OG11b – PRO-ACT

Planetary RObots Deployed for Assembly and Construction Tasks

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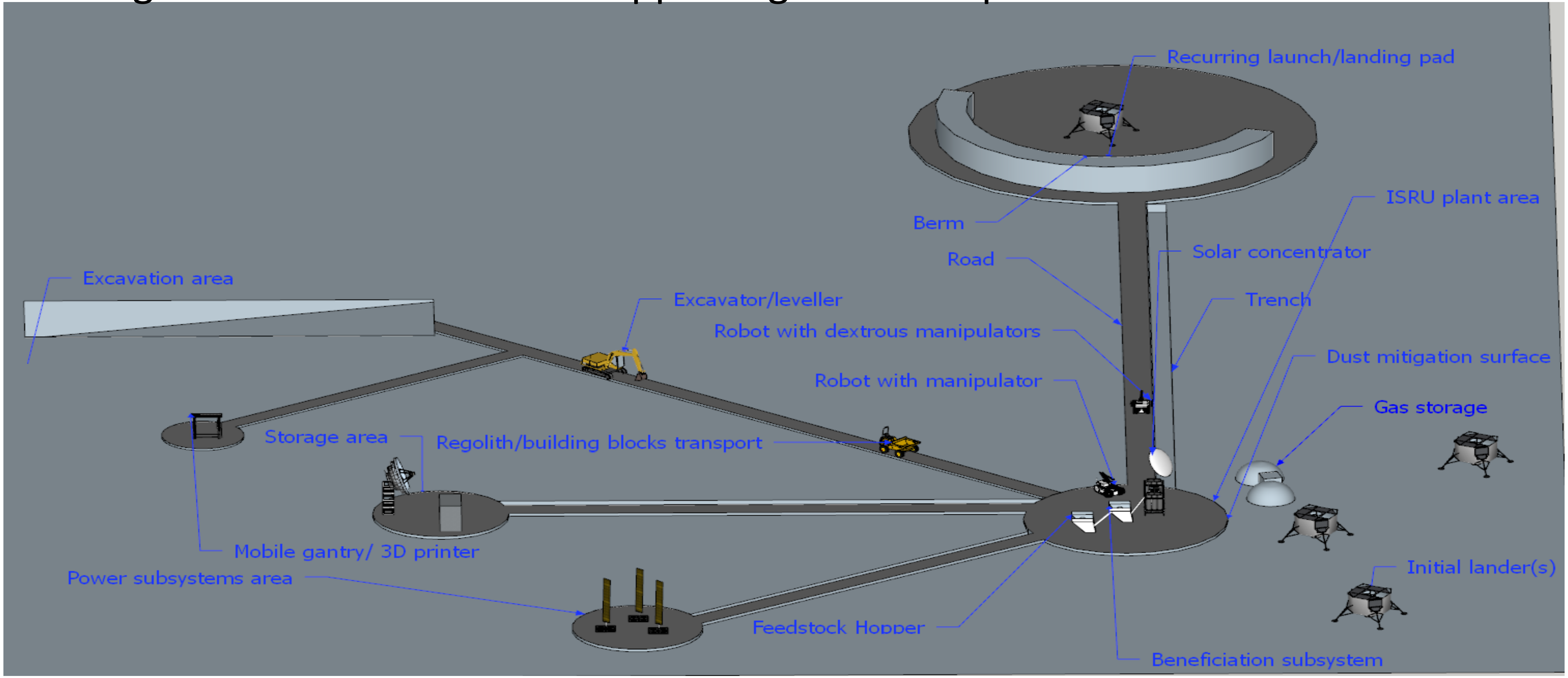
PRO-ACT in a nutshell

- Funded in the EC Horizon 2020 SPACE-12-TEC-2018 « SRC - Space Robotics Technologies »
- 24 months long project
- Starting date: February 1st 2019. – Ending date: January 31st, 2021.
- 9 partners from 6 countries
- Grant amount: 3.1 MEuros
- Total effort: 333 Person Months

Concept: Elements of a future Lunar Base

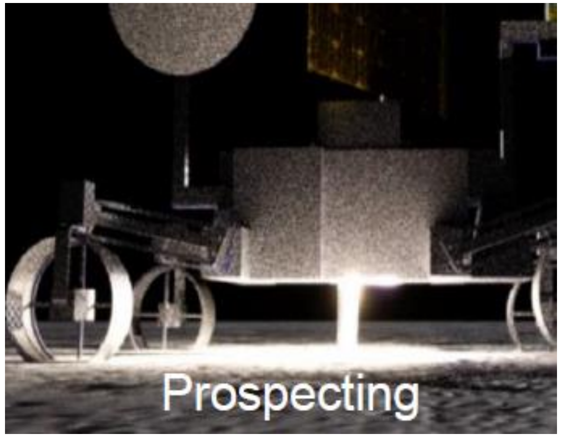
In-Situ Resource Utilisation (ISRU) enables sustainability in space exploration by harnessing available resources for supporting human exploration:



Background: ISRU

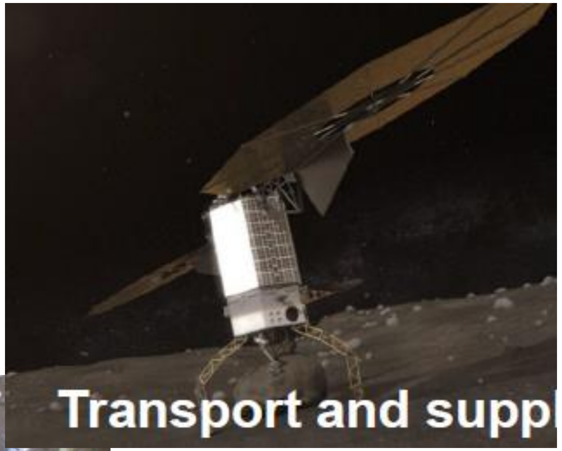
- Establishing structures for lunar habitats and commercial uses
- O2, He3 extraction from Regolith
- Regolith based 3D printing
- Lava tubes – concentrated Ilmenite resources
- Commercial opportunities

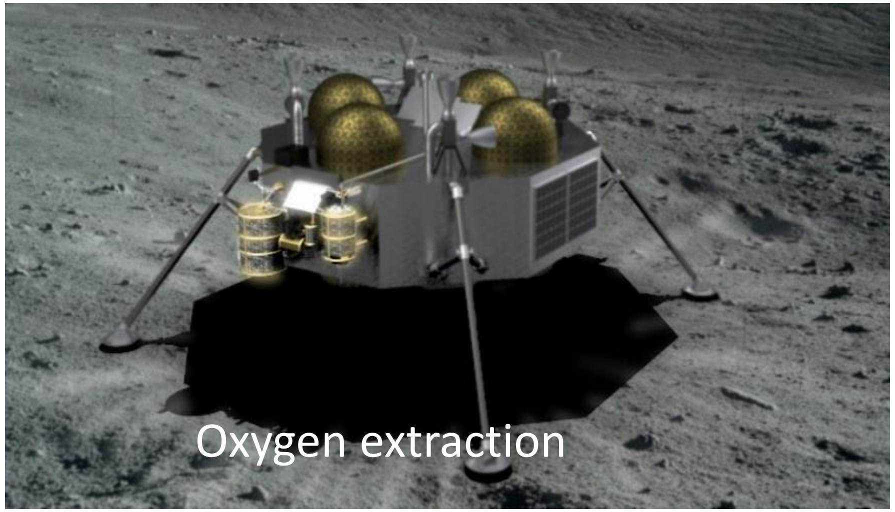

Supply (storage)

