Advanced Space Architecture and Infrastructure

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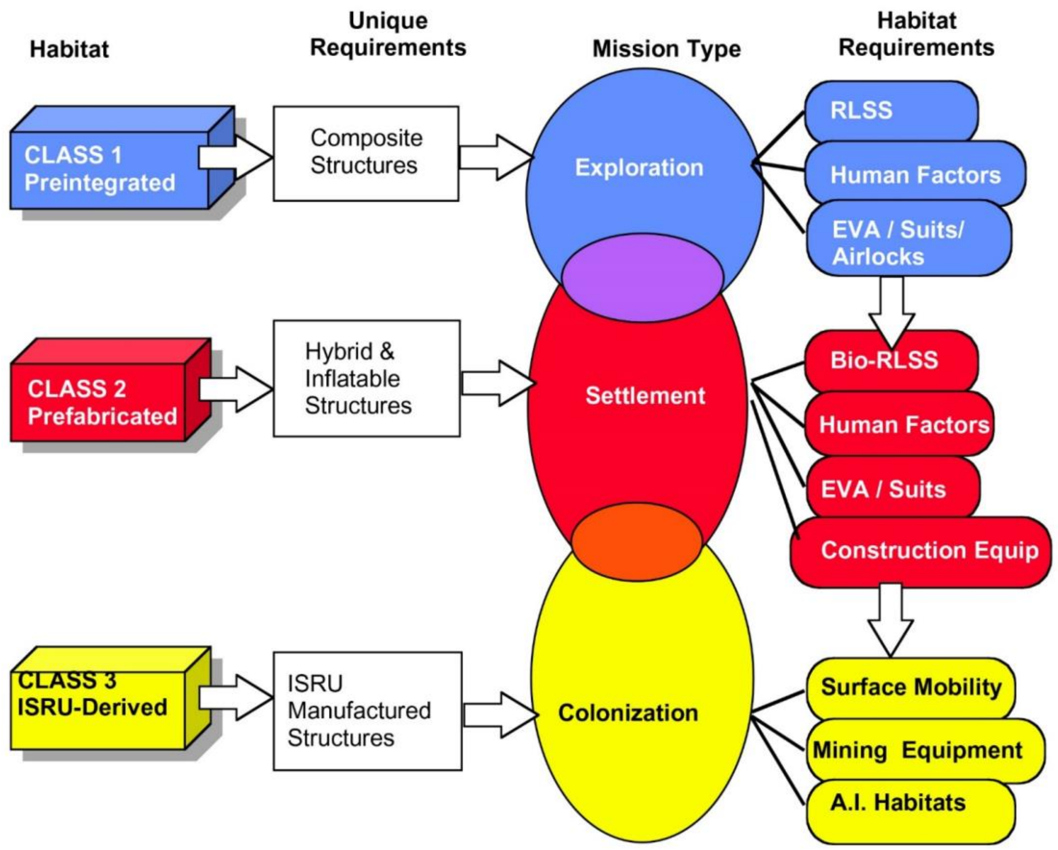
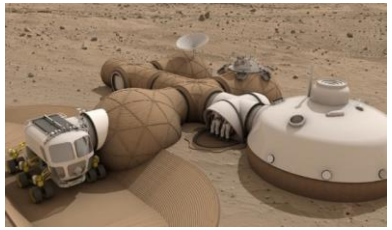
Space Architecture

The advancement of habitat technology is highly dependent on the duration of the mission, distance from the Earth and the environment of the destination



***Classification of space habitats,** Smith, 1993*



What and why:

1. Research at the ACT typically looking 30 to 50 years into the future

2. Therefore, mostly focussing on most advanced habitat technologies through in-situ resource utilization (ISRU) related research: how to construct habitats and infrastructure from local materials (CLASS 3) using various advance manufacturing technologies

3. For many science and technology development activities it is necessary to establish prolonged presence in space which increases the length of the missions

4. To live and work in deep space for months or years mean that crew members have less immediate access to the life-sustaining elements and critical supplies readily available on Earth

5. Resupply missions are expensive and take time

6. Therefore, the farther humans go into deep space, the more important it will be to become self-sustaining, to generate products with local materials, a practice called in-situ resource utilization (ISRU)

Moon Fibre

Project Team:

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Alexander Niecke
Tobias Meinert

ESA, Advanced Concepts Team:
Hanna Läkk
Advenit Makaya

ESA/ European Astronaut Centre:
Aidan Cowley

Study objective:

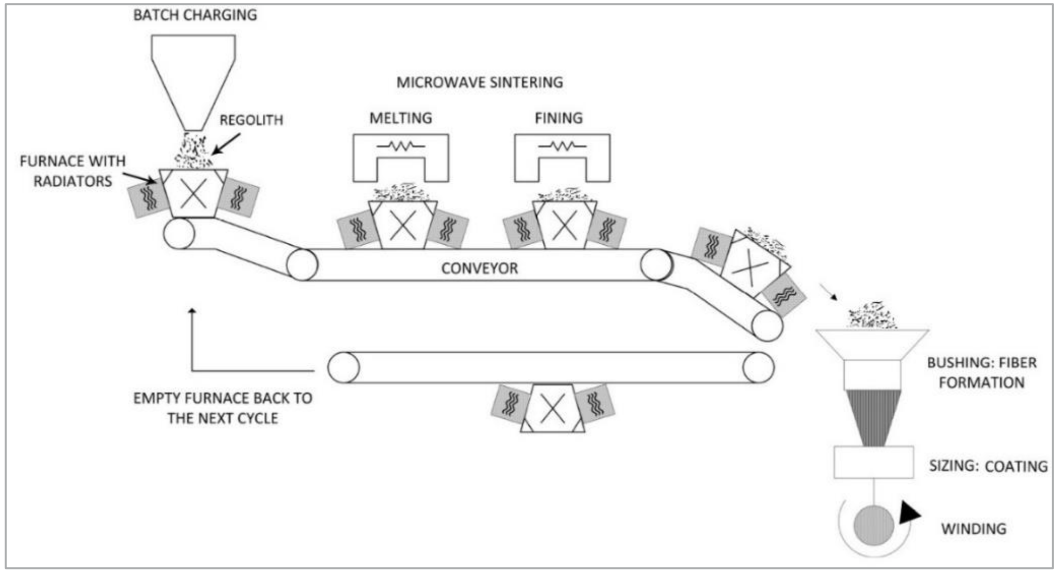
The study aims to take the next steps on the material development of a lunar basalt fibre.

