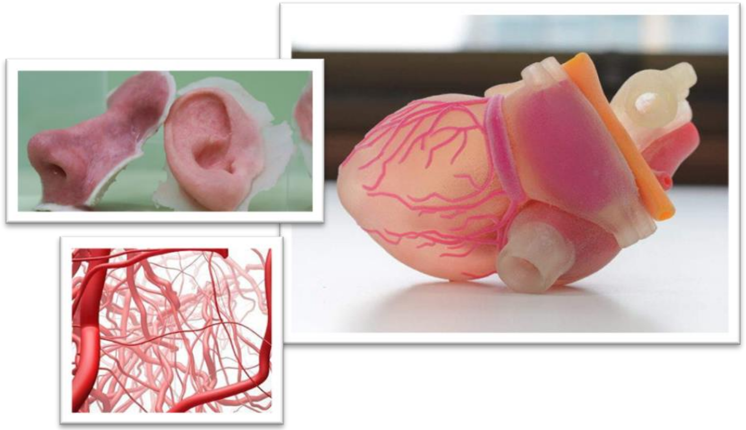


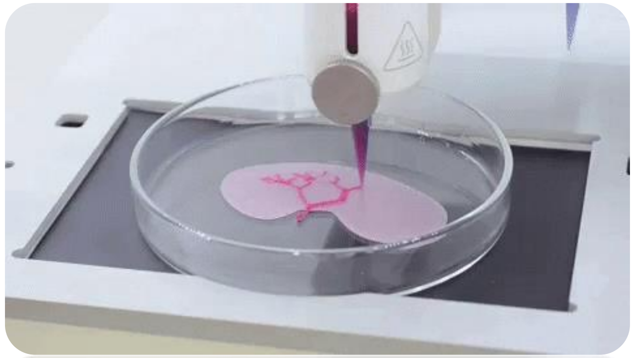


3D bioprinting can be used to produce biomimetic structures based on a CT image obtained from a patient's damaged or injured body organ.

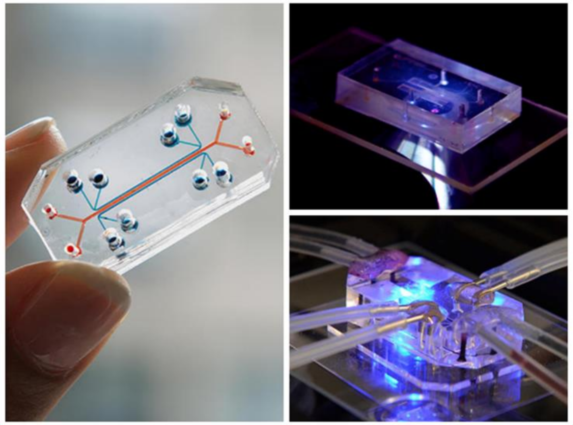
Ultra performance 3D bioprinter at POLITEHNICA Bucharest

- ✓ Natural and synthetic 3D structures
- ✓ Cells incorporation
- ✓ Bioconstructs that stimulate the architecture and properties of biological tissues





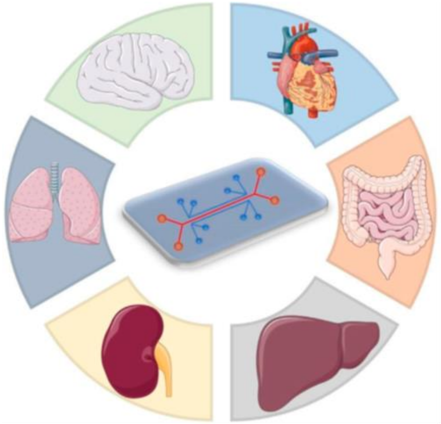
ORGAN ON-A-CHIP (OOC)

