MSc 2 IAP workshop (2024): Space Architecture

Team

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Abstract

Rhizome 1.0 approaches developed in 2021-22 for underground off-Earth habitats on Mars using Design-to-Robotic-Production-Assembly and -Operation (D2RPA&O) methods will be further advanced in Rhizome 2.0 and/ or Moon Station in order to demonstrate the scalability of the concept. The aim is to (a) understand whether approaches are applicable to large i.e., 'real-life' construction scale and (b) outline the associated challenges and develop appropriate solutions. In this context, the design takes functional, structural, material, and operational aspects into account. It furthermore, integrates sensor-actuators into the life-support system of the habitat. It takes advantage of Computer Vision (CV) and Human-Robot Collaboration/ Interaction (HRC/ I) at various stages in the construction process.

Framework

In Spring semester 2024 students engage in the investigation of off-Earth habitats as computationally designed and robotically 3D-printed and assembled structures. Such habitats embed Artificial Intelligence (AI) in their sensor-actuator mechanisms that ensure life-support and allow users to customise their operation. Physical and software components are, in this context, deeply intertwined. Their static and dynamic modalities involve customization and adaptation, which will be achieved by means of Design-to-Robotic-Production and -Operation (D2RP&O).

The course content builds upon Rhizome 1.0 that focused on developing the design of subsurface 3D printed structures on Mars and/ or Moon using regolith-based concrete that can be produced via In-Situ Resource Utilisation (ISRU). In the Rhizome 2.0 study that started 2023 the 3D printing approach will focus on possibilities to print with cementless concrete. An overview on ISRU is available here: Regolith as future habitat construction material.

Several firms have been developing ideas for off-Earth construction such as Autonomous Additive Construction on Mars by Foster+Partners and Marsha and various academic studies have been implemented at TU Delft. The subdivision of space and the integration of environmental control remained, however, sketchy. Also, the Human-Robot Collaboration (HRC) supported assembly of the 3D printed components stayed underdeveloped. Hence, new approaches will be developed 2024 based on the assumption that the habitat serves as workspace and home to 3-5 astronauts.

Alternative to scaling up the Martian habitat, developing the Moon Station (https://www.moonstation2050.com/) is considered. In addition to size, mass, and distance to Earth, the main difference is that Mars is a rocky planet with a diverse surface that includes valleys, canyons, and large volcanoes; it has a thin atmosphere composed mainly of carbon dioxide; while the Moon is rocky and has a surface covered in dust, rocks, and craters; unlike Mars, it lacks a significant atmosphere, which means it has no weather or erosion.

Approach

The development of designs for interactive architecture imbued with cyber-physical systems will be implemented based on user scenarios by students working in groups. They will employ D2RPA&O methods that link design directly to building production, assembly, and operation processes. While D2RP links design to materialisation by integrating all (from functional and formal to structural) requirements in the design of building components, D2RO integrates environmental requirements as distributed robotic devices embedded into those components that are then assembled in the D2RA phase. Together they establish the framework for robotic construction at building scale. The main consideration is that in architecture and building construction the 'factory of the future' will employ building materials and components that can be robotically processed and assembled.

The IAP workshop involves D2RPA&O processes that incorporate material properties in design, control all aspects of the processes numerically, and utilise parametric design principles that can be linked to robotic production and operation. It facilitates development of knowledge and skills in Parametric Design, Programming, and Robotics, which may be new or challenging to some students. In order to address this challenge, tutors are taking a problem-based learning approach. This is an interactive learning approach, wherein students are asked to identify what they know, what they need to learn, and how/ where to access new information, knowledge, and skills that may lead to solving a problem. In this context, students are asked to deal with different, even conflicting ideas co-existing in the contemporary architectural discourse. Students are encouraged to develop an informed opinions allowing them to operate in a dynamic environment that evolves in time depending on the development of their projects and their tutors' input. This implies that process and results emerge in the interaction between students, tutors, and employed data-driven tools and systems.

Objectives

D2RPA&O addresses the question of how robotics are integrated in building processes and the built environment in order to make production of buildings efficient and their utilisation smart. Students will design environments with integrated sensor-actuators as proof of concept for:

(a) Process- and material-efficiency achieved through parametric design and robotic (i.e. selective) material deposition and HRI-supported D2RP&A.

(b) Operation-efficiency by integrating AI-supported environmental and spatial control involving distributed sensor-actuators such as light dependent resistors, infrared distance sensors, pressure sensors, etc. that inform lights, speakers, ventilators, etc. in order to allow users to customise use of the habitat.

<u>D2RPA&O</u>

The D2RPA&O process will focus on three aspects:

1. Additive D2RP: The development of a structurally and functionally optimised 3D printed subsurface habitat inline with the Rhizome 1.0 study;

2. HRI-supported D2RA: The development of stackable Voronoi-based components;

3. D2RO: The development of interactive/responsive lighting/ventilation/heating system and life-support system to accommodate individual needs.

Students work in groups with members taking specific roles focusing on either D2RP, D2RA, D2RO and/ or the integration between them. The design has to be informed by structural, acoustic, and robotic path simulations as well as the integration of the life-support system.

HRI/ C

Robotic Assembly Description-2024.pdf

Site

The site for the project is on Mars (see Rhizome 1.0) or Moon (see https://www.moonstation2050.com/).

Schedule

IAP takes place in the 3rd Quarter and is preliminarily scheduled to take place Fridays 9:00-13:00h. The intro is on 16th of February and midterm and final review are preliminarily scheduled on 1st of March and 19th of April, respectively.

Requirements/ Deliverables

1. PPT presentation (uploaded to the wiki) showing project theme, design strategy, and design from schematic to developed and materialisation design levels.

2. 1- to max. 2-minutes video of HRI-supported D2RPA&O process uploaded to the CpA-wiki.

3. Report (±1500 words) consisting of textual and photo/graphical documentation of HRI-supported D2RPA&O process developed during the course.

4. Clean Rhino and Grasshopper files and refined version HRI-supported D2RPA&O procedures.

5. 3D printed models and prototypes.

Evaluation Criteria

A. Consistency at both thematic as well as the design level: Being true to the concept and demonstration of design development based on the concept; Consistent performance of the group with a well-managed task distribution throughout the semester as well as during the final presentation.
B. Completeness: Fulfilment of deliverables mentioned above
C. Quality and successful working of the prototype: Well built, real-time interactive, robust, successfully serving the purpose of a proof of concept.
D. Quality of presentation: Well structured, within allocated time, high quality videos documenting the prototype construction as well as animations/walkthroughs etc. through the project, well-illustrated parametric design procedures

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