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3D Printing for medicinal chemistry in space: Crafting our way to Mars

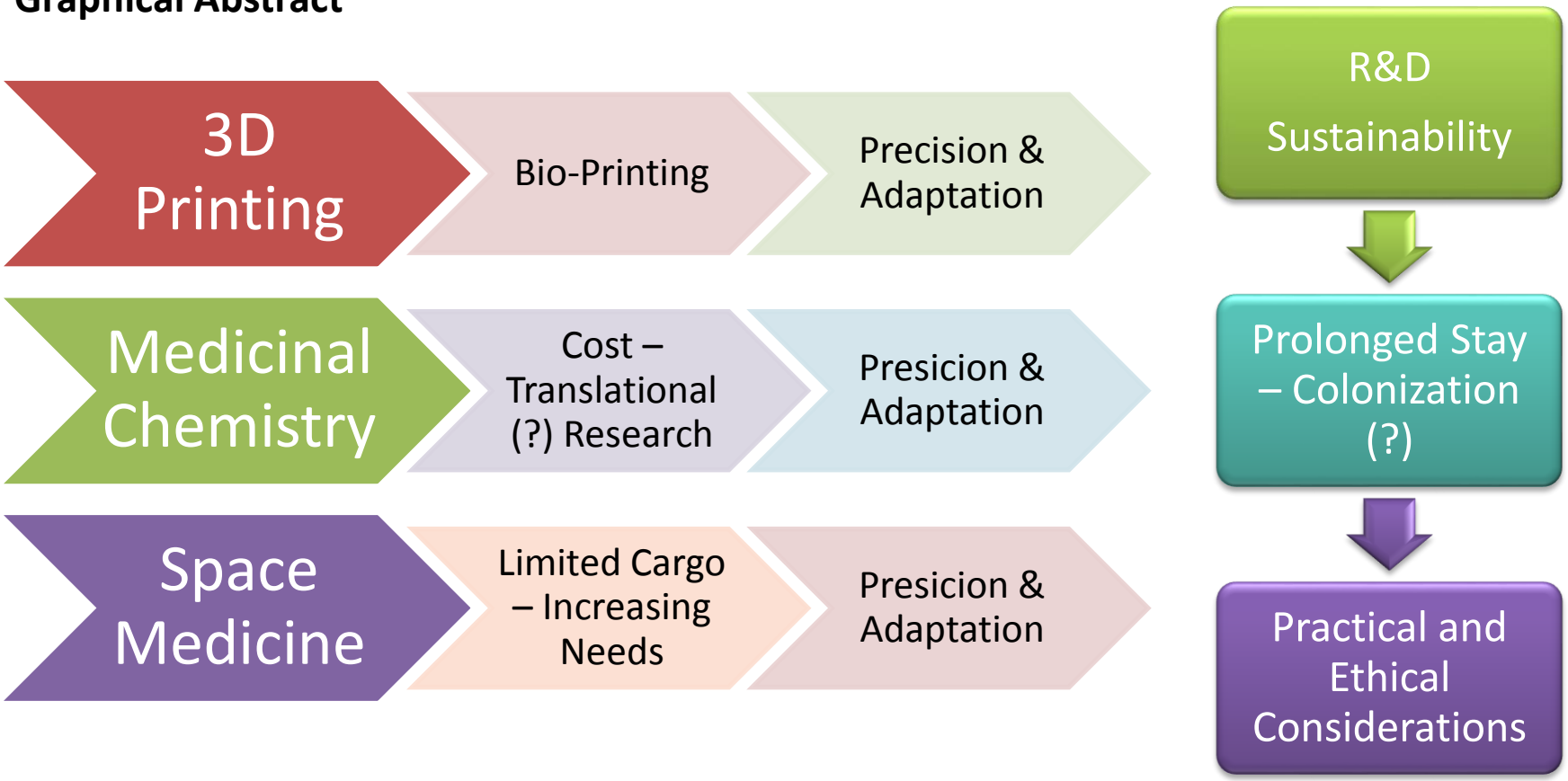
Christos Tsagkaris[1,*], Andrea Camera[2], Ana Sofia Mota[3] and Maria Lydakaki[2]

