HUMAN/ROBOTIC SCIENTIFIC EXPLORATION OF THE MOON AND MARS: BUILDING TOWARD THE FUTURE WITH THE FUNGAL BIOCOMPOSITES. L. J. Rothschild[1], C. Maurer[2], J. W. Head[3], R. Cruz-Perez[4], J. E. Snyder[4], D. Senesky[5], E. Isbell[5], R. J. B. Cordero[6], H. Krivic[7], M. C. Rheinstädter[7], R. Ticknor[1], J. Hinkle[8] and D. Cadogan[8]. [1]NASA Ames Research Center, Moffett Field, CA, 94035, USA, Lynn.J.Rothschild@nasa.gov, [2]redhouse studio, Cleveland, OH 44113, USA, [3]Brown University, Providence, RI, 02912, USA, [4]Blue Marble Space Institute of Science @ NASA Ames, [5]Stanford University, Stanford, CA 94305, USA [6]McMaster University, Hamilton, ON L8S 4M1 CANADA, [7]MelaTech, Baltimore, MD, 21224, USA, [8]Moonprint Solutions, Dover DE, 19901, USA.

Introduction: A turtle carries its own habitat. While reliable, it costs energy and is not adaptable to the environment. NASA makes the same trade-off when it transports habitats and other structures needed to destination. Astronauts stayed on the lunar surface for up to 75 h (Apollo 17), with the lunar module doubling as a habitat. An example of the "build it on Earth, launch it into space" approach is the Habitat Demonstration Unit (HDU) Deep Space Habitat, developed by the Habitat Systems Project (NASA AES). It has a composite fiberglass resin-infused shell attached to eight steel ribs, providing living and working space for four. Even with advanced materials, it weighs >14,000 kg (~466 kg/m^2 living space), leading to high launch costs. Upmass and resupply will result in reduced surface operations, greater mission risk, loss of productivity and psychological stress.

In contrast, a bird builds its home at destination using sustainable manufacturing and in situ materials. In this vein, NASA's Centennial Challenges program ran a 3D printed Habitat design challenge for the Moon, Mars and beyond [1]. Top designs used ISRU, focusing on agglutinated regolith or frozen water. Requirements included a vapor barrier, and a robotic infrastructure for preparing the site, gathering regolith and building. While regolith and ice have advantages as building materials and are compatible add-ons to our concept, regolith alone has disadvantages including rigidity, poor thermal insulation, potential mineral/chemical toxicity and incompatibilities, and a dedicated infrastructure required for production [2].

Vision: In a NASA Innovative Advanced Concepts (NIAC) Phase 1 study, we introduced the concept of structures grown by fungal mycelial at destination (Fig 1). Mycelial materials are thermal insulators, fire resistant, and unlike plastics and glues, do not outgas. They are more flexible and ductile than regolith alone. The density and material properties are tuned during production. The material could be used dry, wet, frozen with water or as part of a self-produced biocomposite which would allow such enhancements as radiation protection and a vapor seal. Even better, it is self- replicating so the habitat could be extended at a future date, and thus also be self-repairing. Some form of this material could be used for a habitat at destination, furniture, storage, additional buildings, and the shell of multiple rovers.

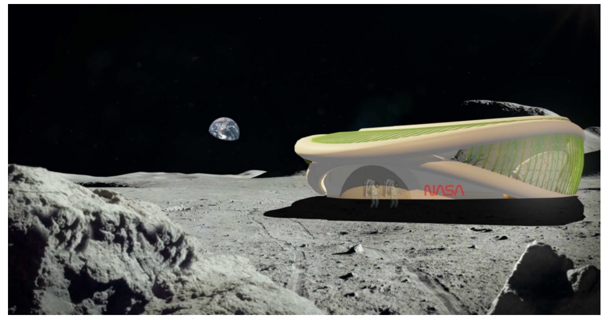

Figure 1: Image of a lunar base building that utilizes in situ grown organisms within inflatable bioreactors to create the insulating, radiation-shielding structure.

As a standalone material or in conjunction with agglutinated or sintered regolith, a mycotectural building envelope could significantly reduce the energy required for building because in the presence of food stock and water it would grow itself. After the arrival of humans, additional structures could be grown with feedstock of mission-produced organic waste streams including inedible plant or soil components, or human waste. When protected, the mycomaterials can have a long life, but at the end of its life cycle the material could be become fertilizer for mission farming or production of new mycomaterials.

In Phase II we explored infusion of mycomaterials as an enabling technology for a 500-day Hadley Max mission. For Phase III, beginning FY25, we have identified the two next goals to prepare for implementing our original vision on the Moon and Mars (Fig. 2). These are the incorporation of the mycotecture into a commercial space station, *Starlab,* and to prepare for deployment of prototypes on the surface of the Moon.