Divided into two parts:

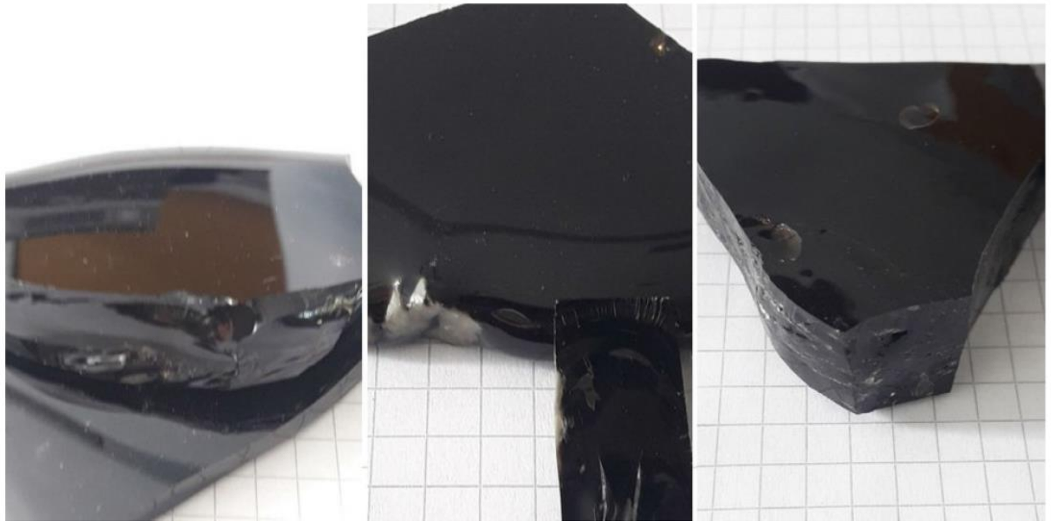
1. Production of a basalt fibre from a number of different lunar regolith simulants by using a hot melt extrusion method. The fibre samples will be structurally, mechanically and thermally characterised, and the most suitable candidate for the lunar applications will be defined based on pre-defined performance criteria.

2. Production of basalt fibre reinforced composites for the application in habitats' pressure shells.

Proposed fibre production plant on the Moon:



Glass Specimens – LHS-1, LHS-1-R (ITA), LMS-1:



Fibres from LMS-1 with the single tip bushing:

Moon Fibre

First results from ITA:

- Commercial lunar regolith simulants LHS-1 and LMS-1 were used, similar chemical composition to the average lunar regoliths of the Mare and Highland regions
- Two laboratory scale bushings were used to perform the fibre forming experiments. The volume of the bushings is about 100 ml. For the production of endless fibres, the vitrified material of the simulants was crushed and then filled into the heated bushing

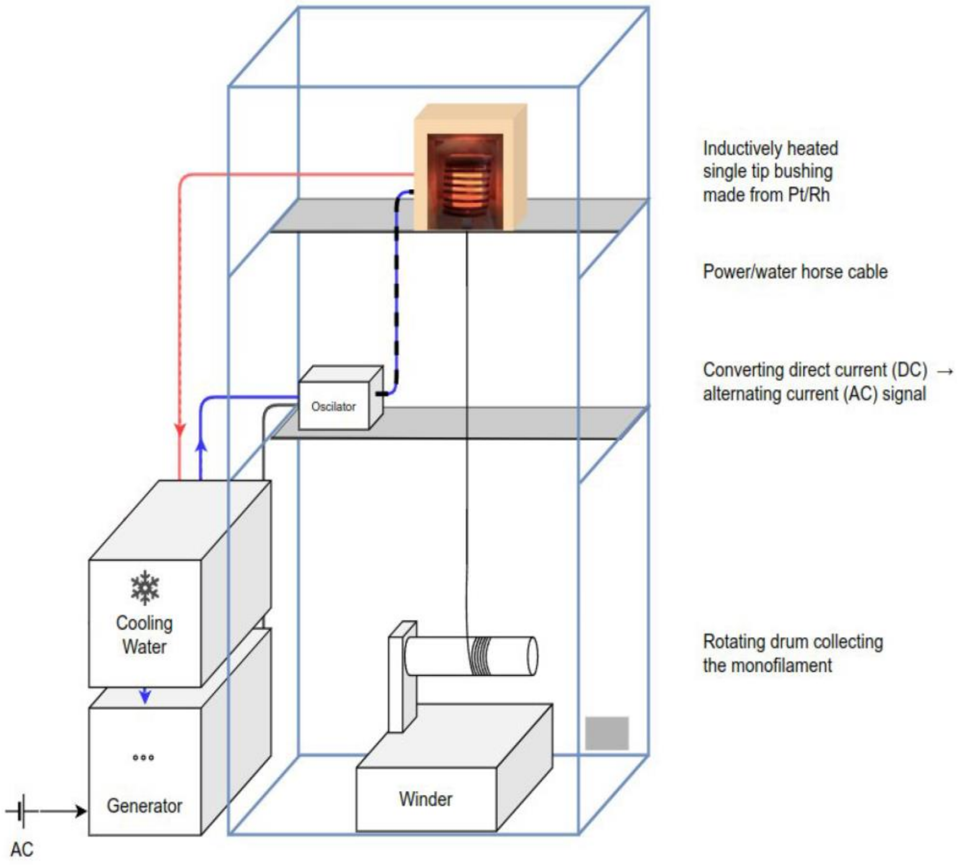
Results for LMS-1:

- For the single tip bushing, the fibre drawing process was stable and the formation of fibres was readily reproducible. The mean thickness of the fibres is 28 µm
- The detected filament imperfections that occurred during the drawing process are critical for continuous fibre forming and prevent a stable process.
- The tensile strength of LMS-1 was determined for single filaments produced on the one and the seven tip bushing. The average value of tensile strength for single tip fibre is 0.84 GPa and the maximum is 2.33 GPa (vs. standard E-glass fibre 3.4 GPa)

Results for LHS-1:

- It was not possible with the present technical capabilities to draw continuous fibres from LHS-1 due to the fibre forming range, i.e. the temperature range between the upper fibre forming temperature and the liquidus temperature, being almost inexistent

Laboratory scale fibre pulling apparatus at ITA:



Bobbin of wound filaments:

Robotic Winding of Basalt-Fibre Structures

FibR reinventing composites

University of Stuttgart
ICD Institute for Computational Design and Construction

esa

Project Team:

Institute for Computational Design and Construction (ICD), University of Stuttgart:

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ESA/ ESTEC:

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Advenit Makaya

Taavi Raadik

Prototypes in collaboration with:

FibR

Study objective:

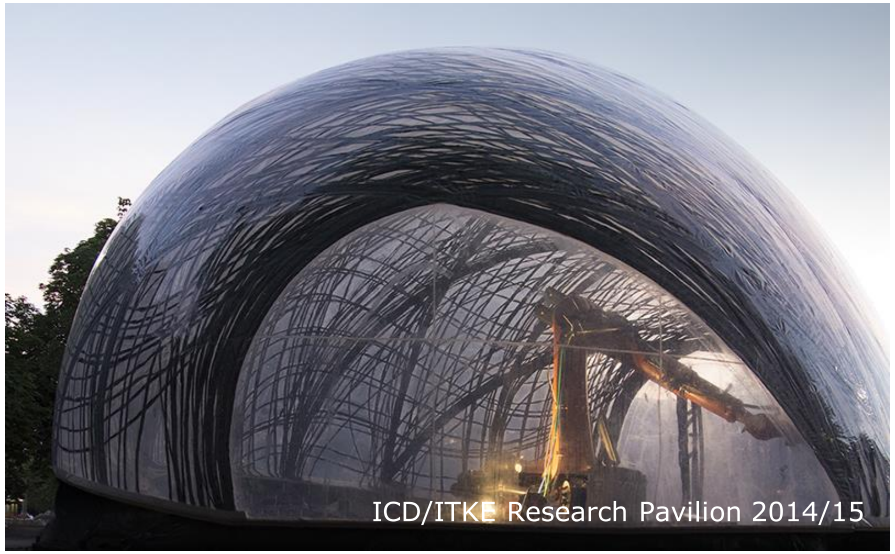
The study aims to identify and develop promising fabrication methodology for a fibre based in-situ robotic fabrication process for potential use in a lunar habitat as an alternative to existing additive manufacturing technologies.

Divided into two parts:

1. Lunar basalt fibre production - possibilities of producing fibres out of lunar regolith simulant
2. Manufacturing of fibre based habitat structure - possible applications of these fibres in robotic fabrication processes

Precursors - ICD/ ITKE Research Pavilions, University of Stuttgart:

ICD/ ITKE Research Pavilion 2016-17



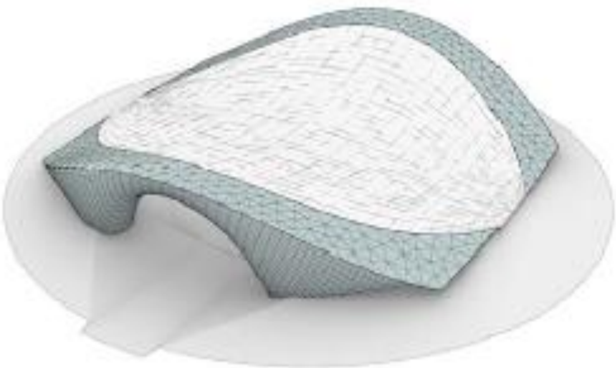
ICD/ITKE Research Pavilion 2014/15

Mobile Robotic Fabrication Eco-System

ICD/ITKE Research Pavilion 2013/14

Robotic Winding of Basalt-Fibre Structures

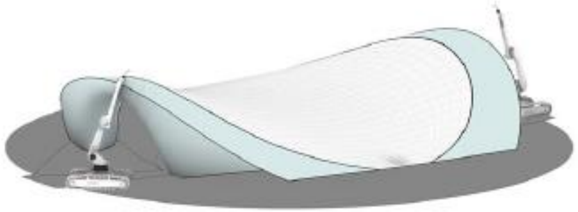
Bending-active hyperbolic shell structure over a crater:



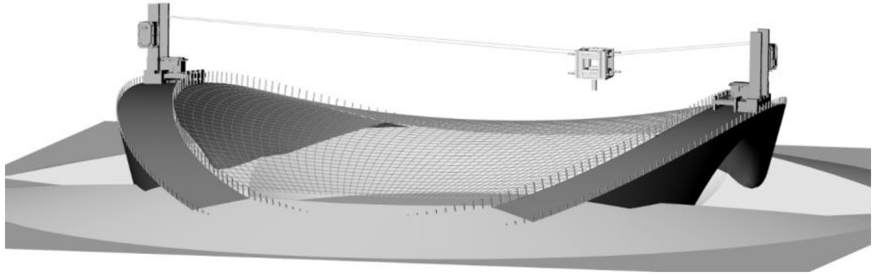
Side views:

Measurements:

Concept of a bend-up and reinforcement of bending-active elements:



Concept for long span fibre winding with mobile cable bots:



- Robot 1 would be a high payload robot or crane mounted on a mobile platform with fibre spools and a resin infusion system, and a robotic end effector tool for filament winding
- Robot 2 robotic system would be cable driven system for long span fibre laying, where a filament end-effector would be transported from one position to another through the relative shortening and lengthening of a two sets of cables

Robotic Winding of Basalt-Fibre Structures

FibR reinventing composites

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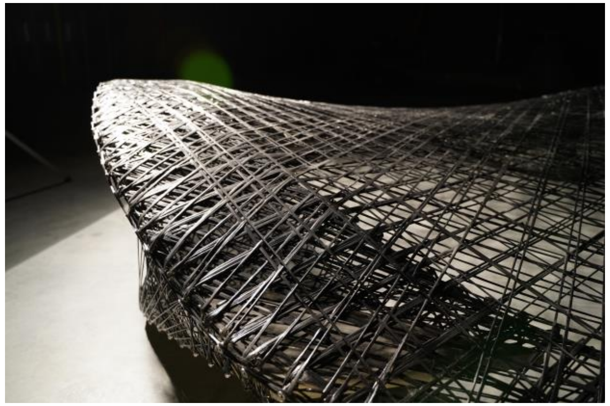
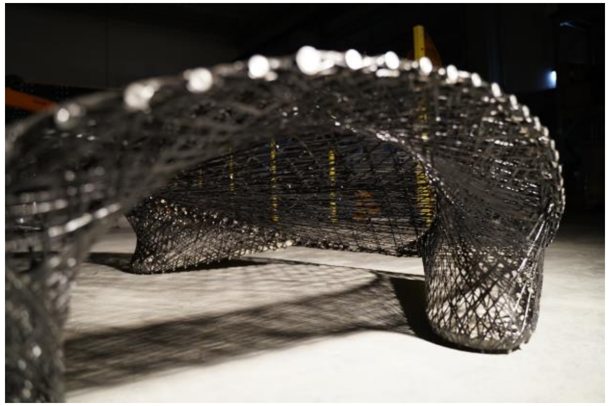
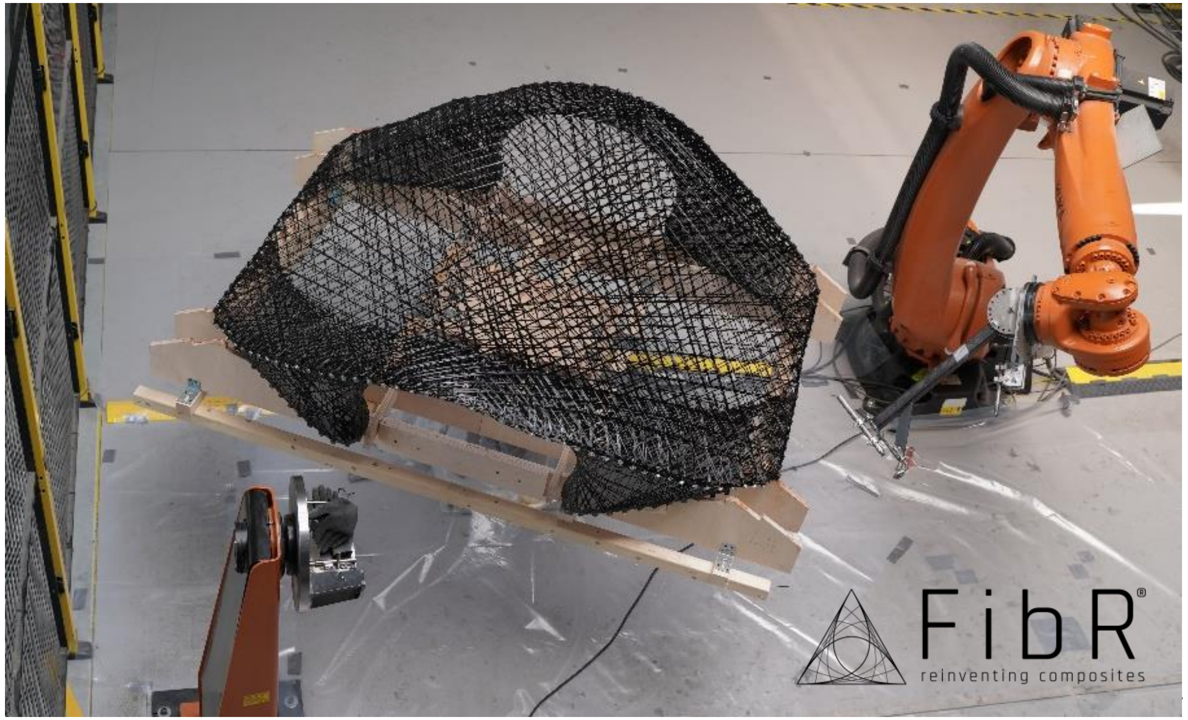
Prototyping 1:10 scale model:







Robotic winding of basalt-fibre structures

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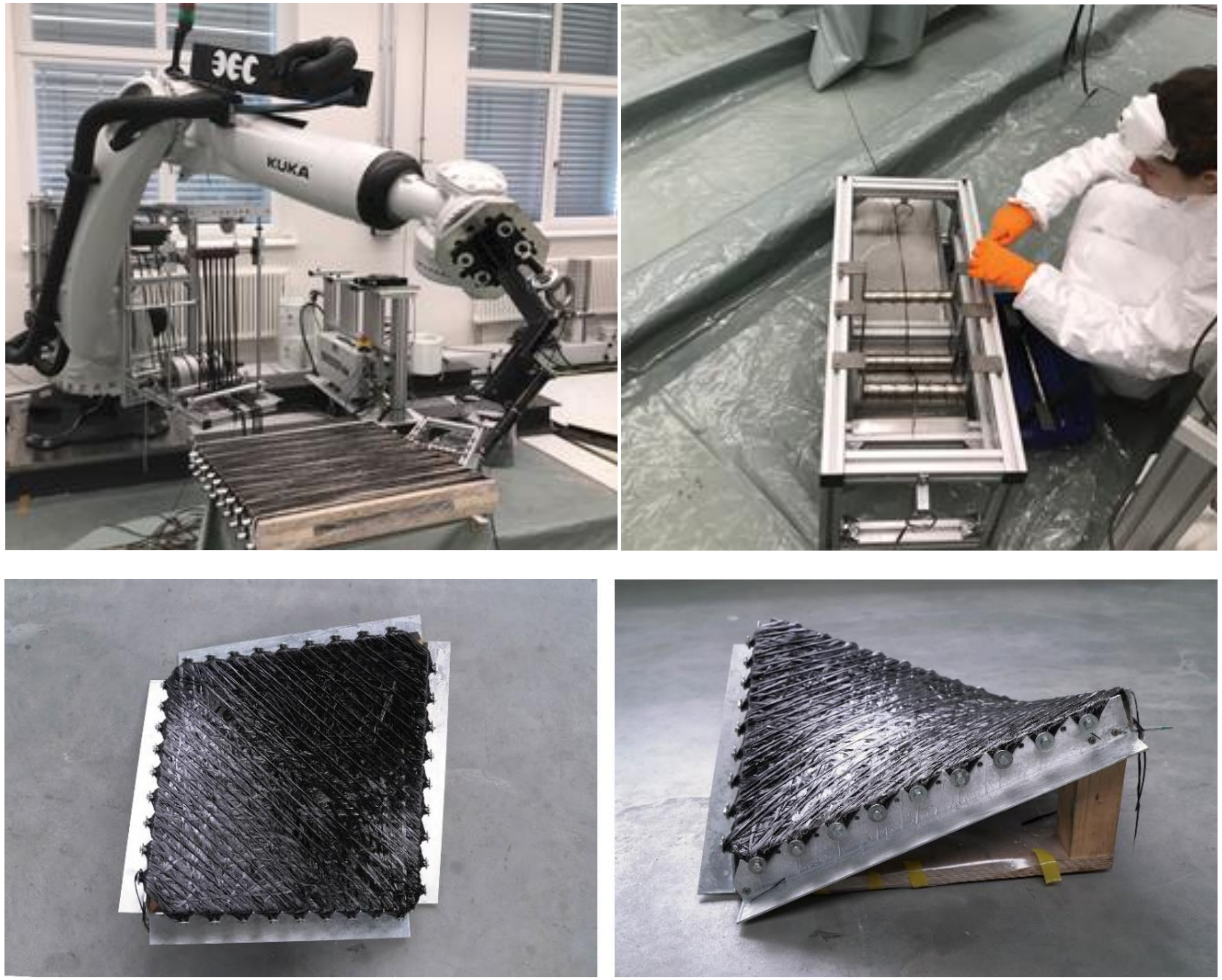
Robotic fabrication setup for production of mechanical samples with a resin bath infusion system:



Mechanical samples produced with two different fibre layouts:

Fungal Based Bio-Composite for Habitats

Project Team:

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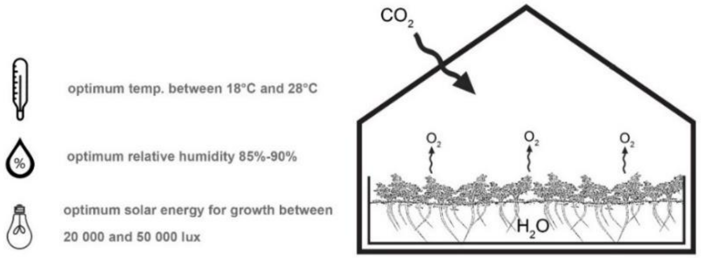
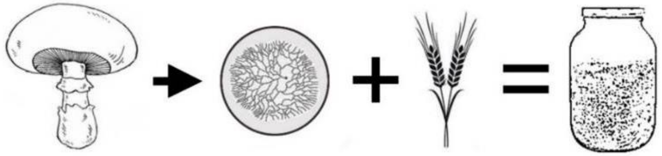
ESA, Advanced Concepts Team:
Hanna Läkk

In collaboration with:
Co-de-it and digifabTURINg

In-situ cultivation of azolla filiculoides:



In-situ cultivation of fungal mycelium:



Study objective:

To investigate the production of structural biocomposites based on fungal mycelium for space applications, such as elements of space habitats.