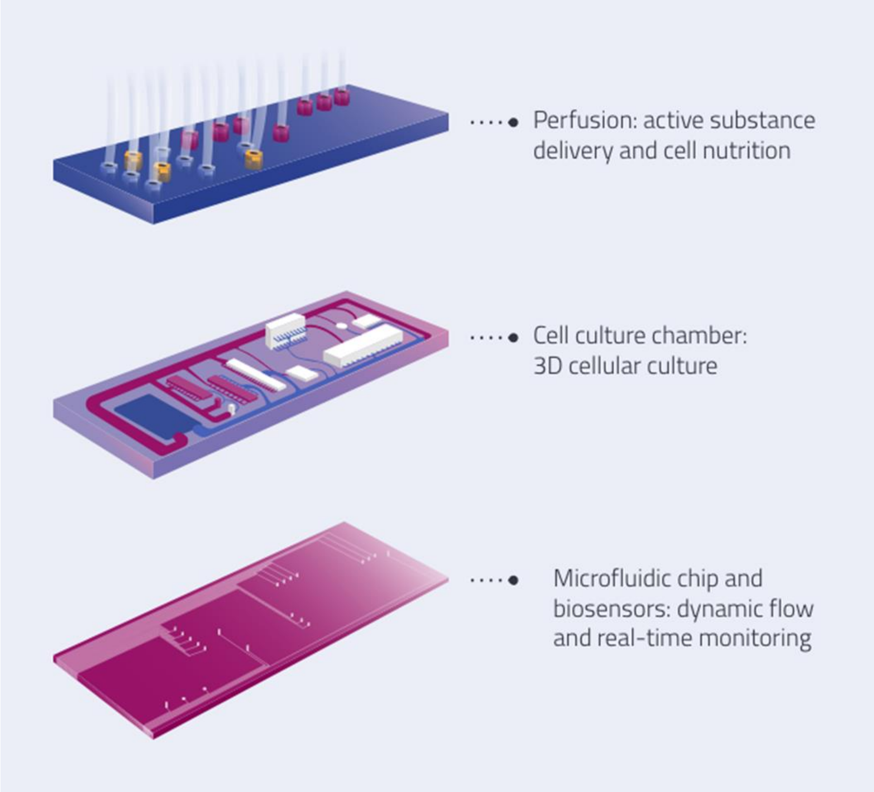


OOC is a biomimetic system that can mimic the environment of a physiological organ, with the ability to regulate key parameters including concentration gradients, shear force, tissue-boundaries, and tissue–organ interactions.

The major aim of this system is to simulate the physiological environment of human organs.

“An Organ-on-Chip is a fit-for-purpose microfluidic device, containing living engineered organ substructures in a controlled microenvironment, that recapitulates one or more aspects of the organ’s dynamics, functionality and (patho)physiological response in vivo under real-time monitoring” - https://euroocs.eu/organ-on-chip/



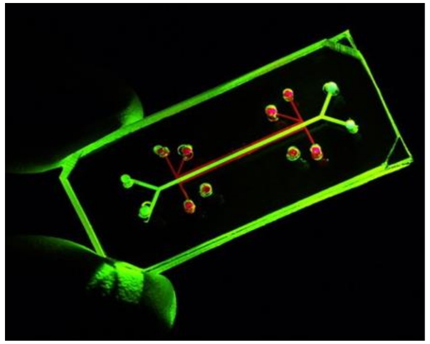


https://euroocs.eu/organ-on-chip/

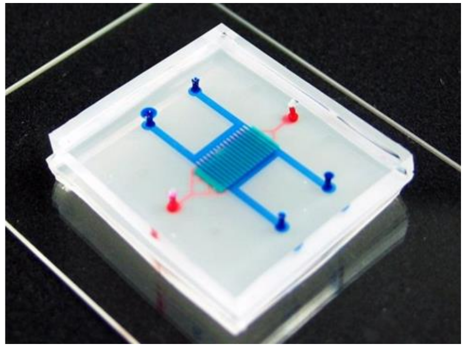
Multi-channel 3-D microfluidic cell culture, integrated circuit (chip) that simulates the activities, mechanics and physiological response of an entire organ or an organ system.