[1] University of Crete, Faculty of Medicine (Heraklion, Greece)
[2] University of Brescia, Department of Clinical and Experimental Science (Brescia, Italy)
[3] University of Lisbon, Faculty of Medicine (Lisbon, Portugal)
[4] University of Athens, Faculty of Law (Athens, Greece)

* Corresponding author: chriss20x@gmail.com

3D Printing for medicinal chemistry in space: Crafting our way to Mars

Graphical Abstract



Abstract:

Three Dimensional Printing (3DP) is an emerging component of Medicinal Chemistry (MC). Space provides a challenging environment where 3DP and MC can offer great services. We first present an overview of existing and emerging applications of the 3DP - MC intersection in Space and we then discuss some debatable aspects from a legal point of view.
This is a literature study. 3DP equipment has recently been installed in the International Space Station marking a revolution in Space Research. In the future 3DP is expected to play a crucial role in Space Exploration as well through long term missions or even colonization of the Moon or Mars. The repercussions of such a 3DP - MC coalition are also expected to have an impact on Earth. Remote healthcare facilities, single laboratories and pharmacists and potentially any trained individual will be able to produce medication and biomaterials. Such a potential hides a considerable amount of controversy. Liability and safety issues, patent obtaining procedures and transferability of Space 3DP - MC research findings to Earth consist of emerging concepts in the field of Space Jurisdiction.

Keywords: Space;3D Printing;Jurisdiction

Introduction

Three Dimensional Printing (3DP): Fabrication of objects through the deposition of a material using a print head, nozzle, or another printer technology

3DP is an emerging component of Medicinal Chemistry (MC)

Space provides a challenging environment

3DP and MC can offer great services expanding their borders with regard to **pharmaceutical design** and **tissue engineering**

Introduction

- ✓ 3DP equipment has recently been installed in **the International Space Station** (ISS) marking a revolution in Space Research
- ✓ 3DP in Space has been a synonym to **Additive Manufacturing** (AM)
- ✓ Astronauts will soon be able **to print medication**, instead of receiving it from Earth, or even **grow tissues** such as skin grafts in case of injuries
- ✓ **Clinical trials** or **pharmaceutical design** experiments may be also carried out in microgravity
- ✓ 3DP mediated MC research in Space investigates also the **recycling** of previously used materials or even debris in pharmaceutical design and bioengineering.

Methods

This is a literature study.

We searched biomedical (Pubmed, Google Scholar) and tech – oriented (InTech) databases

Key words (3D Printing, Medicinal Chemistry, Space).

Official websites and depositories of national or international Space Agencies.

Results

- Existing Applications
- Future Applications and Prospectives

The International Space Station

International Space Station 3D Printer
Credit: NASA

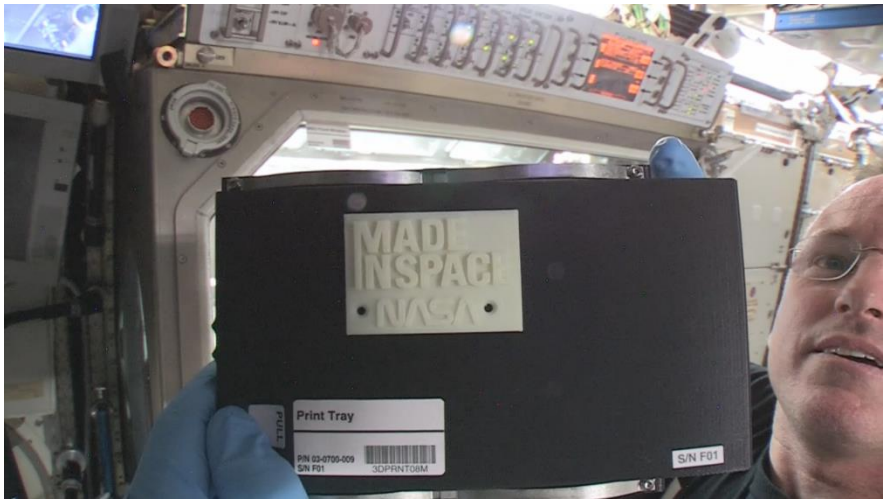
In Space Manufacturing Initiatives : Overview and Update. NASA 2018. R.G. Clinton Jr.