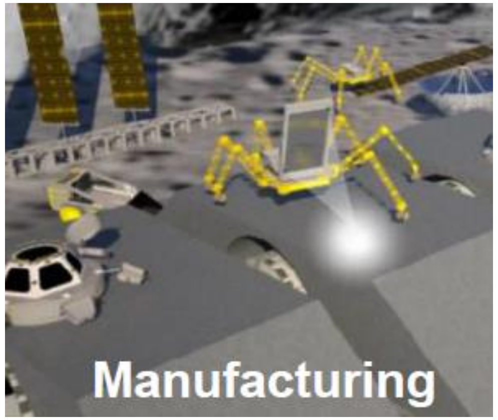

Prospecting


Refinement


Support


Transport and suppl


Oxygen extraction


Manufacturing

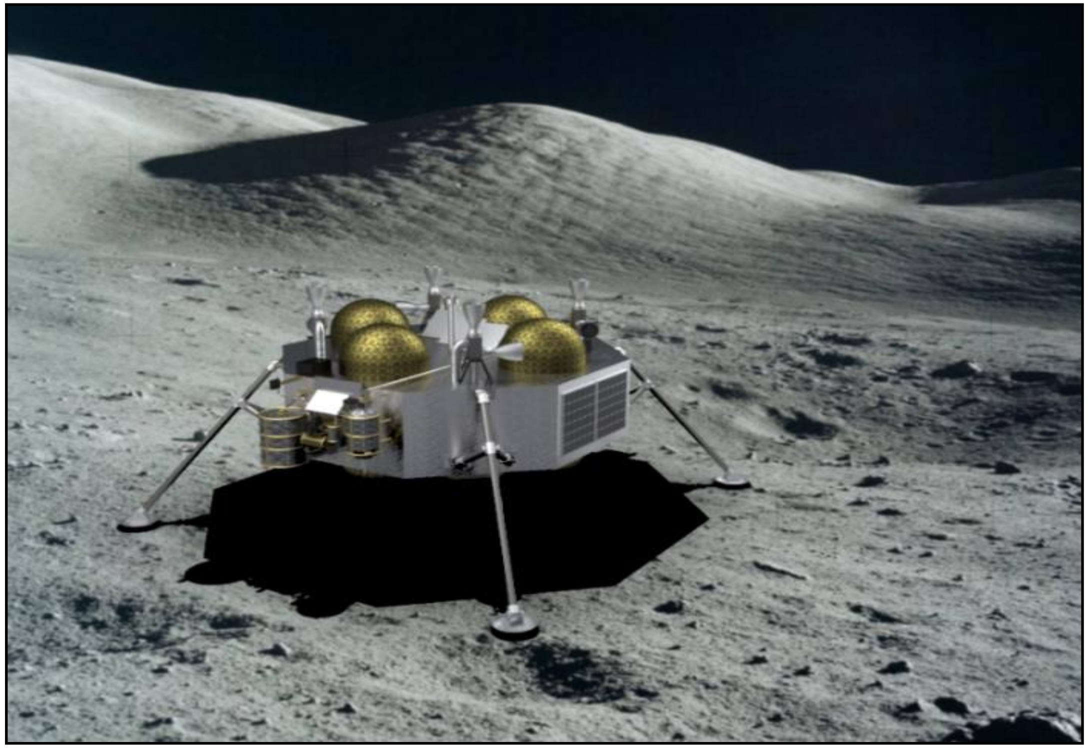

Mining

Background: ESA ISRU Demo Mission

- **ESA** is preparing Lunar ISRU Demonstration Mission (ISRU-DM) - by 2025, extraction of water or oxygen from the lunar regolith.
- Mining related activities include excavation and beneficiation (enrichment).
- **Ilmenite reduction process**: FeO-bearing minerals like Ilmenite, beneficiated from lunar regolith, are reacted with hydrogen in a reactor at 900-1000 deg C to produce water

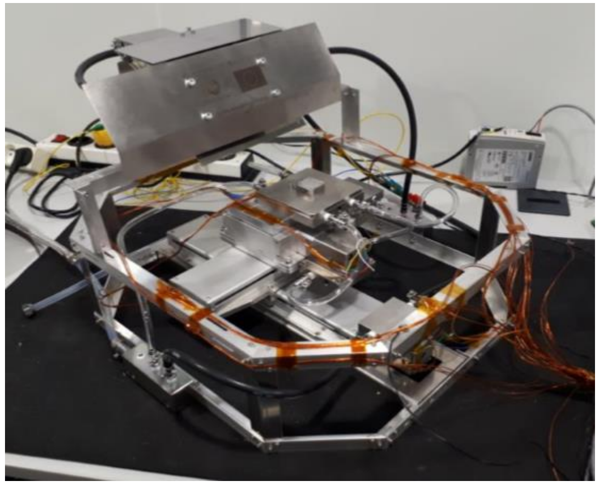
$$FeTiO_3 + H_2 \rightarrow TiO_2 + H_2O + Fe$$
$$H_2O \rightarrow H_2 + \tfrac{1}{2} O_2$$

- O2 and H2 electrolytically produced
- SpaceApps ESA Projects:
  - Phase 0 study (ALCHEMIST) 2018
  - Earth-based ISRU demo plant breadboarding (ALCHEMIST-ED) 2019
  - Phase A/B1 + Breadboarding (ALPHA) 2019
  - Aim: to produce 100 grams of water on the Lunar surface by 2025-2028