SINGLE OOC

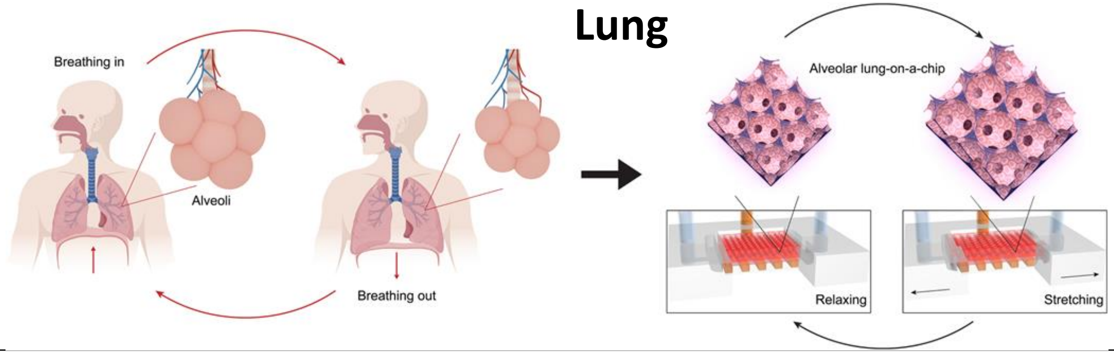
Brain



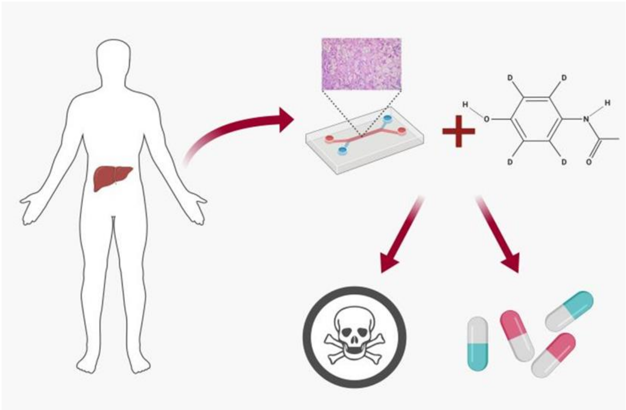
Heart



Lung



Liver



Blood vessels

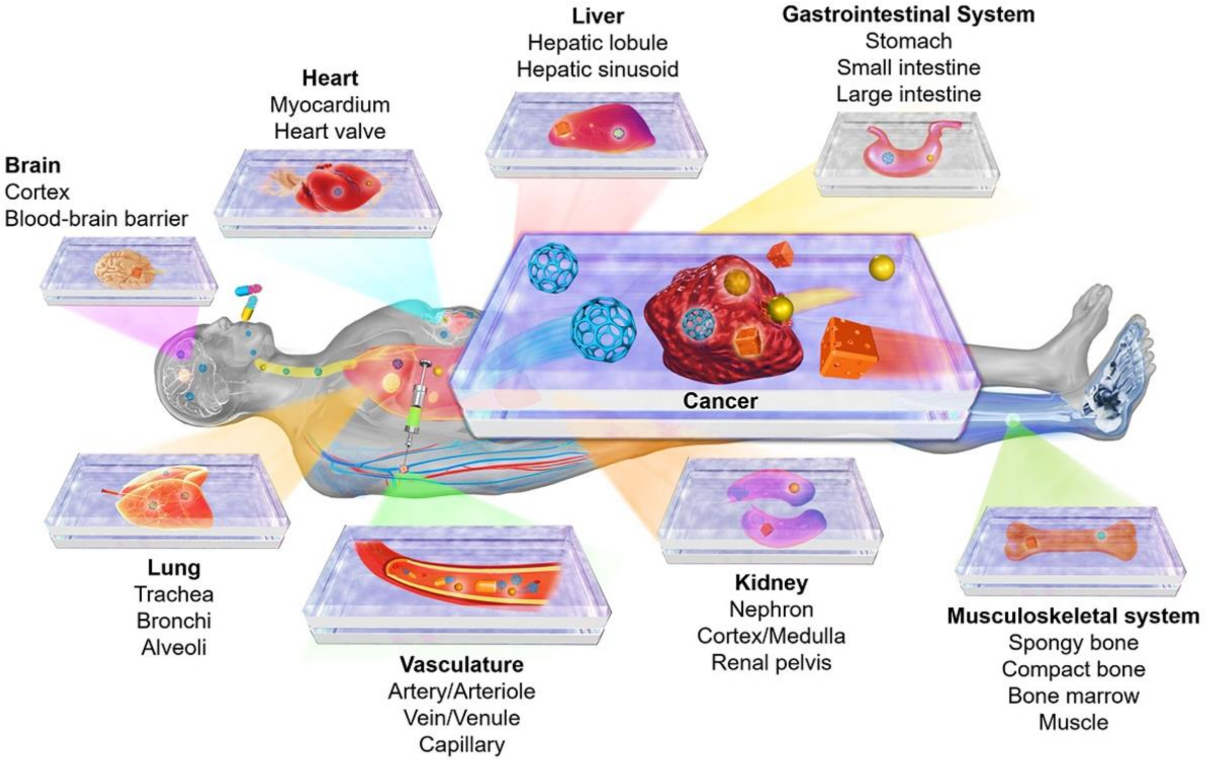
Intestine

Skin

Cancer

MULTI OOC

Human on-a-chip



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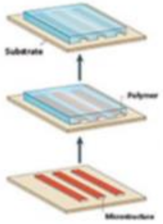
FABRICATION TECHNIQUES FOR OOC

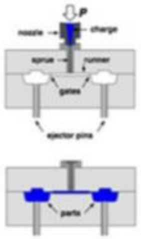


Soft-lithography

- Combination of photolithography and molding
- Suitable for elastomeric materials

