
Introduction: Beginning with the Hadley Max 500-day Design Reference Mission (DRM) conceptual background [1], we proceeded to utilize Apollo 15 mission scientific goals and objectives, together with expanded broad scientific goals and objectives derived from Apollo 15 mission results and recent regional geologic mapping [2], as a basis to identify the resulting Regions of Scientific Interest (ROI) for the Hadley Max DRM [3], and used these scientific requirements to define the Mission Architecture [4], in preparation for more detailed mission design and traverse planning activities [5]. We then turned to addressing the major upmass challenges revealed by any long-term residence and sustained presence on the Moon, first assessing reduction in upmass demands by employing in situ Myco-Architecture [6], and here exploring reducing upmass demands utilizing in situ inflatable structures.

Definition of Required Habitats, Enclosures and Related Architectural Elements: We previously identified the types of habitats, enclosures and related architectural elements [4] dictated by the Hadley Max scientific objectives [3] as follows: 1. Landing Pads (LP): For both Human and Robotic missions; like helo pads; flat, devoid of soil backwash contaminant, retroreflector for guidance. 2. Initial Base Structure (IBS): Living and working habitat; follows the initial stages where there is a landing module (LM). 3. Evolutionary Base Structure (EBS): Larger scale, separation of work/living activities; increased in situ science activities; IBS evolves to dust mitigation structure. 4. Outposts: Remote Science Bases (RSB): Modeled after IBS, but located >10 km radius from Landing Site. Require up to ~5 RSBs for in depth, in situ science activities. Increase number in order of science priority. 5. ‘Pony Express’ Stations (PEX): These are the lunar ‘pup tents’ that will be precursors to the Remote Science Bases (RSB), and then Earth-day sleep-stations on the way to the final Remote Science Bases (RSB). Sample storage stations, geophysical stations; can be resupplied/samples collected by CLPS missions. 6. Robotic Rover Requirements: a) LRV garage at base for surviving lunar night, re-outfitted; b) Robotic LRV ‘pup tents’ for surviving lunar night, caching samples. 7. Application to the Artemis Circumpolar Environment (ACE): How do we optimize these basic requirements and DRM concepts for the harsh conditions of the South Circumpolar Region, and the lunar farside? 8. Assessing Feed-Forward to Mars Exploration: How does the Mars environment modulate and modify these DRM strategies and architectural elements?

These required structures are the basis for using the Myco-Architecture [6] concept to explore reducing upmass demands utilizing in situ inflatable structures.

Architectural designs and deployable in situ construction methodologies: In concert with the development of Myco-Architectural biological material, architectural designs and deployable in situ construction methodologies were developed at redhouse studio, including plans, 3d models, section details, and animations of various designs and building processes. After assessing many ways to deploy bio-composites off planet (including lightweight formwork, masonry and additive manufacturing), redhouse arrived at a ‘sealed bag’ deployment (Fig. 1) as the best option to control the environment for growth, develop the shape of the shelter, and protect the lunar environments from potential contamination. The sealed bag concept will allow the bio-composites to self-assemble in multiple layers of membranes that can provide redundant protection, channel nutrients, and create warm habitable spaces within the framework. This can be achieved at many scales and could be utilized as a platform technology for building any mission structure or object (Fig. 1, 2).

Evolution of Architectural Concepts: The design concept started as deployable habitat shell that would grow like a living organism at destination with the aid of in situ resources. This would be less energy intensive and leave a smaller planetary footprint then mining or melting surface material. Intense team study and analysis has enabled the initial concept to grow and evolve new multi-functional facets. We found that the biological functions that enable growth of the materials also provide such benefits as oxygen production and may also be used to generate heat and electricity. Thus, this biomimetic and bio-utilitarian option provides potential options to very high up-mass costs of prefabricated structures that come fully outfitted, and other construction materials. Detailed architectural and design analyses suggested that necessary attributes, such as plumbing lines, stovetops, and floormats, can be folded into the form, plugged-in ready to go, and the floors, walls and windows can be grown in place so that the in situ grown building is comparable to a high-mass Earth-fabricated, and then delivered to the site, structure. In order to accomplish this, however, the challenge is in the packing of the habitat shell into off-planet deliverable cargo geometry constraints. We found that many of the domestic utilities, scientific equipment, furnishings, and fixtures can be built directly into the expandable shell. More detailed assessments showed that such self-contained modules can be wrapped into the larger structure and secondarily de-
ployed once robotic-enabled construction of the shell is finished.

