Designing Greenhouse Subsystems for a Lunar Mission: The LOOPS - M Project

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Abstract

The 2020s is a very important decade in the space sector, where international cooperation is moving towards the exploration of the Moon and will lead to stable lunar settlements, which will require new, innovative, and efficient technologies. In this context, the project LOOPS–M (Lunar Operative Outpost for the Production and Storage of Microgreens) was created by students from Sapienza University of Rome with the objective of designing some of the main features of a lunar greenhouse. The project was developed for the IGLUNA 2021 campaign, an interdisciplinary platform coordinated by Space Innovation as part of the ESA Lab@ initiative. The LOOPS-M mission was successfully concluded during the Virtual Field Campaign that took place in July 2021. This project is a follow-up of the V-GELM Project, which took part in IGLUNA 2020 with the realization in Virtual Reality of a Lunar Greenhouse: a simulation of the main operations connected to the cultivation module, the HORT[3], which was already developed by ENEA (Italian National Agency for New Technologies, Energy and Sustainable Economic Development) during the AMADEE-18 mission inside the HORTSPACE project. This paper will briefly describe the main features designed and developed for the lunar greenhouse and their simulation in a VR environment: an autonomous cultivation system able to handle the main cultivation tasks of the previous cultivation system, a bioconversion system that can recycle into new resources the cultivation waste with the use of insects as a biodegradation system, and a shield able of withstanding hypervelocity impacts and the harsh lunar environment. A wide overview of the main challenges faced, and lessons learned by the team to obtain these results, will be given. The first challenge was the initial inexperience that characterized all the team members, being for most the first experience with an activity structured as a space mission, starting with little to no know-how regarding the software and hardware needed for the project, and how to structure documentation and tasks, which was acquired throughout the year. An added difficulty was the nature of LOOPS-M, which included very different objectives that required different fields of expertise, ranging from various engineering sectors to biology and entomology. During the year, the team managed to learn how to handle all these hurdles and the organizational standpoint, working as a group, even if remotely due to the Covid-19 pandemic. Through careful planning, hard work and the help of supervisors, the activity was carried out through reviews, up to the prototyping phase and the test campaign with a successful outcome in each aspect of the project. By the end of the year everyone involved had acquired new knowledge, both practical and theoretical, and learned how to reach out and present their work to sponsors and to the scientific community.

Keywords

Education, LOOPS-M, IGLUNA

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Acronyms/Abbreviations

ENEA	*Italian National Agency for New Technologies, Energy and Sustainable Economic Development*
LOOPS-M	*Lunar Operative Outpost for the Production and Storage of Microgreens*
SPENVIS	*Space Environment Information System*
SWS	*Stuffed Whipple Shield*
TRL	*Technology Readiness Level*
V-GELM	*Virtual Greenhouse Lunar Experimental Module*

1. Introduction

The Moon is at present considered as the gateway for further voyages in the solar system. As such, national agencies are cooperating to design and conduct missions regarding the exploration of the satellite, in preparation for future more distant space travels. These missions require innovations with the highest TRL (Technology Readiness Level) available, to ensure safety during the achievement of their objectives.

To cultivate such technologies and to assist the younger generations contribute to the lunar colonization, the IGLUNA platform was created by Space Innovation as part of the ESA_Lab@ initiative launched by ESA. During each IGLUNA Campaign, teams from allover the world worked on a project regarding the main aspects of lunar settlements, ranging from structures to power generation. These projects were structured as real technological development project, undergoing reviews typical of space missions such as PDR (Preliminary Design Review), CDR (Critical Design Review) and RR (Readiness Review) under the judgement of experts. In this context, the LOOPS-M Project took place, participating in the IGLUNA 2021 Campaign [1].

The project had a wide heritage from the earlier projects V-GELM (Virtual Greenhouse Lunar Experimental Module) and HORTSPACE that took part in respectively the IGLUNA 2020 Campaign, and the AMADEE-18 mission [2][3]. HORTSPACE featured the first version of the cultivation module used in the later campaigns, the HORT^3, a vertical hydroponic cultivation element fit for the production of microgreens, which as per mission objective, was tested and validated in the Oman Desert. V-GELM studied the design for a lunar greenhouse employing the HORT^3, later realized in a virtual environment creating a digital twin of the designs. The LOOPS-M project was therefore aimed to enhance the designs of both the module created for HORTSPACE and the lunar greenhouse design created with V-GELM. It was divided in four main objectives: creating a new fully automated vertical cultivation system (the HORT^3 MKII), designing a shield for the lunar greenhouse from both micrometeorites and the lunar environment, adding a new layer of sustainability with a new bioconversion system, and lastly to represent these innovations in virtual reality. All these systems were successful in reaching their prototyping phases. The vertical cultivation system was based on the heritage from the HORT^3, but was completely revised and built anew to be compatible with a robotic arm capable of conducting all the operations from sowing to collection of microgreens autonomously.