Goals:

1. Identify a substrate material for the composite where fungus can grow on
1. Identify the effects of space environment on fungus (radiation, microgravity)
2. Develop a suitable consistency for the 3D printing paste

3D printing study with biocomposite paste:

Fungal Based Bio-Composite for Habitats

Universiteit Utrecht

Composition of fungal biocomposites:

plant based substrate (straw)

mycelium

- Composed of fungal mycelium and a plant waste substrate
- Fungus uses mycelium to absorb nutrients from the environment containing carbon and nitrogen in a two-step process:

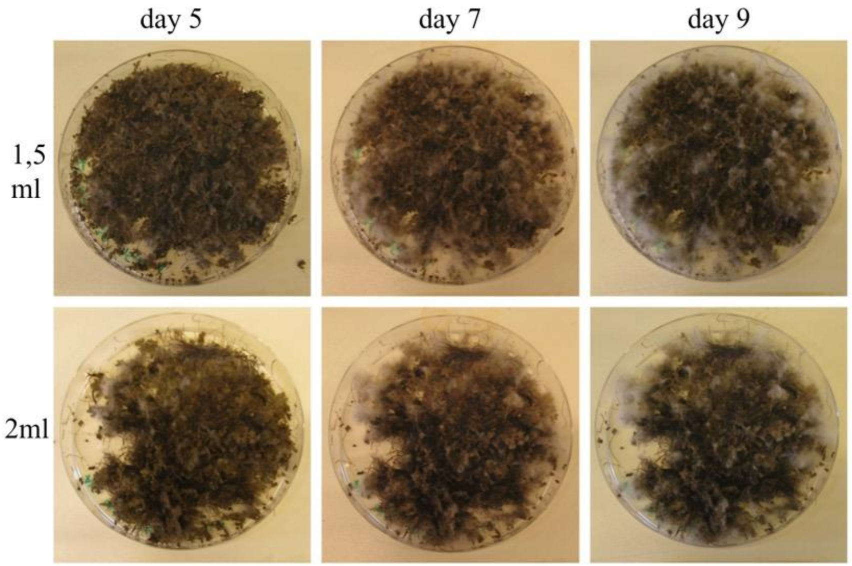
1. First, enzymes are secreted onto or into the food source by mycelium to break down biological polymers into smaller monomers
2. These monomers are then absorbed into the mycelium by diffusion and active transport

- By consuming plant based waste products, such as sawdust, mycelium's dense network binds the substrate into a material composite

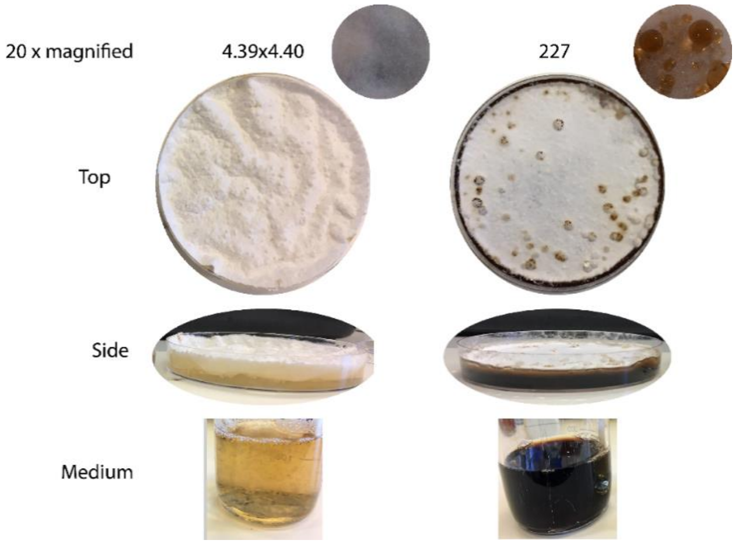
Fungal Based Bio-Composite for Habitats

Universiteit Utrecht

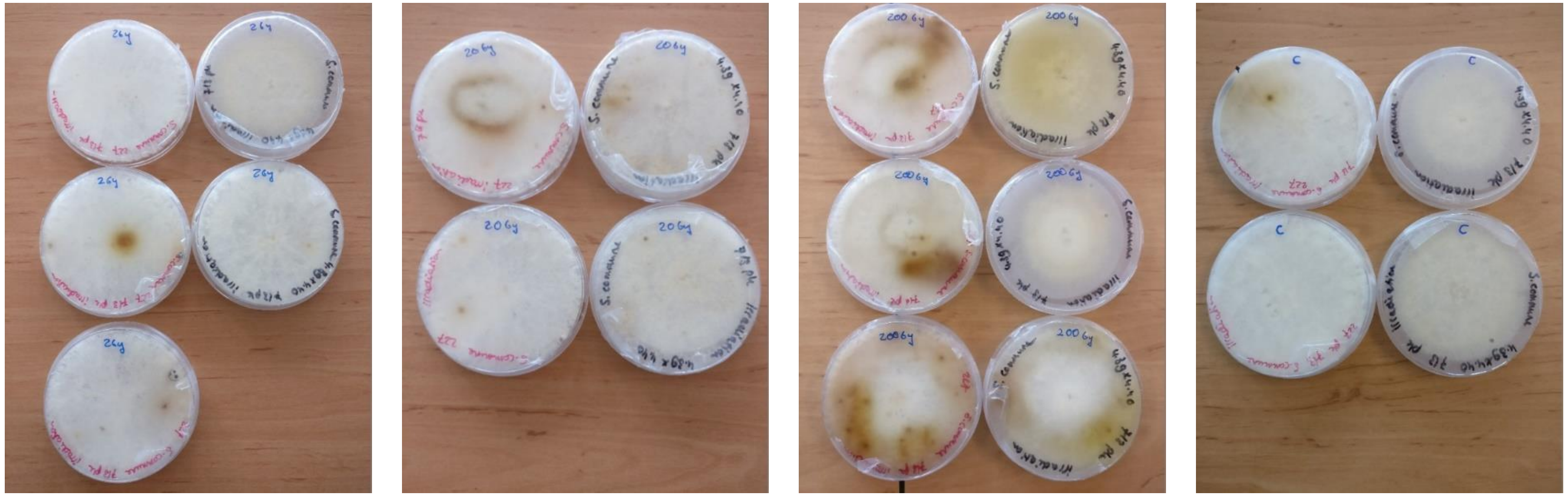
1. Matching fungal strains with plant substrate (azolla):



