Farming

Off-Earth manufacturing of crop-friendly Lunar greenhouses

Executive summary

Contract no: 4000134231/21/NL/GLC/kk
Document No.: CIRiS-Farming-Executive summary
Issue: 1.1
Release date: 31.05.2023

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DOCUMENT CHANGE RECORD

Issue	Date	Change Description	Page/Chapter Affected
1	18.04.2023	First issue	
1.1	31.05.2023	Remove of copyright	All

APPLICABLE DOCUMENTS

This document shall be read in conjunction with documents listed hereafter, which form part of this document to the extent specified herein.

AD No.	Doc. No.	Issue	Title
[AD1]	ESA-TECSF-SOW-018347	1.1	Statement of Work

EXECUTIVE SUMMARY

Bio-Regenerative Life Support Systems (BRLSS) based on microbial conversion of organic matter followed by photosynthesis are foreseen as important technologies to produce food, oxygen and pure water during long-term human space missions. Previous scientific investigations towards plants in BRLSS have ranged from fundamental plant physiology under fractional gravity conditions to applied edible crop cultivation in Earth analogue constructions, including various techno-biological aspects such as illumination alternatives, nutrient delivery strategies and cultivation strategies.

The span of previous research corroborated the challenges associated with the design and construction of Lunar greenhouses, including the mass and volume of materials required, installation and maintenance complexity, and launcher capabilities and costs. One approach to Lunar greenhouse design is the use of in situ resource utilization (ISRU) to manufacture structures from Lunar materials.

The *Off-Earth manufacturing of crop-friendly Lunar greenhouses* project, referred as Farming, outlines the conceptualization of a hypothetical Lunar greenhouse named ReLGreen module, designed for Off-Earth manufacturing using a proposed novel Lightweight Expanded Regolith (LER) technology.

Key scientific specifications for a Lunar greenhouse were identified considering the Lunar environment and plant characteristics and tolerances, pointing towards hydroponic crop cultivation in a controlled environment. The ReLGreen Module is thus inspired by terrestrial Controlled Environment Agriculture and designed to address the limited resources on the Moon. The ReLGreen module's primary structure comprises an inflatable hexagonal shape structure providing a closed controlled environment and stacked LER blocks and loose regolith for radiation and micrometeoroid protection. A double walled pressurized membrane is used to store the water needed for the cultivation system inside the walls and ceiling of the module.

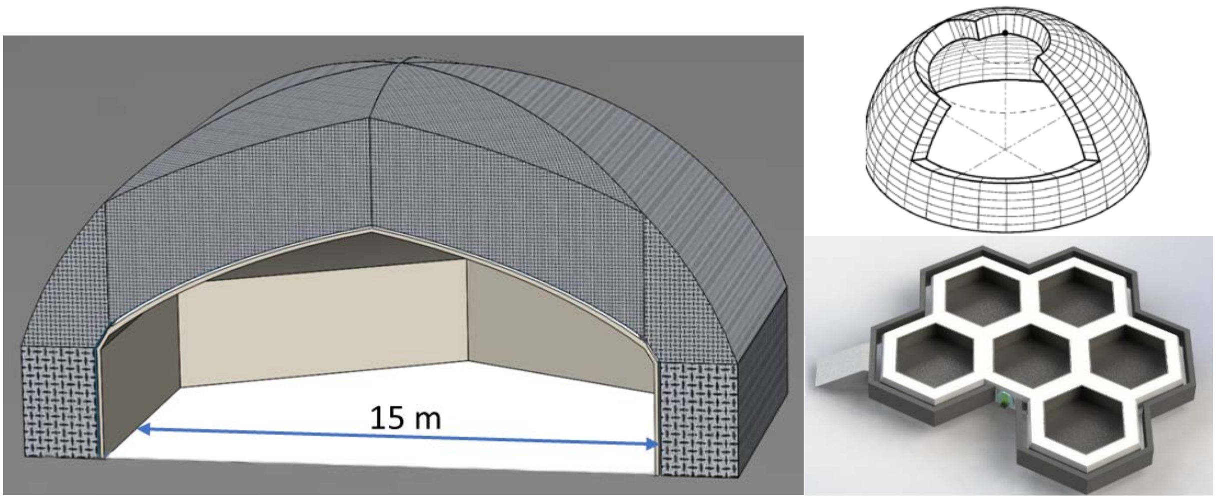

Figure 1. Left: Concept for ReLGreen primary structure using stacked LER blocks as the outer structure. Top right: Principle for dome structure stacking. Bottom right: Suggested arrangement of multiple ReLGreen modules.

The proposed cultivation system of the ReLGreen Module is made of substructure elements produced by the LER technology, including gully, shelf, and fluid reservoir. The elements were further arranged into a hydroponic system consisting of 424 gullies with 0.48 m^2 cultivation area each, able to accommodate plants of various sizes and high-density germination units. The proposed ReLGreen module offers a total cultivation area of 200 m^2 for various crops, able to feed 3 crew members if aiming for an all-crop diet minimizing the requirement for other foodstuffs.