Figure 1 Autonomous Cultivation System [1]

The shield was based on the Stuffed Whipple Shield (SWS) and was designed to withstand the harsh environmental conditions on the moon surface such as the temperature and the radiations, while also protecting the greenhouse from potential micrometeorites [4].

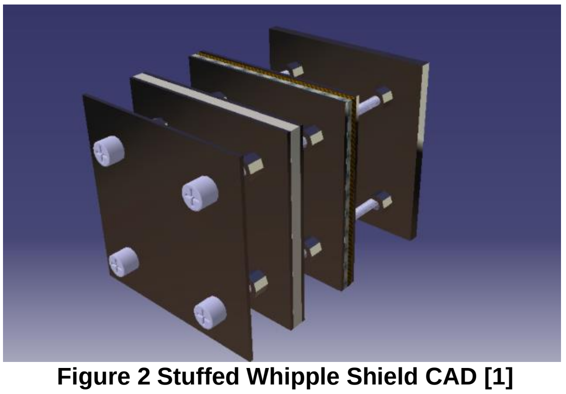

Figure 2 Stuffed Whipple Shield CAD [1]

The bioconversion system was designed to use insects for the biodegradation process of excess microgreens and their resource recycling, turning waste into potential protein and fertilizer.

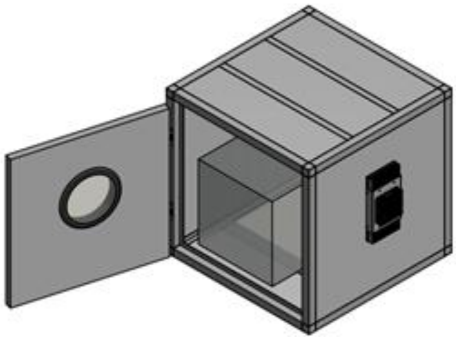

Figure 3 Bioconversion System Design [1]

The virtual reality simulation was created to represent these new systems in a virtual environment to allow further and more optimized monitoring, diagnostics, and prognostics to modify the assets to enhance their capabilities and ensure their performance, but also to show through a more successful mean the potential of the project.

Figure 4 Virtual Reality Outside Overview [1]

To reach all these achievements, the activities were led by a team of twenty students coming mainly from Sapienza university of Rome, under the guidance of supervisors of both the university and ENEA.
During the development of the four systems the teams had to face various hurdles, that will be discussed in this paper. These obstacles once overcome became an important part of the expertise gained by the students, which would have otherwise not been achieved during normal course studies. The activities will be categorized as: Management, Knowhow and Outreach.

2. Management

Management is a crucial aspect of every space mission. A very clear team structure is fundamental, but there are also many other instances in which the management capabilities are fundamental. In this paper, the focus will be laid on team management, documentation, and sponsorships.

2.1. Team Management

In this paragraph the general organization of the LOOPS-M team will be addressed, starting from its overall structure to the tasks division via a top-down approach.
To deal with all the project's aspects the team members had a Project Manager to refer to and were divided into four sub teams, each developing a precise lunar greenhouse subsystem. This division led to the birth of units regarding Automation, Bioconversion, Micrometeorite Shield and Virtual Reality. Each of the four resulting sub teams had a Team Leader who was responsible for the internal sub team organization to comply with the schedule, to interact with the LOOPS-M Project Manager and all the supervisors both from La Sapienza university of Rome and from our project partner ENEA. Another sub team composed of members coming from each other separate unit was assigned with the task of managing LOOPS-M social media, which were used to spread information regarding the objectives and outcomes of the project. Each sub team had to face deadlines not coming only from the IGLUNA 2021 mission, but also from supervisors and sponsors, as the latter needed the team's directives to manufacture the components they were committed to supply.
To meet the deadlines, all the tasks were equally divided among each sub team's members, taking into consideration the personal university commitments. To guarantee this flexibility the most trying tasks (e.g., the technical ones) were assigned preferably to at least two team members.
Most team members did not have or had limited experience; therefore, it was difficult to schedule activities predicting their exact time duration. In fact, the team accumulated delays also depending also on other major causes such the Covid-19 pandemic; however, all these possible delays were estimated during the risk analysis, one of the major skills obtained by the students during the activities, and thanks to time buffers the delays still brought to a successful prototyping phase within the time restraints of the IGLUNA Campaign.
With the aim of making the team organization function optimally updates to project manager and the supervisors were scheduled through weekly meetings with the whole LOOPS-M

team, along with updates via weekly documents. Individually each team member learned how to manage its time between the project, university, and personal life.