Existing Applications

The ISS is currently the only test bed for investigating the effects of consistent microgravity on additive manufacturing.

NASA's 3D Printing Mission

- NASA's 3D printer was the first 3D printer to operate into space, on board of the International Space Station.
- The 3D Print used extrusion-based additive manufacturing, which involves building an object out of plastic, in this case ABS, deposited by a wire feed via an extruder head.
- It was developed under a contract with the startup Made In Space.
- The 3D Print payload was launched via a Falcon 9 rocket on 21 September 2014.
- The Phase I printing occurred from 24 November 2014 to 15 December 2014.
- The Phase I prints were brought to Earth on 10 February 2015.



The first 3D printed object in space
Credit: Made In Space/NASA

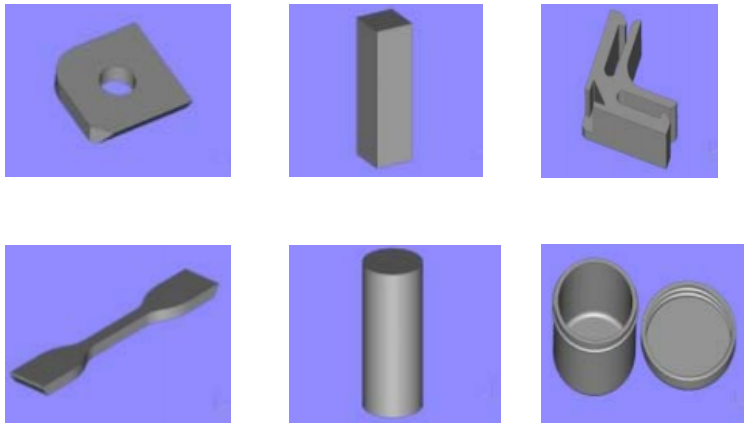
Bean QA, Cooper KG, Edmunson JE, Johnston MM, Werkheiser MJ. International Space Station (ISS) 3D Printer Performance and Material Characterization Methodology.

Main goal of NASA's 3D Printing Mission

Technical understanding of the physics affecting the material characteristics of 3D printed parts in microgravity

Specific Objectives:

1. Perform extrusion-based additive manufacturing with ABS filament material on-board the ISS.
2. Demonstrate nominal extrusion and traversing activities.
3. Perform 'on-demand' print capability via computer-aided design (CAD) file uplink for requested parts as defined.
4. Mitigate functional risks and design risks for future facilities and technology advancements.
5. Test print volume scalability 6. Replace and refill filament material (i.e., feedstock) on demand.
6. Perform science, technology, engineering, and mathematics (STEM) outreach

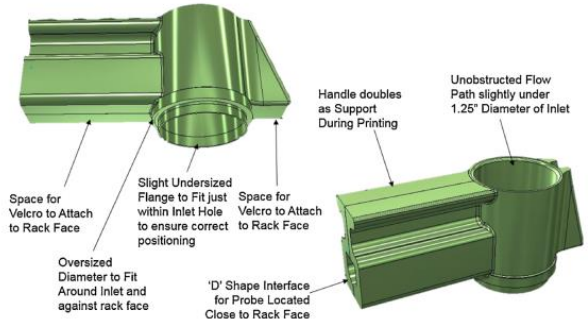


Examples of printed items

Bean QA, Cooper KG, Edmunson JE, Johnston MM, Werkheiser MJ. International Space Station (ISS) 3D Printer Performance and Material Characterization Methodology.

ISS 3D Printing of Oxygen Generator System (OGS) Velocicalc Adapter

Attempt at the use of the payload 3D printers onboard the ISS to produce a device for use in nominal space station operations. It was conducted in 2016.



