Growing fungi structures in space

Study reference number: 16-6101
Type of activity: Standard study (30 k€)

Project Summary

Objective

The study investigates the possibility of using fungi for growing structures in a space environment

Target university partner competences

Microbiology, Ascomycota, Basidiomycota, fungi based biomaterials, mycelium design

ACT provided competences

Space architecture, textile technology

Keywords

Biomaterials, biocomposite, fungi, mycelium, space habitat, growing architecture, in situ manufacturing, robotic manufacturing, additive manufacturing, 4D printing

Study Objective

The primary objective of the study is to investigate the production of structural biocomposites with fungi for space applications, which could include elements of space habitats. The secondary objective is to assess potential advantages and disadvantages compared to alternative solutions.

Background and Study Motivation

Any further step for human exploration beyond the current low Earth orbit habitats, and especially habitats on the Moon, asteroids or Mars, will offer a new trade-off space for minimizing volume and mass of materials and products to be transported from Earth. In situ resource utilization (ISRU), the use of local resources, has the greatest value when the ratio between the mass of materials supplied by ISRU and mass of the ISRU system brought from Earth is large. From a broader point of view the investment in ISRU includes the costs of (a) prospecting to locate and validate the accessibility of indigenous resources, (b) developing and demonstrating capabilities to extract indigenous resources, (c) developing capabilities for processing indigenous resources to convert them to needed products, and (d) any ancillary requirements specifically dictated by use of ISRU. [1]

Developing suitable technology in order to employ in-situ materials plays an important role in improving mission sustainability and providing new capabilities. Initial development of ISRU technology has focused mainly on life support consumables, such as water and oxygen, and on propellants for ascent. [1] [2] An increasing number of studies have shown that there are other resources available in the lunar and Martian regolith, which can be used for, for example, the production of surface habitats and infrastructure by various additive manufacturing technologies. [2] [3] [4] [5] [6] [7] [8]

The additive manufacturing technology is very promising technique for utilizing in situ resources on the Moon and Mars. However, when using the indigenous resources, it is also important to consider the investments needed for (a) prospecting to locate and validate the accessibility of indigenous resources and (b) developing and demonstrating capabilities to extract indigenous resources, as mentioned before. [1] In that case, fungi based biocomposites might offer a cost effective alternative for constructing structures in situ. In situ manufacturing of fungi structures would require bringing seeds of specific fungi to space which then would grow into composite structures in situ. However, only a minimum amount of seeds should be brought from the Earth for the pilot structure as the seeds for the following projects would be produced in situ. The production of fungi structures could be low cost and could require only limited human assistance, eliminating therefore costly and time consuming locating, validating and extracting processes of local resources. [9]

Fungi based biocomposites are produced by combining fungal mycelium with a natural reinforcement or filler. These materials are renewable and recyclable, and are slowly starting to replace various plastics, packaging and insulating materials on Earth. [9] The fungi based biocomposite is also being discovered by artist, designers and architects who have been successful in using these materials in many new ways (Figure 1). [10] Bricks and new architectural structures have been produced with fungi. [11] as well as various fungi based products [12][13] [14] The combination of 3D printing with living organisms has been studied using 3D printing technique with organic waste, which then formed the basis for the mycelium growth. The mycelium grew through the organic waste, forming a network of interwoven roots, which then bound the material into cohesive and strong biocomposite structure. [15]

Figure 1. Mycelium bricks used as a structural material in ‘Hy-Fi’ by The Living (left) [13] [14] and 3D printed ‘Mycelium Chair’ by Eric Klarenbeek (right) [15]

From a large group of fungi, Ascomycota and Basidiomycota are known to be the best type of fungi to create mycelium based materials as they can construct larger and more complex organic structures than other fungi. [9] From the two, Basidiomycota have two important properties which can make them more suitable for producing biocomposites: Septa and Anastomosis. Septa, special transverse cell walls, have an opening that can be closed in order to block the draining of a cytoplasma through the rapture when hypha becomes damaged. This will decrease the damage of the colony and therefore will lead to faster colonization of a substrate. Also anastomosis increases the growth speed of mycelium by fusing two different hyphae together when they meet. In addition, it creates a more homogeneous network of mycelium which promotes a fast transport of nutrients.