**Materialization:** The process of making fungal composites includes growing filamentous saprophytic fungi on biomass substrates that can become fused at a cellular level. Our team has demonstrated composites that have structural characteristics superior to wood framing, thermal resistance characteristics superior to fiber-glass batt insulation, and fire resistance equivalent to type-X gypsum board, that is, construction industry standards, all comparable or superior to other ISRU suggested materials.

**Construction Methods:** In order to save transport mass and still have robustly tested technology and structures the mycotecture team proposes developing an inflatable structure that can fill will living bio-materials (bioterials) that harden in place to form a solid, insulative, radiation-attenuating structure using the inflatable as permanent formwork for the grown-in-place building. This enables us to source most (up to 90%) of the mass in situ by way of water, gasses, and trace nutrients that are easily accessible and are planned to be stockpiled by NASA. The design concept of a deployable self-growing structure must take into consideration the viability of growing the constituent organisms at destination. Lunar and Martian environments are very extreme and do not support life. The solution is to use the example of the only living organisms to go to the Moon and return alive as our model. Twelve Americans have walked on the Moon and when they did they were protected from the lunar environment by their A7L spacesuits (designed to provide an astronaut life-sustaining environment during periods of extra vehicular activity and unpressurized spacecraft operation). The suits, made of a white, non-flammable material called beta cloth and Teflon-coated fiberglass, were produced by ILC Dover. These suits and subsequent EVA mobility units have made space conditions bearable by creating an enclosure that mimics Earth environments in atmosphere, temperature, and pressure. The same requirements exist for our microorganisms. The architectural designs produced by this team link these enclosures that are analogous to biological cells with an analog circulatory system. These cells or, lunar optimized bio-reactor enclosures (LOBE), act like space suits for the production of bioterials within the inflated scaffolding. The LOBEs are linked together and are transported in folded inflatable structures to create bio-performative living shells that replace the air and water in the shell cavities as they grow-in-place.

**Synthesis:** In situ inflatable structures clearly permit significant reductions in upmass penalties, and also offer many other ancillary benefits, such as radiation protection. They also offer significant reduction in environmental impacts of on-site construction from local materials. We are continuing to explore innovative ways in which a) in situ Myco-Architecture, combined with b) inflatable structure concepts, can optimize the scientific goals and objectives of long-term missions to the Moon and Mars, as illustrated by the Hadley Max 500-day DRM [1-6].

**References:** 1. Daniti et al. (2024) LPSC 55. 2. Iqbal et al. (2021) LPSC 52 #1917. 3. Mickey et al. (2024) LPSC 55. 4. Fryd et al. (2024) LPSC 55. 5. Eppler et al. (2024) LPSC 55. 6. Rothschild et al. (2024) LPSC 55. **Acknowledgement:** We gratefully acknowledge support from the NASA NIAC Program and the Brown University UTRA program.

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**Figure 1:** Section through prototypical habitat showing lunar optimized bioreactor enclosures (LOBEs) from left to right first growing photosynthetic organisms that are then converted into a composite bioterial by the growth of fungal mycelium.

**Figure 2:** Stills from animation showing the "growth" of a prototypical building.

**Fig. 3.** Left. Brown Undergraduate Christian Wu and his “Flexible Origami” inflatable cargo storage solutions. Right. Strength of “Flexible Origami” (I-Phone atop structure).