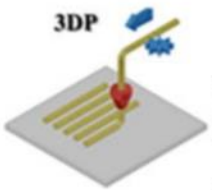
Hot Embossing

- Requires master mold fabrication
- Suitable for polymeric materials



Injection Molding

- Requires master mold fabrication
- Low-cost high precision microfabrication suitable for batch production



3D Printing

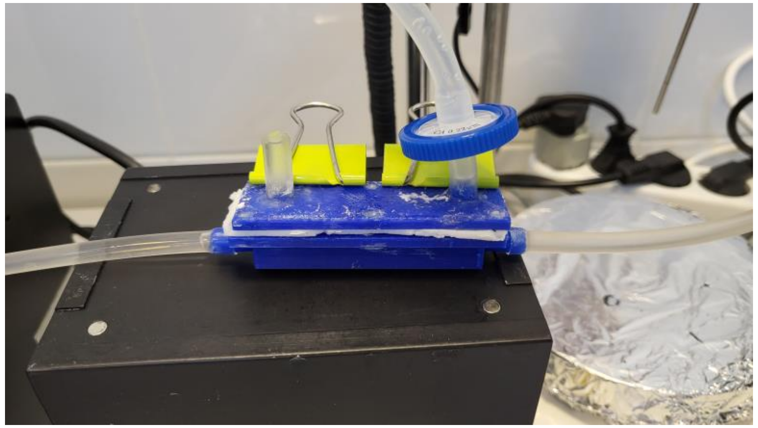
- Supports both additive and subtractive manufacturing
- Used for master preparation

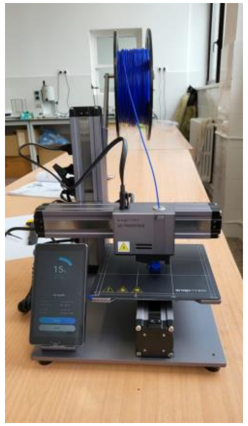
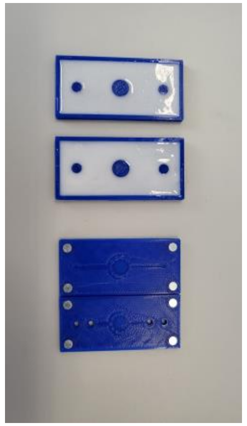
SLA, DLP