First part proposed for 3D printing and use on the ISS

<u>This process demonstrated the feasibility of the use of an onboard 3D Printer to benefit nominal ISS Operations.</u>

Since that, several more functional parts were printed on board of the ISS

O'Hara WJ, Kish JM, Werkheiser MJ. Turn-key use of an onboard 3D printer for international space station operations. Addit Manuf. 2018;24(October):560–5

Made in Space's second generation printer: Additive Manufacturing Facility

Enclosure for radiation monitors

Antenna Feed Horn

In Space Manufacturing Initiatives : Overview and Update. NASA 2018. R.G. Clinton

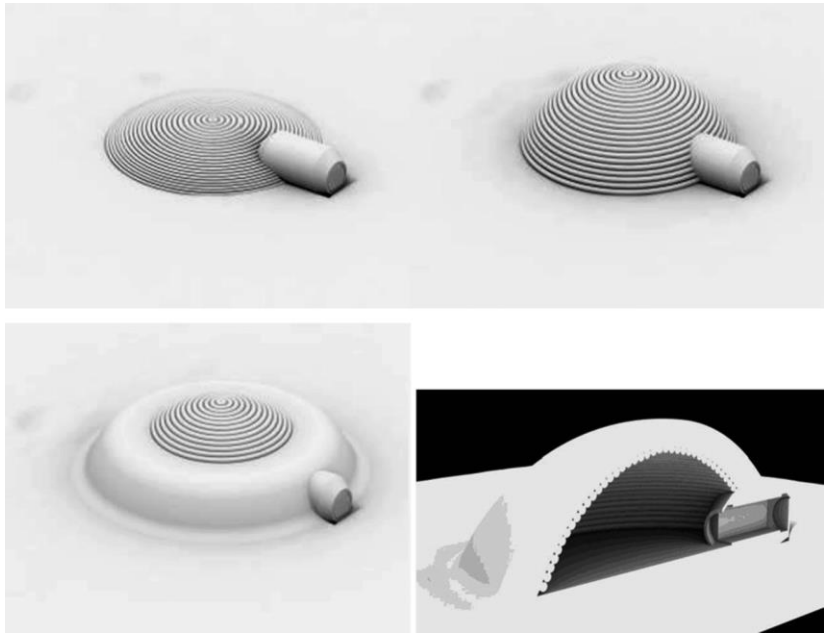
Plastic recycling in a microgravity environment for long duration missions

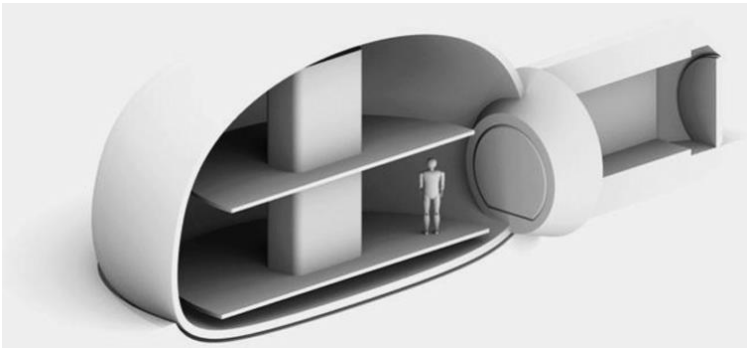
In Space Manufacturing Initiatives : Overview and Update. NASA 2018. R.G. Clinton

Future Applications and Prospectives

Towards the Deep Space Gateway and beyond !
Credit: European Space Agency

3D Printing Technologies for a Lunar Soil Outpost

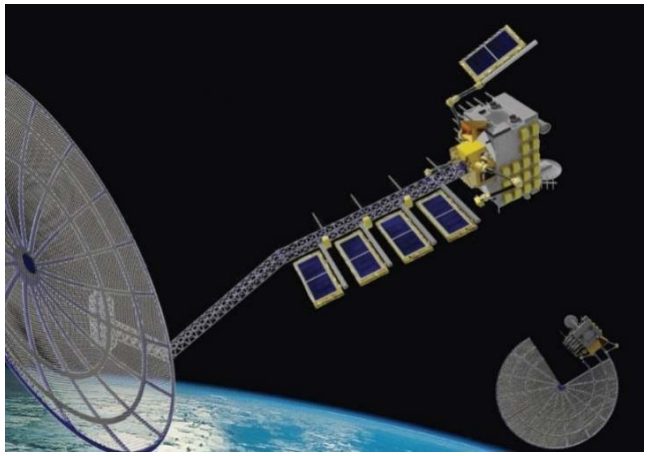




Exploiting in-situ resources for the construction of buildings in harsh spatial environments.