2. Constitutive melanin production:



3. Effects of ionizing radiation (Co60) on SC:



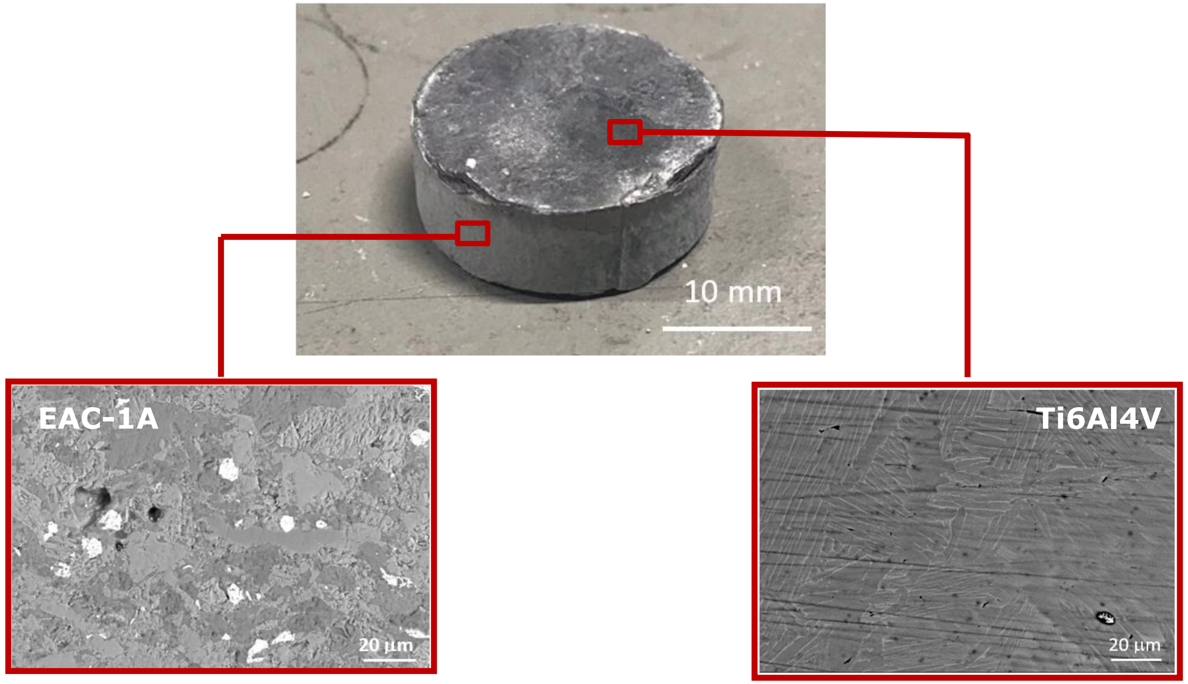
4. Effects of simulated micro-gravity on SC:

Functionally-Graded Regolith-Metallic Composites

Cheibas, I., Laot, M. , Popovich, V.A. , Rich, B. and Rodriguez Castillo, S.

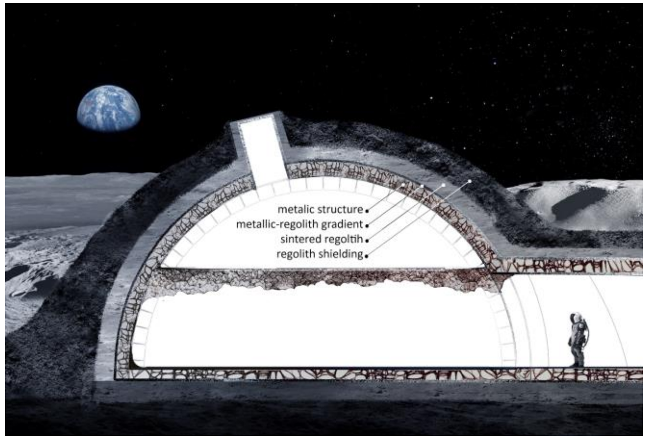
- Functionally Graded Materials (FGMs) are composite materials with variation in material morphology & properties
- An alternative to multi-layer material solutions (such as habitat structures)
- Materials mismatch is mitigated

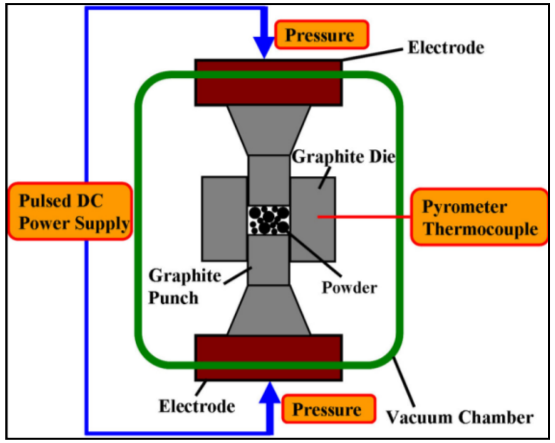
- Regolith (EAC-1A) samples produced first, followed by graded metallic-regolith samples (Ti6Al4V and stainless steel)
- Consolidation methods selected: Digital Light Processing (DLP) and Spark Plasma Sintering (SPS)



Main findings:

- Regolith consolidation was poor with DLP alone
- FGM consolidation was successful with SPS
- Vickers microhardness showed gradual transition in properties as expected
- Improved interfacial properties, tuneable properties, many potential applications in advanced off-earth manufacturing
- But current proposed methods less suitable for space (high pressure, small scale, use of resin)
- Recommendation to utilise DLP for shape optimisation and SPS for consolidation & densification





Fibre-Reinforced Geopolymer for Radiation Shielding

Arnhof, M., Pilehvar, S., Erichsen, A., Valentini, L. and Kjøniksen, A.-L.