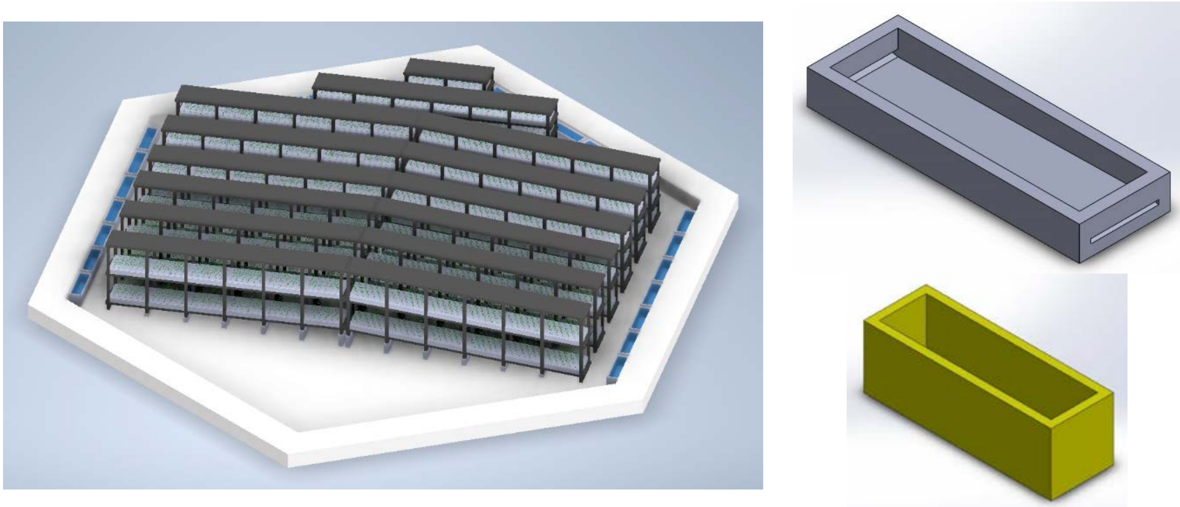

Figure 2. Left: Hydroponic system of the ReLGreen module. Right: Substructure LER parts of the ReLGreen Module: gully (top), liquid reservoir (bottom).

According to a literature review on additive manufacturing technologies weighed against Lunar environmental conditions for construction activity, sintering and melting of regolith appears more promising than extrusion-based processes for Off-Earth manufacturing, resulting in the selection of the proposed LER technology for the ReLGreen module.

The novel LER technology is based on the process used for making Light Weight Aggregate. It consists of expanding, at high temperatures, a regolith-carbon mix into a predefined mold with the geometry of the element to produce. The demonstrated and reproducible expansion results from the gas formation upon heating to 1200 °C from the reaction between iron oxide in regolith simulant and low amount of a carbon source. The porous LER elements can further be coated with a molten sulfur layer to make them watertight for hydroponic applications.

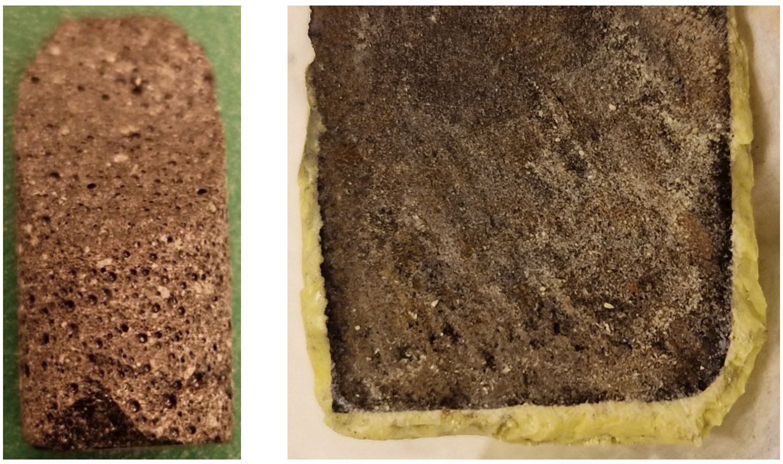

Figure 3. Left: Expanded LER sample. Right: Cross-section image of a sulfur coated regolith sintered sample.

A hydroponic crop cultivation campaign growing lettuce using deep-water cultures (DWC) and nutrient film technique (NFT) was successfully conducted in a controlled environment to validate the LER technology, associated with sulfur coating for watertightness, in the context of a ReLGreen module.

Under the tested conditions, the lettuce plants generally grew well, with no significant negative effects, in sulfur-coated DWC and NFT test models and when exposed to the key materials of the proposed LER-based hydroponic system. Some leaching of selected elements and ions from the materials in question were reported during the crop cultivation test campaign, though not to concentration levels considered to represent toxic conditions for the plants.

Figure 4. Healthy plants growing in the NFT and the DWC sulfur coated systems.

The LER technology associated with sulfur coating for watertightness was proven to be a relevant Off-Earth manufacturing technology for a ReLGreen module. Further optimization of the proposed concepts, technologies and strategies would nevertheless help bring a lab-scale ReLGreen Module to a demonstrated prototype level. By using Lunar materials and innovative manufacturing techniques, the Farming project is paving the way for long-term human habitation in space.