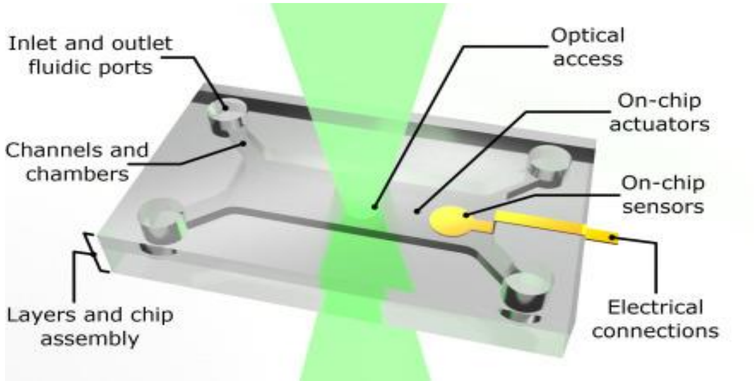
3D Bioprinting

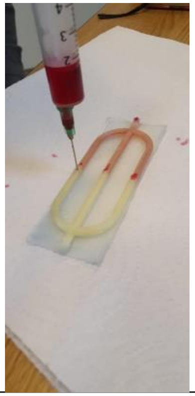
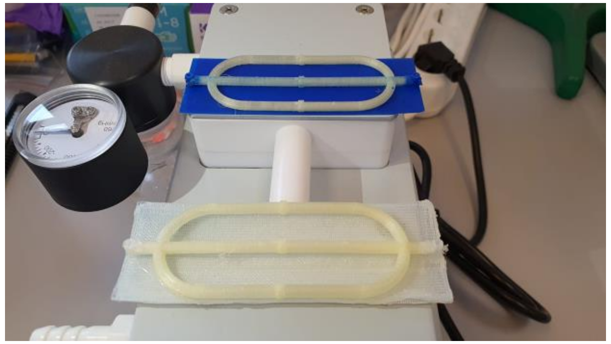
FDM