Cesaretti G, Dini E, De Kestelier X, Colla V, Pambaguian L. Building components for an outpost on the Lunar soil by means of a novel 3D printing technology. Acta Astronaut. 2014

In-Space Robotic Manufacturing and Assembly (IRMA)



Archinaut

Made in Space, Northrop Grumman Corp., Oceaneering Space Systems, Ames Research Center

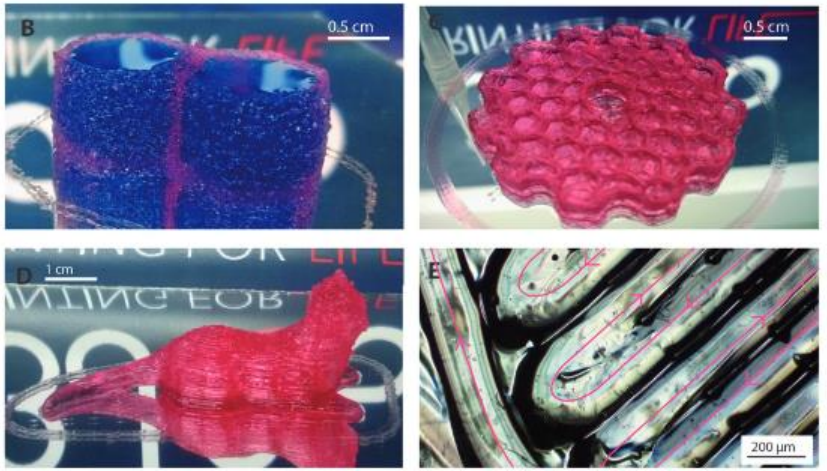
Dragonfly

Space Systems/Loral, Langley Research Center, Ames Research Center, Tethers Unlimited, MDA US & Brampton

In Space Manufacturing Initiatives : Overview and Update. NASA 2018. R.G. Clinton

3D Bioprinting for Regenerative Medicine to Support Human Space Exploration

Wake Forest Baptist Medical Centre
Winston-Salem, North Carolina, USA

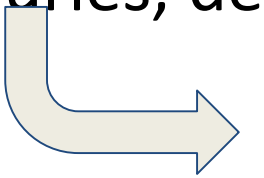


Léa J. Pourchet et al, Adv. Healthcare Mater.2017, 6, 1601101

Why is 3D useful for Space Missions ?

Actual Problems

- Resources utilization
- Sterilization
- In flight screening, diagnosis and treatment
  - Bone fractures, musculoskeletal injuries, dental care



On-site production

On demand

Decrease in overall launch mass

Recycling

Costs

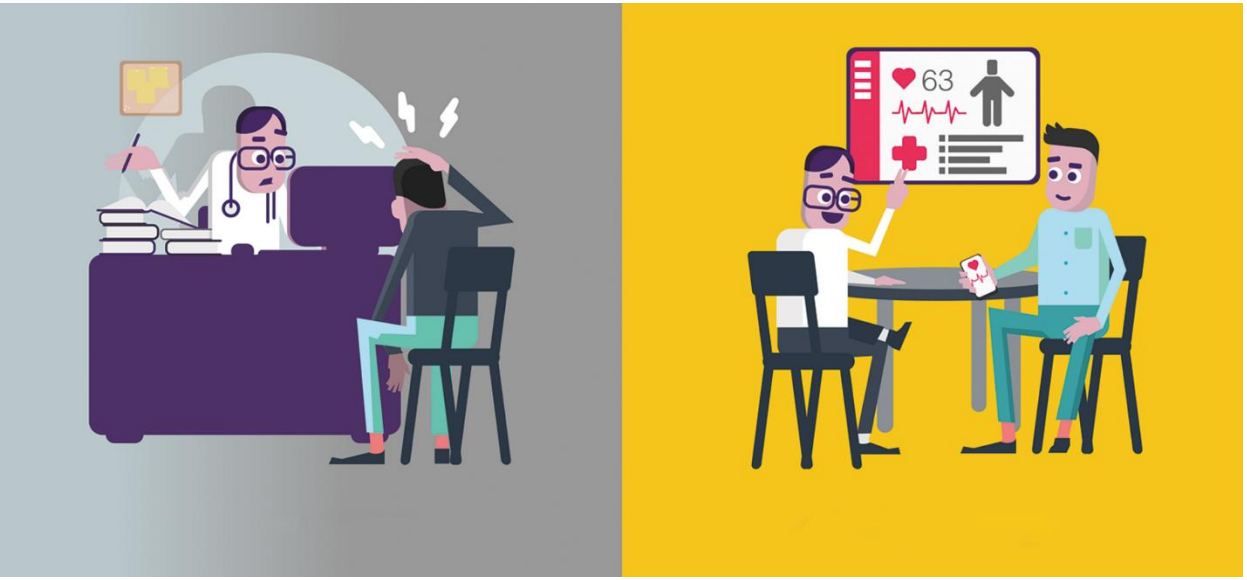
Depends on the material !