2.2. Documentation

The project was structured as a space mission, which in turn required an accurate documentation depicting everything that regarded the project. This guided the team through the management and careful planning of activities. The team members learned how to successfully write a documentation using technical phrasing, work in a group on each technical feature and how to express them clearly, but especially had to work on new aspects never encountered in their academic courses. These aspects were the mission planning in form of work breakdown structures, the risk analysis that required foresightedness, and timelines which required concrete knowledge of the theoretical aspects of the project.
All the documentation was managed by each sub team for their own subsystem, revised by the project manager, and then revised by the supervisors, only then to be delivered to the expert panel for the official reviews. This organization required planning around deadlines, but also personal life commitments such as exams.

2.3. Sponsorship

The last management goal was to plan activities also according to the sponsors' needs and to learn how to handle the supplies. The team had to find on their own sponsors and supplier to make their project feasible, which required reaching out to many companies, only a handful of which actually supported the project, also because of difficulties brought up by the Covid-19 pandemic. This made the team face many trade-offs to bring the subsystems into existence, managing the needs in terms of hardware and software based on the possibilities given by the sponsors, modifying the project as the possibilities changed. Moreover, they also learned how to negotiate with suppliers, and manage deliveries and contracts.

3. Knowhow

Since the beginning of the project the team has been engaged with different tasks and challenges, related to software implementations and hardware integration. Such assignments are key to every engineering project and can use technologies that vary widely depending on the subsystem that is currently under study. Therefore, all the sub teams had to learn how to utilize various software languages and how to properly handle the hardware for the prototyping. The team during the integration and design phases had the possibility to have technical discussions with ENEA experts that had expertise with either tools or specific systems.

3.1. Software

The use of various types of software required the team to acquire knowledge regarding a wide variety of programs and their applications.
In the earliest phase of the project the team had to design theoretically the prototypes to satisfy the project purposes in terms of required performances. According to the preliminary studies, the prototypes have been designed using different typologies of software for developing CADs and 3D modeling, such as SolidEdge and Blender for more refined and complex models, or Catia for models to be later used in mechanical simulations. These software for creating CADs have been chosen because of their integrability with other numerical simulation software.
Each sub team needed specific software to simulate very distinct problems, mainly ranging from testing of hypervelocity impacts, radiative or thermal analysis to autonomous activities and system control.
For the first two cases, which regarded the micrometeorite shield, Ansys and SPENVIS (Space Environment Information System) were employed.
Ansys is an engineering simulation software, that has been utilized to analyze the shield thermal conductivity and its behavior under projectile impacts, in terms of deformation, stress and threshold thickness. The SPENVIS is an ESA operational software, and it has been used to simulate the radiative lunar environment.
To investigate the conditions and to conduct activities autonomously, Grolab and the Farmbot Web App were employed.
GroLab was needed to control all sensors to measure the environmental parameters and more such as humidity of the soil, ambient temperature, water level stored in the tank and power supply. The FarmBot Web App is a software used to customize the growing process of the microgreens, seeding, watering and pruning, and was utilized to handle to vertical operating robotic arm.
The team learned also to program using languages, as MatLab, C++ and Python, that

were fundamental for many applications throughout the project. MatLab was needed to integrate additional computations with the Ansys simulation results. A code written in C++ operated through an Arduino allowed to implement a system to control fundamental components of the vertical cultivation unit. Lastly, the team has developed a web socket in Python to establish a connection between the GroLab sensors and the FarmBot Web App controlling the actuators.
Lastly, the Virtual Reality simulation was powered by the Unreal Engine, which required a great amount of optimization of models and activities, for it to be run successfully using an Oculus Quest device.