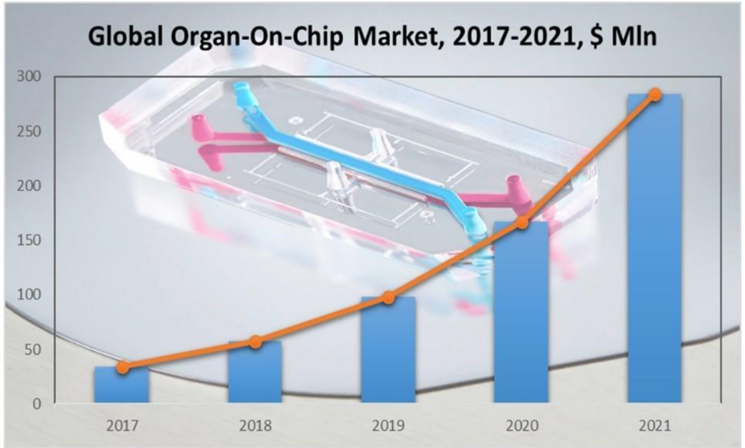
ORGAN ON-A-CHIP MODELS IN OUR GROUP

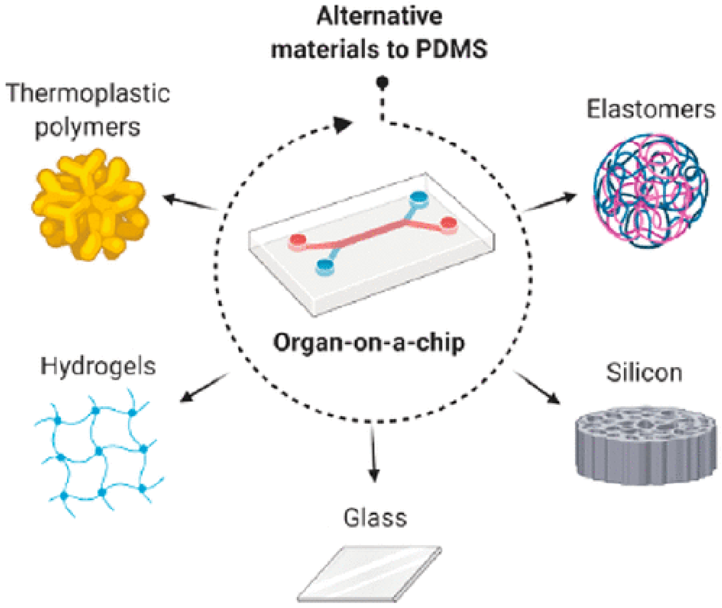





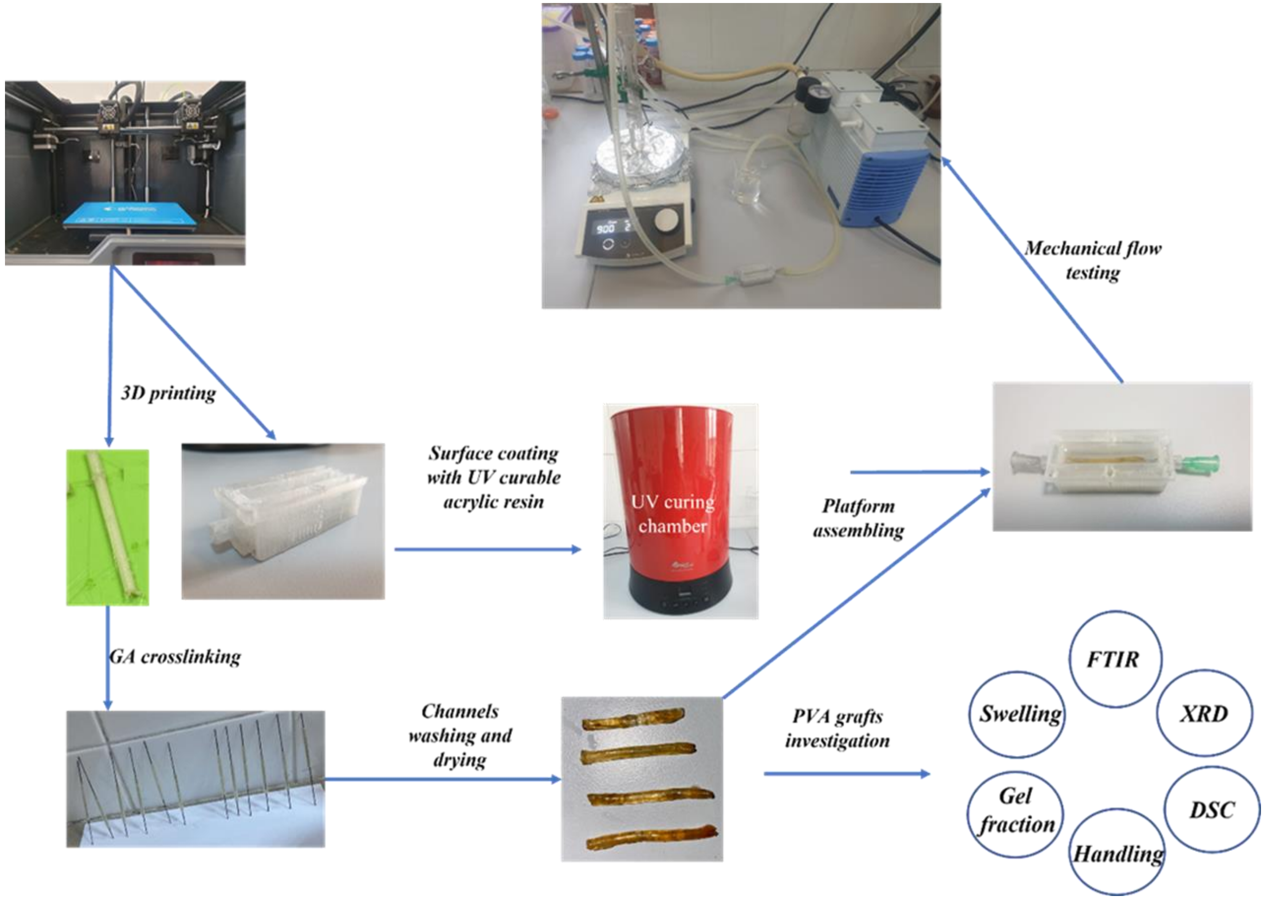


Source: The Business Research Company



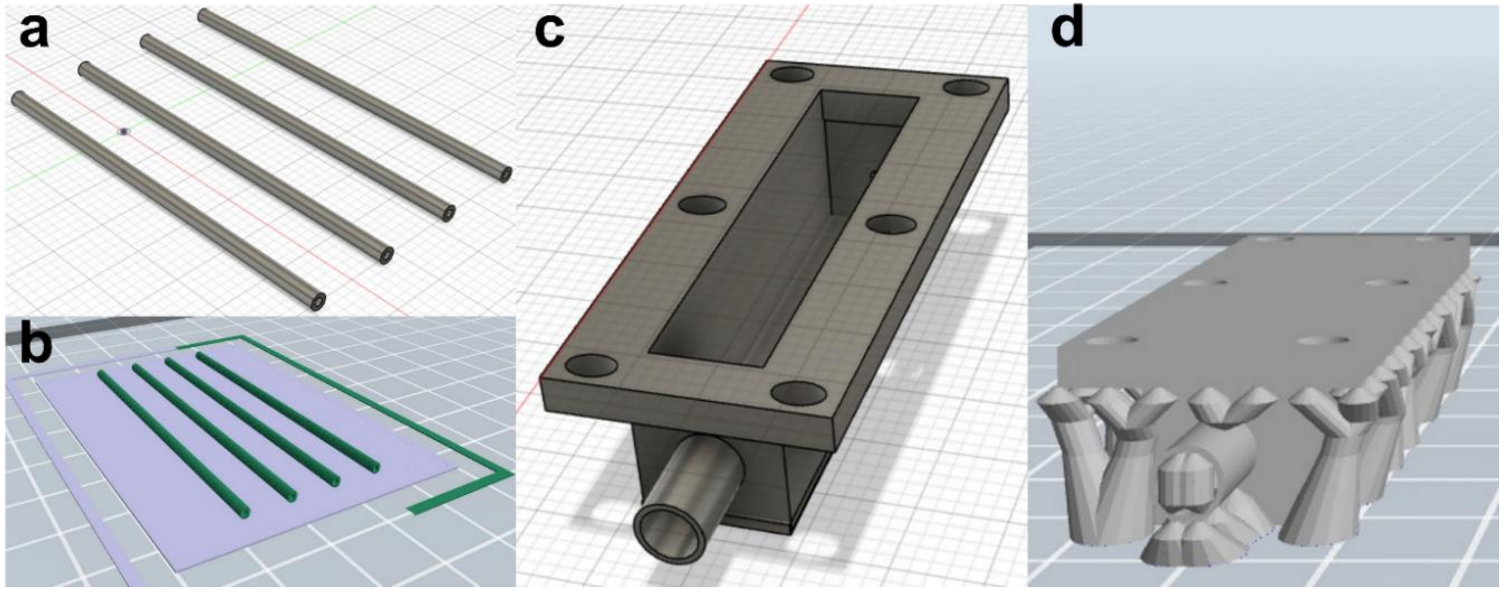
Alternative Materials to PDMS for Organ-on-a-Chip

https://www.prnewswire.com/news-releases/organs-on-chips-to-revolutionize-the-drug-development-industry-300569606.html



ARTIFICIAL BLOOD VESSES BY 3D PRINTING (FDM) – APMG LABS

C. Zaharia et.al., ENGINEERED 3D-PRINTED POLYVINYL ALCOHOL VASCULAR GRAFTS. IMPACT OF THERMAL TREATMENT AND FUNCTIONALIZATION, International Journal of Bioprinting, IF 8.4, 2024, in press



Computer-aided design of the channel and platform:

a – 3D representation of the channels in Fusion 360 software; b - 3D representation of the channels in the 3D printer software; c – 3D representation of the PETG platform in Fusion 360; d - 3D representation of the PETG platform the 3D printer software

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Erasmus+ Programme Key Action 2 Cooperation Partnerships
for Higher Education (KA220-HED)

Agreement number 2023-1-RO01-KA220-HED-000155412

European Network for Additive Manufacturing in Industrial Design for Ukrainian Context
Staff Training (STTE) – Edibon International S.A., Madrid, Spain, 7-10 May 2024