As each kilogram launched into space is very expensive, 3D-printing considerably reduces the mission costs !

BUT...

FedTech Magazine (2019). *International Space Station Expedition 42 Commander Barry "Butch" Wilmore shows off a ratchet wrench made with a 3D printer on the station*

Digital Health and Space Medicine



"the cultural transformation of how disruptive technologies that provide digital and objective data accessible to both caregivers and patients leads to an equal level doctor-patient relationship with shared decision-making and the democratization of care"

Digital Health and Space Medicine

Disruptive Technology	Medical Use
Virtual reality	Reduce pain and anxiety
Health sensor	Improving physical exercises, monitoring vital signs, improving sleep quality
Augmented reality	Better preparation for surgical procedures
Gamification	Improving compliance and monitoring
Telemedicine	Improving access to care
Direct-to-consumer genomics	Assessing risks for medical conditions
Portable diagnostic devices	Makes patients the point-of-care
3D printing	Producing medical equipment, drugs, casts, biomaterials, prosthetics
Narrow artificial intelligence	Supporting medical decision-making
Surgical robots	Performing semiautonomous procedures

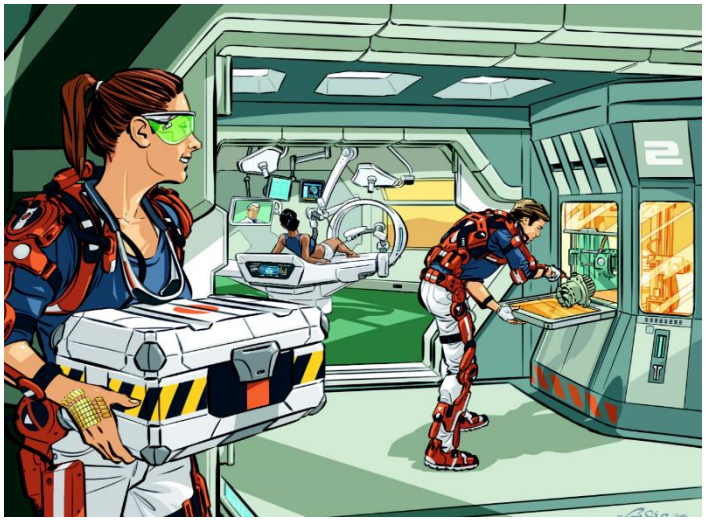
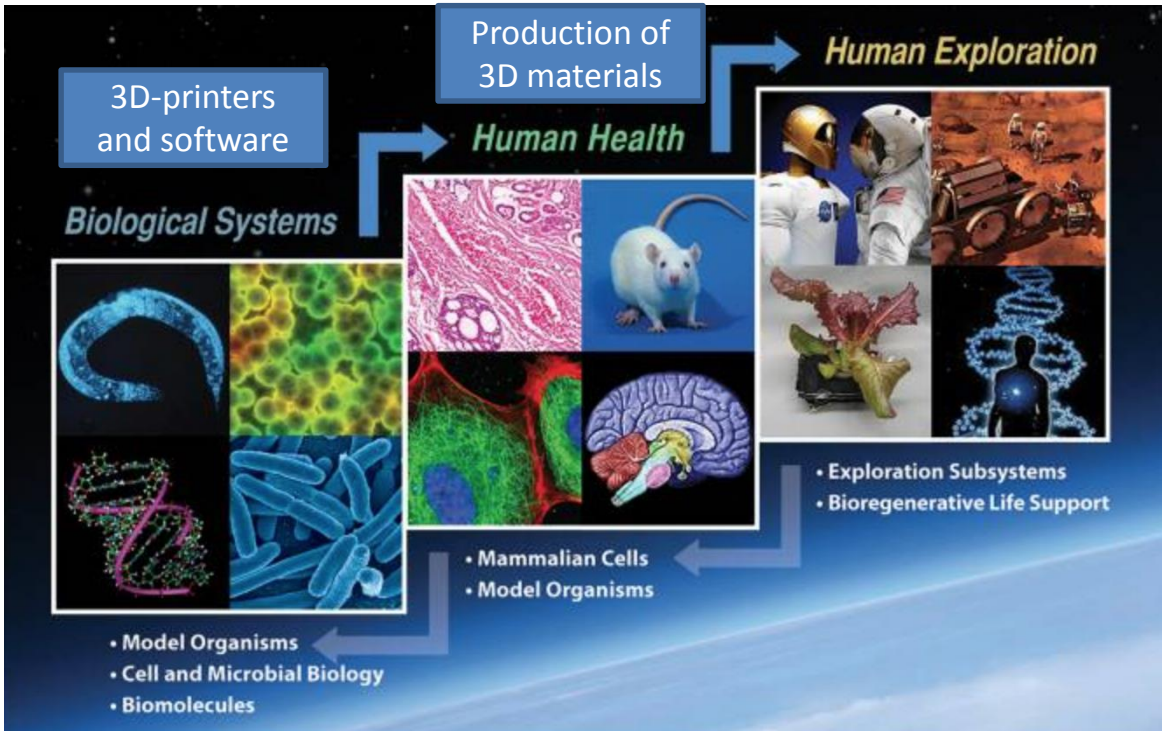


Table and Image taken from: Mesko, B. (2018). Digital Health Technologies to Support Human Missions to Mars. *New Space*, 6(2), pp.109-116.

3D-Printing: An example of Translational Research



The NASA Life Sciences Translational Path.

Considerations

Each coin has two sides

The expansion of 3DP research and application with regard to MC in Space may face considerable legal and ethical obstacles.

From a legal point of view, we address

1. Critical Concepts of Legislation, accepted in international level

- *Public Law*
- *Civil Law*