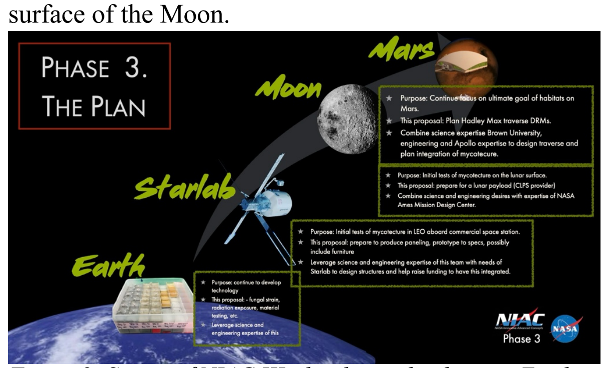

Figure 2: Stages of NIAC III: develop technology on Earth, test in LEO with Starlab, deploy test on the moon with CLPS.

Mycotecture in Low Earth Orbit: Starlab Space LLC is a US-led international joint venture with Voyager Space and Airbus, and Mitsubishi. Starlab Space is designing, building, and will operate the *Starlab* commercial space station, and is a strong potential customer for mycoarchitecture in LEO. During FY25 we focused on infusing mycomaterials in both the research areas as a veneer for internal panels and for growth experiments, and in the living quarters for structures such as beds.

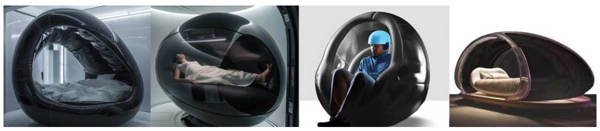

Figure 3: In LEO, mycotecture could be used to make radiation shielding furniture for long durational activities. Above are from the NIAC Black series that uses melanin rich fungi in inflatable furniture.

To integrate mycotecture in a human-rated vehicle, it must undergo material testing. With Hilton Hotels leading the design of the living quarters, we have learned that no bio-based material is currently flight qualified. We believe the most challenging tests will be flammability and outgassing to meet testing standards of NASA-STD-6001.[3] Initial tests have been conducted on flammability and tvac, with promising results. Additional tests for radiation shielding have been conducted at Brookhaven National Labs, and mechanical testing at Stanford University.

A prototype on the Moon: NASA's Commercial Lunar Payload Services (CLPS) project coordinates and contracts with commercial providers to land scientific and technology payloads on the lunar surface.[4]. Our vision for a CLPS payload would be to deploy miniaturized models of the mycotecture habitats on the surface of the Moon and monitor their growth. The model would be enclosed with a rack of the CLPS with 2-way communication for assisting and documenting the growth of the model building. This mission would provide invaluable data prior to deploying usable mycelial structures on the Moon.

We are prototyping as a potential payload for Institutive Machines IM3 mission [5], currently slated to launch October 2026. We plan to test components of the system, and funding permitting, would deploy the "CityScape" payload (Figure 4). Because of temperature constraints and the instability of liquid water on the lunar surface, the fungi will be grown in inflatables, currently being developed by Moonprint Solutions.

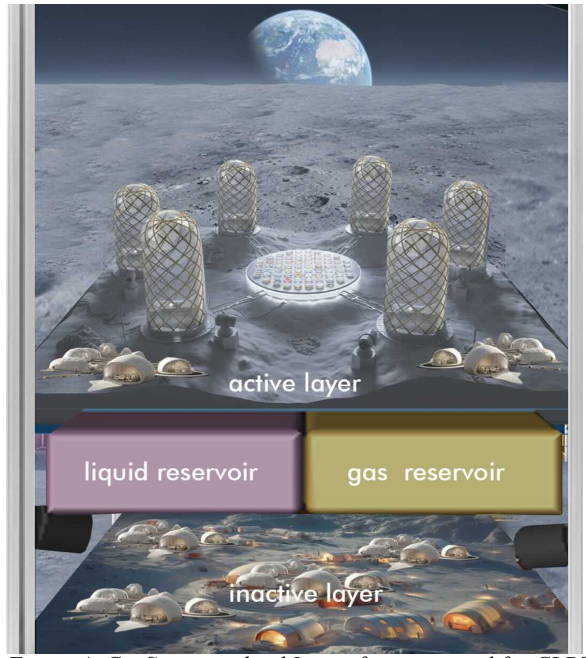

Figure 4: CityScape payload Image from proposal for CLPS demonstration where mycelium materials grown in situ within novel inflatable bioreactors to take the form of an architectural scale model of a lunar city.

Acknowledgments: We are indebted to NASA's NIAC program for their enthusiasm, guidance and financial support.

References:[1] *https://www.nasa.gov/directorates/s pacetech/centennial_challenges/3DPHab/about.html* [2] Lipińska, M., Maurer, C., Morrow, R., Dade-Robertson, M., Senesky, Magdalini Theodoridou, D., Zhang, M. & Rothschild, L. (2022) *Front Built Environ* doi.org/10.3389/fbuil.2022.965145. [3] https://standards.nasa.gov/standard/NASA/NASA-STD-6001 [4](www.nasa.gov/commercial-lunar-payload-services/) [5] https://www.intuitivemachines.com/im-3-lunar-mission