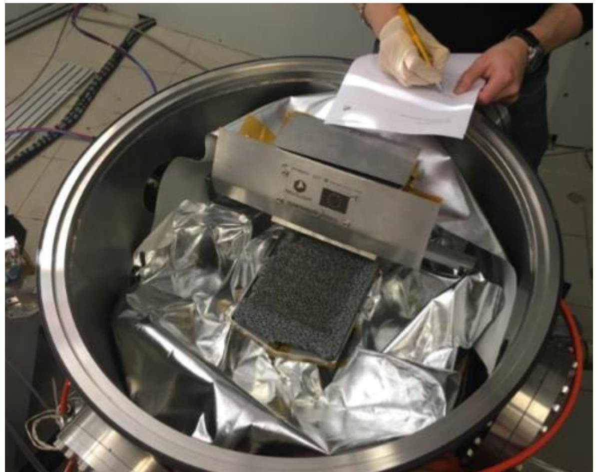
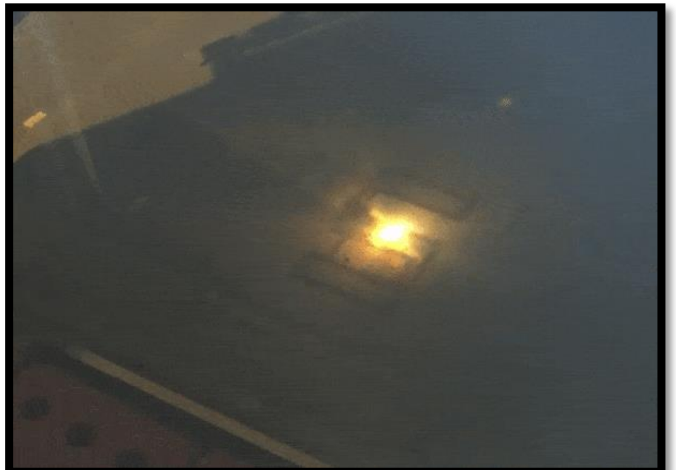


Background: Solar 3D printing using Regolith

- NASA Regolith Simulants
  - JSC-1AF, fine, 27 µm average size
  - JSC-1A, a reproduction of JSC 1, less than 1 mm size
  - JSC-1AC, coarse, a distribution of sizes < 5 mm






PRO-ACT: Objectives

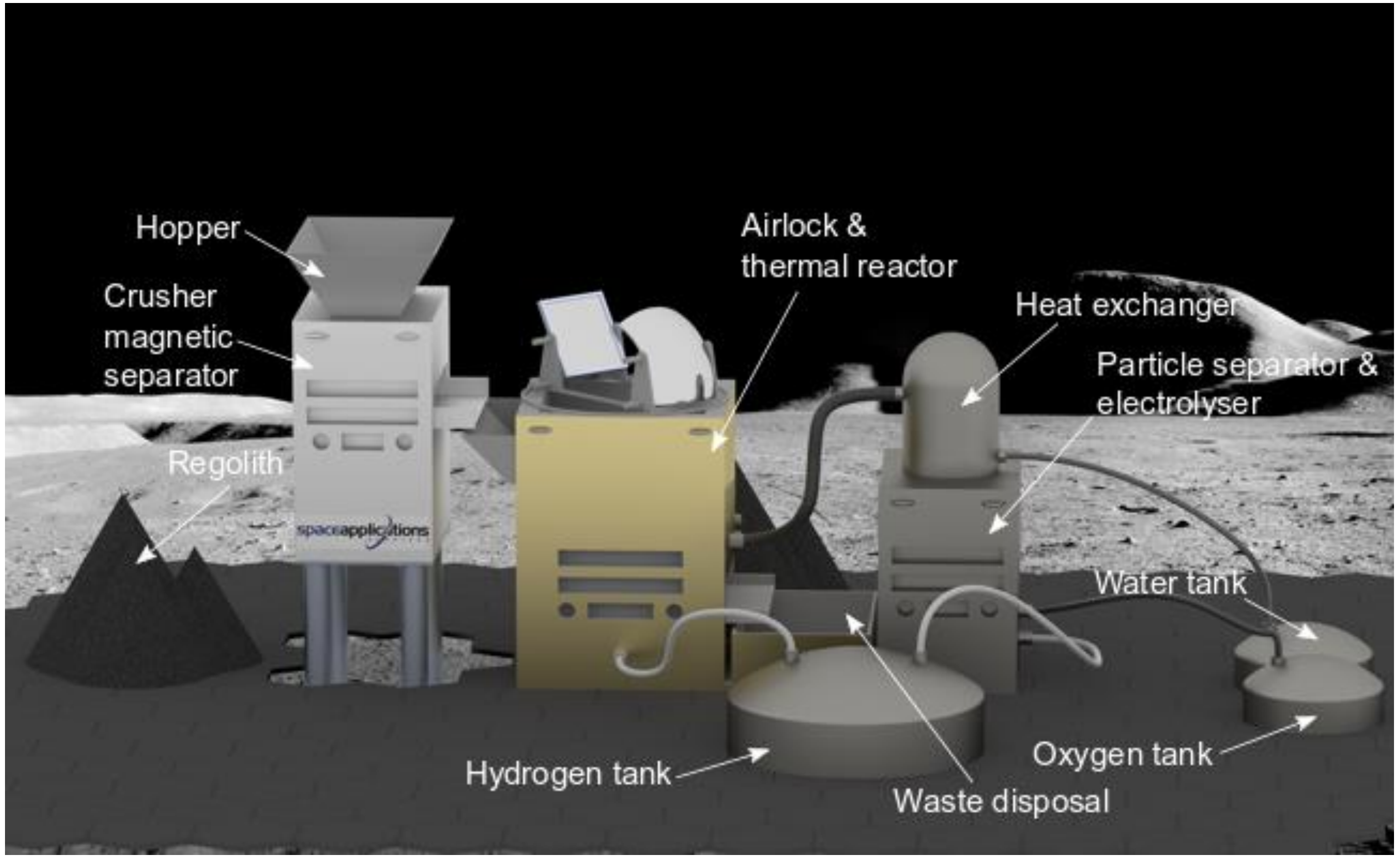
Implement and demonstrate multi-robot collaborative planning and manipulation capabilities in a lunar mining and construction context.