2. Legislative Proposals and Motions issued by significant institutions and key players in the field

- *FDA*
- *EU*
- *ISO*

Legal Considerations

- **Public law, Field of Fundamental Rights:**

Bioprinting for research purposes ⇨ under the protection of academic freedom.

The commercialization of the products ⇨ debate (similar to cloning) concerning the nonhuman use of technology, as well as the possible violation of human rights (unequal access to such services = indirect discrimination).

If carefully restricted, 3D bioprinting could put an end to illegal organ trade and lawfully facilitate transplants.

Legal Considerations

Civil Law, Field of Intellectual Property:

Ownership – Copyright – Patent: ⇨ Who owns the products?, Could one patent a nature's design, organs?

- Processing of sensitive **personal data** ⇨ used to achieve compatibility.
- Who has **jurisdiction** since the whole procedure takes place in space?

Legislation

- **Food and Drug Administration of the US**, May 2016:

"Technical Considerations for Additive Manufactured Medical Devices". (Draft)

This guidance does not establish any rights for any person and is not binding on FDA or the public.

- **EU:** These products are currently regulated as medicinal products.

Documents and reports with legislative and regulatory recommendations are published. (Joëlle Bergeron's report is adopted by MEPs).

- **ISO/TC 261**. Additive manufacturing:

The International Organization for Standardization has published six standards, concerning general principles on process, test methods, data processing and so on.

European Parliament

Acknowledgments

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We declare no conflict of interest

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Thank you for your attention!

Jules Vernes, From the Earth to the Moon, Animated Illustration, Source