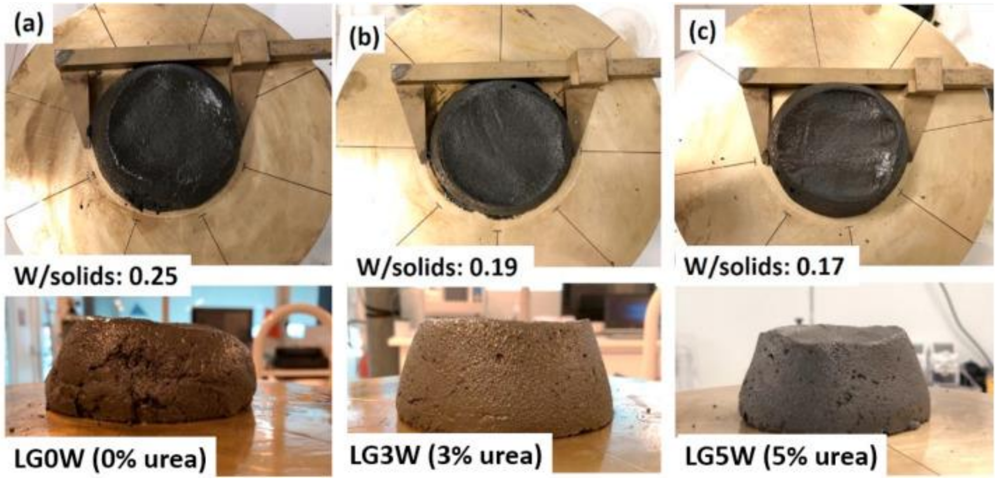
- Geopolymers: alumino-silicate polymers, environmentally-friendly alternative to Portland cement
- Terrestrial geopolymer precursor (fly ash) has similar composition to lunar regolith
- Potential lunar construction material
- Water content and viscosity must be addressed

- Basalt fibre could also be employed to reinforce structural geopolymer
- Urea plasticiser proposed as an alternative to existing superplasticisers (polycarboxylate, naphthalene)

Main findings:

- Urea plasticiser (3%) minimised water requirement and delayed curing, while retaining geopolymer workability
- Temperature cycles increased compressive strength
- Urea & vacuum decreased compressive strength

- Superior compressive properties, all required materials can be sourced in-situ (regolith, water, urea from astronauts, hydroxide from beneficiated metals)
- But complex resource extraction required. Additional urea from Earth may be required to achieve scalability



Space Architecture: Future Trends

Design:

- Parametric design (generative design)
- Collaborative cloud based design tools
- Big Data
- Adaptable/ responsive/ reconfigurable systems
- Circular economy

Test:

- VR/ AR testing and design tools

Manufacture:

- Additive manufacturing
- Advanced/ composite materials
- Robotics/ automation, human-robot collaboration
- Laser machining/ welding
- Nanotechnology

Operate:

- Smart habitats (that learn and communicate) by network/ IT integration (IoT)

Cloud computing and AI

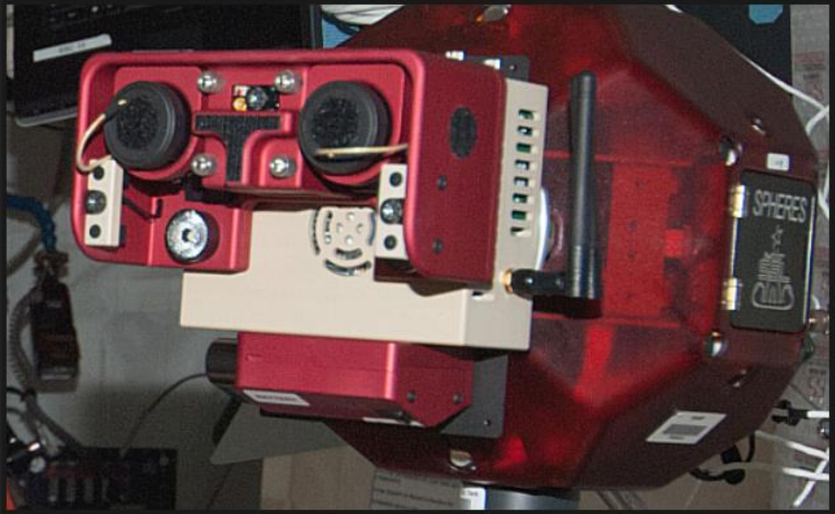
- SENSORY: Simulation of human senses to perceive environmental stimuli
- LANGUAGE PROCESSING: Processing of human-generated stimuli
- PERCEPTION: Simulation of human emotions/ feelings to recognize and interpret environmental stimuli
- KNOWLEDGE REPRESENTATION: Make available structured and unstructured knowledge in appropriate representative form
- LEARNING: Algorithmic learning to perform tasks without explicit programming
- DECISION-MAKING: Autonomous decision-making in complex problems considering various factors
- AUGMENTED CREATIVITY: Creation of novel output independent of human supervision or direction
- MOTION: Independent movements in uncontrolled environments

For more information visit our website https://www.esa.int/gsp/ACT/

Menu Advanced Concepts Team

Advanced Concepts Team

Our mission is to monitor and perform research on advanced space concepts and technologies, preparing ESA for any disruptive change to come.



NEWS

Robot learns "to see"

During an experiment performed on board of the International Space Station (ISS) a small drone successfully taught itself ... see distances with one eye.

Read more