Research Proposal

Integration of a Robotically Operated Greenhouse in the Life Support System of a Subsurface Mars Habitat

as part of Rhizome 2.0

Master Honours Programme – Faculty for Architecture and the Built Environment

TU Delft

Antonia Sattler

Supervisors

Dr. Henriette Bier

M.Sc. Arwin Hidding

1. Introduction

The Rhizome study executed by TU Delft and funded by the European Space Agency investigates the construction of subsurface habitats on Mars through 3D printing and robotic support (Bier, et al., 2024). For a permanent settling like this, a greenhouse as sustainable source to grow fresh food is inevitable to ensure a self-sufficient, balanced diet of the crew members. In addition to the technical purpose of the greenhouse (the source of food), it has the potential to contribute to various aspects of the habitability of the station. The temperature and light influences from the greenhouse could contribute to the human comfort in the habitat, while the oxygen produced by the plants could add to the life support systems' air revitalization. Plants and greens have also shown to have a positive impact on the human mental health (Hall, & Knuth, 2019). Despite the inevitable need for a greenhouse as part of a Martian settlement, planting, nurturing, and harvesting the crops can be time-intense, challenging and potentially error-prone work. To solve these issues, future (extra)terrestrial greenhouses could profit from the integration of robotic support. Robotically operated architecture, just as cyber-physical and adaptive architecture all describe (with some variations) systems that enable adaption to changing inputs given by environments, inhabitants, or objects by using sensors, actuators, and an underlying ICT-infrastructure (Schnädelbach, 2010; Bier & Mostafavi, 2016). Using robotically operated systems can on the one side help monitor and adjust several parameters influencing plant growth like light, temperature, humidity, soil moisture, fertilization, water requirements, pH, planting density, pesticides, diseases, and weeds. On the other side they can perform physical labour like moving, spraying, planting, and harvesting plants (Tangarife, et al., 2017). The goal of this research is the development of a robotically operated greenhouse design considering its technical feasibility and architectural integration in the Rhizome concept with a special focus on the illumination system.

2. Review of Literature

Past and current concepts range from greenhouses that include robotic-monitoring, -assessment and -operation, and AI-supported control as well as their integration in the building or space habitat. Several studies implemented for terrestrial applications looked at the use of mobile robots like ground based AGVs (automated guided vehicles) and UAVs (unmanned aerial vehicles) (Thomopoulos, et al., 2021) that analogue to human farmers move through the greenhouse from plant to plant and execute necessary tasks like spraying plants and harvesting them (Bagagiolo, et al., 2022; Seo, et al., 2021).

Other ideas include the design of a robotically controlled environment that is itself nurturing the crops it houses. The EU-funded EDEN ISS project is an example of such a greenhouse system for hydroponic plants that can automatically capture and distribute data from its large sensor array and high-definition cameras to monitor the plant health which allows for a partially remote operation of the greenhouse (Zeidler, et al., 2019). Fernando, et al. (2020) introduced an *AI Based Greenhouse Farming Support System with Robotic Monitoring* that can monitor and control the environmental factors inside the greenhouse like temperature, soil moisture, humidity, and pH. This is achieved through the use of a cloud connected mobile robot, image processing and machine learning.

Examples for greenhouse concepts in space such as the *Robotic System for Plant Tending in Remote Habitat* developed by NASA Kennedy Space Center, Lockheed Martin Space and academic partners use different tools like vision systems to 3D reconstruct plants, remote teleoperation, and 6 DOF robotic arms (Hament, et al., 2021). In any configuration, several system parts in the design of an extraterrestrial greenhouse come together as demonstrated by *Greenhouse Module for Space System: A Lunar Greenhouse Design* (Zeidler, et al., 2017) and *From ice to space: a greenhouse design for Moon or Mars based on a prototype deployed in Antarctica* (Maiwald, et al., 2021). Both studies illustrate the need for an atmosphere management system, a nutrient delivery system, thermal control system, and illumination system, with the first also detailing a power control and distribution system and control and data handling system. As current research shows, the complexity of the interplay between the subsystems of a greenhouse in a potentially remote, self-sustaining environment can be addressed by different forms of robotic support.

3. Research Methodology

The implementation of the research is threefold. The first part **Case Study Research and Concept Development** will be based on literature and case study review. This will enable the detailing of the design concept considering the state of the art and most recent research. For that, the different systems (atmosphere management system, nutrition delivery system, thermal control system, illumination system, power control and distribution system and data handling and control system), their dimensions, position and purpose in the Rhizome structure will be defined.

The second part of the research is concerned with the **Technical Feasibility** of the robotically operated greenhouse and will contain the detailed design of the greenhouse and its components. The purpose of this is to have a comprehensive overview of the needed components for the above-mentioned systems, their functionality, and the interaction between them including the sensors (UV, humidity, etc.), actuators (lamps for illumination, pipes for water supply, etc.), battery technology, communication technology (wire-technology or IoT), and safety system.