In general the mycelium materials are produced in six steps. The production starts by creating a suitable substrate for the fungus. The choice of a substrate depends on the function and required properties of the final product, but is also connected to the type of fungi used as every fungi has its specific needs for the growth environment. The substrate can be any cellulose rich material as fungi are special in that they can break cellulose down into glucose as opposed to other organisms. It is therefore also smart to use cellulose-rich materials in order to prevent contamination by other organisms. When the substrate is selected it needs to be sterilized in order to prevent contamination by other organisms. The sterilization can be done in three ways: by pasteurization, hydrogen-peroxide solution or natural composting. After sterilization the substrate is inoculated with the spawn and the colonization of the substrate can start. It is important, however, that the right growth conditions for the specific fungi is met. In average, it takes about two weeks for the mycelium to fully colonize the substrate. When the substrate is fully grown, the growth of the mycelium has to be stopped in order to prevent the total consumption of the substrate and production of fruiting bodies. The growth can be stopped by heating. After the growth has been stopped the material can be treated with a surface finishing if needed. [9]

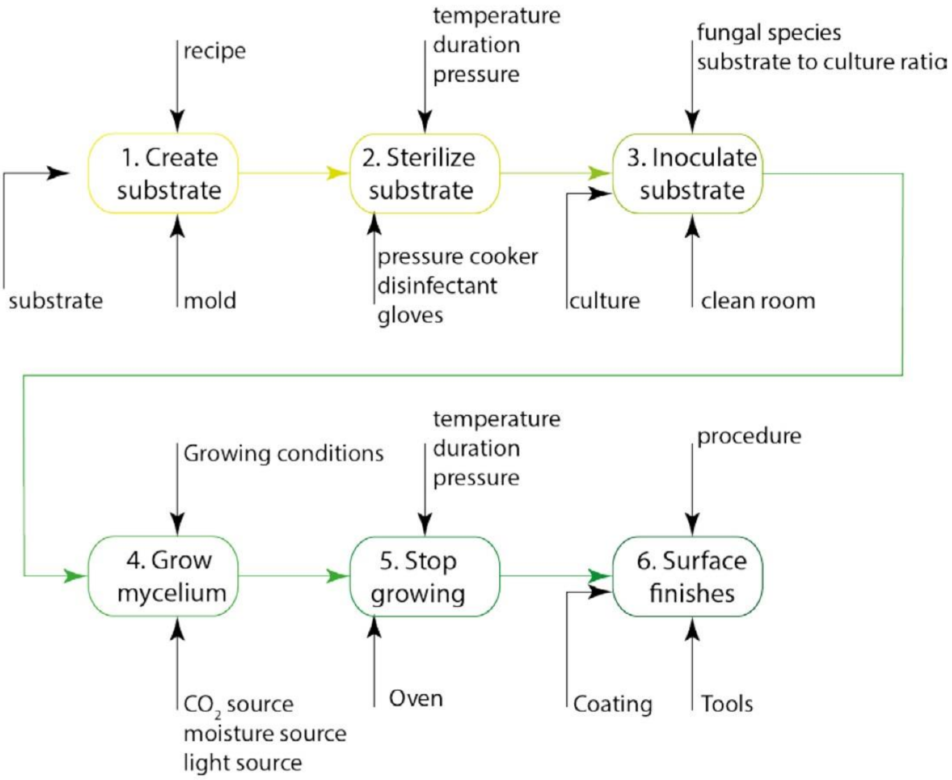

Figure 3. Scheme of producing mycelium materials by R.J.J. Lelivelt [9]

The current baseline estimate for the process of manufacturing fungi structures in space environment is:

1. Collecting material for the production of substrate (any cellulose-rich organic waste, possibly agricultural waste from, for example, greenhouses, or some combination of soil)
2. Sterilizing the substrate by pasteurization or natural composting
3. Creating suitable conditions for the growth of fungi (possibly inflating a temporary shelter of air thigh thermal control layer (MLI of inflatables) for the environmental control, depends on the type of fungus but in general: humidity >90%, temperature <30°C, no light, high CO_2, O_2 for growth)
4. Using additive manufacturing technique to print the structure and inoculate the substrate (by 6-axis robotic arm)
5. Removing the shelter to heat up the structure in the UV light and stop the mycelium growth
6. Treating the structure with surface finishing if needed