3.2. Hardware

The LOOPS-M team designed and developed three main physical protypes: the HORT^3 MKII (fig.1) which is an autonomous system for the cultivation of microgreens and a SWS (fig. 2) for the protection from micrometeorites, and a Rearing Module used as bioconversion system. The prototype realization was a challenging task for the team since all team members had little experience regarding hardware integration. The main issue during the prototype realization was to ensure that all the operations were carried out safely and without any risk. One of the first struggles encountered during the assembly process was the utilization of tools never used before by any team member. Concerning the HORT^3 MKII, the team had to design and realize electrical and hydraulic connections which required a deep understanding of the behaviour of complex integrated systems such as the robotic arm and the irrigation system and the interface with a control system. The main challenges that the team faced in the SWS integration was the choice of materials appropriate with the requirements and then the approach with materials such as Kevlar, Nextel and Aerogel which required specific processing before utilization. The shield assembly required a specific procedure that the team members acquired after several protype realization to avoid mechanical interference. Analogously, the most challenging aspect of the Bioconversion unit was understanding the right parameters for the biological processes to occur and therefore the integration in the system.
All the prototypes had to go through extensive test campaigns to ensure that they would be able to function properly in their respective working space. The tests were conducted in both Sapienza and ENEA facilities, and required a new type of expertise to completely validate the prototypes. The prototypes were therefore tested for their components, as for the Automation and Bioconversion units, and regarding the operational conditions, such as the thermal test, and especially the radiative test conducted and the Calliope Co-60 Gamma Irradiation facility at Enea Casaccia Research Centre.

4. Outreach

The goals of promoting the LOOPS-M Project and its achievements were various. The first objective was to show the public the importance of scientific research conducted and the impact that the technology progress has to everyday life. Then there was the goal of creating a sense of community, to create attachment to the project and make people intrigued about lunar exploration and human colonization. Lastly, there was the necessity to have both financial and technical support to make feasible the project and it was decided to involve time and energies in showing to companies and experts in the field the potential of LOOPS-M ideas and designs. To reach these goals, the team worked mainly in three different communication areas: social media, sponsorship communication and technical and disclosure presentations.

4.1. Social Media

Thanks to social media we had the opportunity to share the project and the team's passion for research and technology with a wide public (both technical and general). Three main social media profiles were used: Instagram, Facebook, mainly to reach the general public of different ages, and LinkedIn, to reach companies and experts. A proper editorial plan for each platform was devised, with weekly appointments and updates on each project sections. The contents were prepared specifically to reach platform specific users and with different formats, languages, and communication styles. Other pages and entities were contacted to explain the project and create social collaboration with two main aims: to variegate the content proposed and to show LOOPS-M to a wider public.

4.2. Sponsorship

During the development of the project the team had to interact with sponsors and supporters in different ways at the beginning, during and at the end of the project. For example, once deals had been reached, often companies asked the team to write about the project and its goals on their website. During the development of the project, the team would update them on progress made and collaborate with the sponsor on different aspects of the project. The possibility to be helped by companies that had more knowhow than the team increased the quality of the project and the individual skills of each member. At the end of the project, the team sent reports on the results obtained and the visibility received by the sponsor. This experience taught the team how to look for and collaborate in an adequate way with a sponsor supporting the project.

4.3. Presentation and scientific disclosure

Presenting to an audience, whether it be technically expert or simply curious, leads to face multiple challenges, especially for unexperienced students as the team was composed of.

To understand how to communicate effectively with the target listener, the team had to learn how to approach differently an expert panel and the general public. The presenters adapted the vocabulary and the presentation itself according to the target. The public got easily involved by avoiding too technical terms and numerical values, while these were required for official scientific presentations and project design reviews.

Disclosure and comprehension were facilitated by the introduction of photos, videos, animations, and CAD models aiming also to etch the project on the audience mind. Moreover, as a further learning, each member, in turn, was encouraged to be a speaker. This was not only helpful to overcome introversion, but also to show the project dimension and team members variety.

5. Results

During the IGLUNA 2021 Campaign, the team members of the LOOPS-M Project managed to successfully prototype four different subsystems of a lunar greenhouse, while learning on the field various important lessons regarding management, knowhow and outreach. The project was carried out fruitfully throughout its many milestones as a true space mission, organized internally and judged externally by a panel of experts. The feedback by experts, industrial partners and sponsors was positive and led to a complete success for the LOOPS-M project, that has been thereafter disseminated.

6. Conclusions

The team learned personally about management, knowhow and outreach in their field, but also had an increased personal growth thanks to the many revisions and assistance of supervisors that followed their steps throughout the project. All the activities conducted, and the important lessons learned would have not been possible during an academic course of studies, which remarks the importance of such extracurricular activities.

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