The last part of the project **Parametric Design and/or Partial Physical Mock-up** will use the gained knowledge from the first two phases to implement an experimental study. Option one is a numerical study concerned with the design and code of a parametric greenhouse in Rhino Grasshopper. This would result in a tool that can be used in the further development of the Rhizome project. The parametric design would allow the greenhouse configuration to change depending on variable parameters like for example crew size. The other possible project outcome is experimental and would entail the construction of a low-fidelity, physical mock-up that can be integrated in the 3D printed Rhizome structure. This serves the purpose of a proof-of-concept to verify (in a small scale) the value and feasibility of a robotically operated greenhouse in the configuration and with the components as defined in this research.

4. Research Timeline

The research is divided into five phases with Phase 3 entailing two different options, whose implementation will be decided when the project has progressed further.

	Research Phase	Objectives	Deadline
1	Case Study Research and Concept Development	• System and component overview • Geometrical properties of components • Technical properties of components	30.06.24
2	Technical Feasibility	• Wire-Technology/IoT • Sensors and actuators • Battery technology • Safety system	30.09.24
3	Parametric Design *and/or* Partial Physical Mock-up	• Grasshopper-Script that is adapting the greenhouse design according to changing parameters *and/or* • Physical integration of the greenhouse system in the 3D print to visualize/test functionality	15.11.24
4	Writing	• Analysing findings • Summarizing work • Completion of first draft	30.12.24
5	Finalisation	• Getting feedback from supervisors • Rewriting • Completion of second draft • Submission and presentation	30.01.25

5. Aims and Objectives

The project focuses on the following three main objectives:

1) Design and overview of the technical systems, their needs, functions, and cooperation needed for the greenhouse
2) Architectural integration of the greenhouse in the Rhizome concept with a focus on the illumination system
3) Integration of the greenhouse's influence on the air quality, thermal quality, light quality, acoustic quality, and mental health of the astronauts

6. References

Bier, H., Hidding, A., Veer, F., Peternel, L., Schnmehl, R., Cervone, A., & Verma, M. (2024). Advancing Design-To-Robotic-Production and-Assembly of Underground Habitats on Mars. In Adaptive On-and Off-Earth Environments (pp. 21-38). Springer, Cham.

Hall, C., & Knuth, M. (2019). An update of the literature supporting the well-being benefits of plants: A review of the emotional and mental health benefits of plants. Journal of Environmental Horticulture, 37(1), 30-38.

Schnädelbach, H. (2010). Adaptive architecture-a conceptual framework. proceedings of Media City, 197, 522-538.

Bier, H. H., & Mostafavi, S. (2016). Robotic building as physically built robotic environments and robotically supported building processes. Architecture and Interaction: Human Computer Interaction in Space and Place, 253-271.

Tangarife, H. I., & Díaz, A. E. (2017, October). Robotic applications in the automation of agricultural production under greenhouse: A review. In 2017 IEEE 3rd Colombian Conference on Automatic Control (CCAC) (pp. 1-6). IEEE.

Thomopoulos, V., Bitas, D., Papastavros, K. N., Tsipianitis, D., & Kavga, A. (2021). Development of an integrated IoT-based greenhouse control three-device robotic system. Agronomy, 11(2), 405.

Zeidler, C., Zabel, P., Vrakking, V., Dorn, M., Bamsey, M., Schubert, D., ... & Ferl, R. J. (2019). The plant health monitoring system of the EDEN ISS space greenhouse in Antarctica during the 2018 experiment phase. Frontiers in Plant Science, 10, 1457.

Bagagiolo, G., Matranga, G., Cavallo, E., & Pampuro, N. (2022). Greenhouse Robots: Ultimate Solutions to Improve Automation in Protected Cropping Systems—A Review. Sustainability, 14(11), 6436.

Seo, D., Cho, B. H., & Kim, K. C. (2021). Development of monitoring robot system for tomato fruits in hydroponic greenhouses. Agronomy, 11(11), 2211.

Fernando, S., Nethmi, R., Silva, A., Perera, A., De Silva, R., & Abeygunawardhana, P. W. (2020, November). Ai based greenhouse farming support system with robotic monitoring. In 2020 IEEE region 10 conference (tencon) (pp. 1368-1373). IEEE.

Hament, B., Oh, P., Carr, D., Moore, C., Dev, S., Ferguson, I., ... & Ehrlich, J. W. (2021, November). Robotic System for Plant Tending in Remote Habitat. In ASME International Mechanical Engineering Congress and Exposition (Vol. 85611, p. V07AT07A019). American Society of Mechanical Engineers.

Zeidler, C., Vrakking, V., Bamsey, M., Poulet, L., Zabel, P., Schubert, D., Paille, C., Mazzoleni, E. & Domurath, N. (2017). Greenhouse Module for Space System: A Lunar Greenhouse Design. Open Agriculture, 2(1), 116-132. https://doi.org/10.1515/opag-2017-0011

Maiwald, V., Vrakking, V., Zabel, P., Schubert, D., Waclavicek, R., Dorn, M., ... & Zeidler, C. (2021). From ice to space: a greenhouse design for Moon or Mars based on a prototype deployed in Antarctica. CEAS Space Journal, 13, 17-37.