It is possible to create suitable growing conditions for fungi regarding temperature, humidity and atmosphere in a space environment. An important question, however, is whether fungi are able to survive in environments with a high radiation level. Due to weak or inexistent magnetic field, the Moon and Mars are exposed to galactic cosmic radiation (GCR), solar winds and solar particle events (SPEs). There is, however, evidence that a specific type of fungi can survive the simulated Martian conditions [16] [17] and that the ionizing radiation can even enhance the growth of melanised black fungi. [18] [19] [20] Onofri, de Vera, Zucconi, et al proved in their Lichens and Fungi Experiment (LIFE) that *Cryomyces antarcticus* and *Cryomyces minteri* are able to survive the simulated martian conditions aboard the Internatinal Space Station for 18 months. They found that more than 60% of the cells and rock communities did not undergo any change due to the exposure. [17] Dadachova, Bryan, Huang, et al studied melanised microorganisms, such as *Cryptococcus neoformans*, *Wangiella dermatitidis* and *Cladosporium sphaerospermum* and found that ionizing radiation changes the electronic properties of the organisms and enhances their growth. [19] In another study, researchers were able to provide clues how melanised black yeast *Wangiella dermatitidis* has adapted the ability to survive or even benefit from exposure to ionizing radiation. [20] These studies suggest that melanin pigments play a crucial role in the survival of fungi when exposed to radiation, which could mean that it is necessary to choose, either melanin containing fungal species when developing the architectural structures for space environment, or add melanin pigments to the species which does not contain them yet.

Fungi based biomaterials could offer the following advantages over other in situ manufacturing technologies:

1. Costs: Lower manufacturing and energy costs due to excluding the costs of (a) prospecting to locate and validate the accessibility of indigenous resources, (b) developing and demonstrating capabilities to extract indigenous resources and (c) developing capabilities for processing indigenous resources to convert them to needed products [1]
2. Manufacturing: Full manufacturing loop following a cradle-to-cradle principle: the waste of another process (e.g. greenhouse) can be used as a basis for building structures, which at the end of their service period can be used biodegraded
3. Mass: Light weigh, therefore easy to handle. Can be used for complex shapes
4. Known to hold compressive and tension stresses. Non-flammable, waterproof, good insulation properties.

5. Strength: Forms a fibrous composite with a substrate, which enhances the material strength. Can be used for complex shapes
6. Diversity of applications and products: Enables to produce a variety of different fungi based materials: from transparent films to concrete/ brick like materials
7. Speed: Grows relatively fast (in general two weeks)

The main weaknesses include:

1. Needs special environment during the growth period (humidity >90%, temperature <30°C, no light, high CO_2, O_2, so energy is needed to sustain that environment)
2. Due to autonomous growing process there is a factor of uncontrollability and uncertainty of the final material properties

Figure 4. The range of materials produced from fungi [10] [21] [22]

Proposed Methodology

The following methodology is proposed for the study, though applicants are invited to propose different approaches which they see fitting better within the scope of this work.

- Determine the type of fungi which could be used in space environment (possibly radiation resistant species or assume the possibility of genetic modification to increase the resistance)
- Conduct an analysis of contamination (mutation rate, influence on human health, vitality, survival, air contamination)
- Determine the variation of fungi based materials we could produce in situ
- Determine the type of scaffolding substrates (waste/ soil) available in situ which could be used in the composites
- Develop a closed loop process between the waste producing system and construction of fungi structures
- Produce a range of sample materials based on different substrate and fungi combinations
- Test the materials for compression strength, stiffness and failure mode, tension, cyclic tests, air permeability, vacuum
- Determine the range of (architectural) structures these materials could be used for
- Develop a way to repair the structure

ACT/ ESA Contribution

The project will be conducted in close scientific collaboration with ESA researchers. In particular ESA researchers will provide technical expertise in space architecture, material science, mechanical engineering, additive manufacturing and advanced manufacturing processes, with the focus on the suitability of the fungi based materials for human spaceflight missions.

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