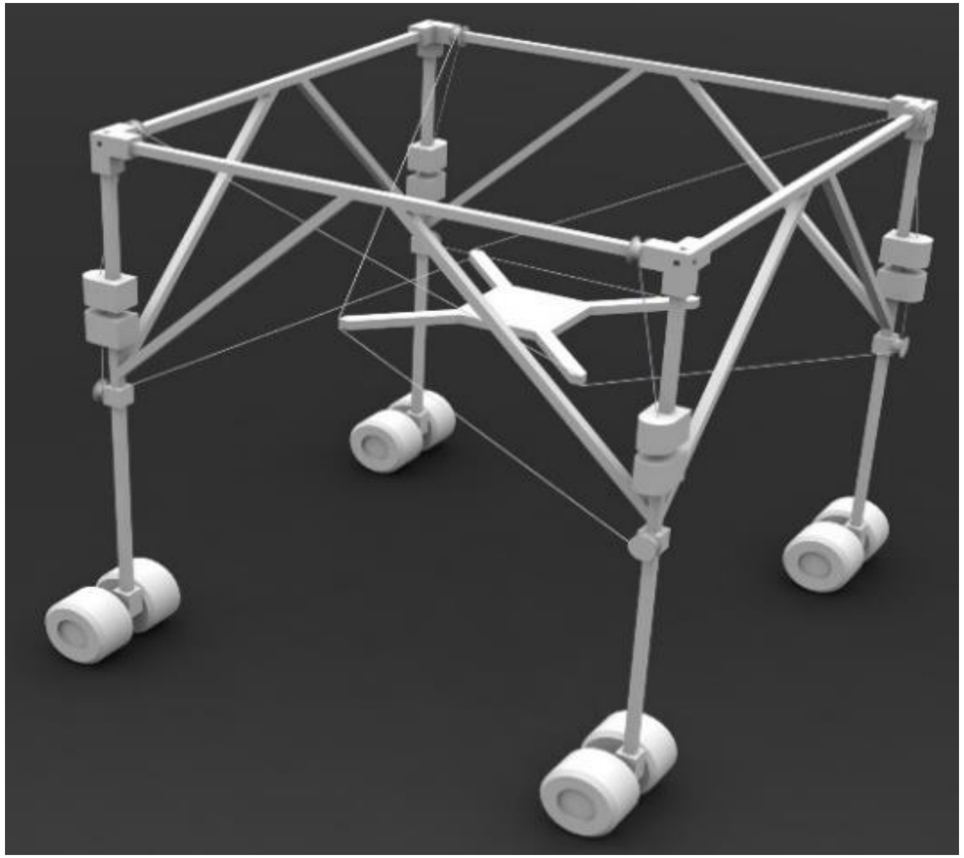
- Cooperative exploration, excavation and preparation of sites
- Cooperative mission planning, goal decomposition and task execution
- Collaborative assembly of an Lunar ISRU plant components
- Assisting (partial) assembly of a mobile gantry - lifting and 3D printing building and dust mitigation elements

PRO-ACT – Specific Objectives

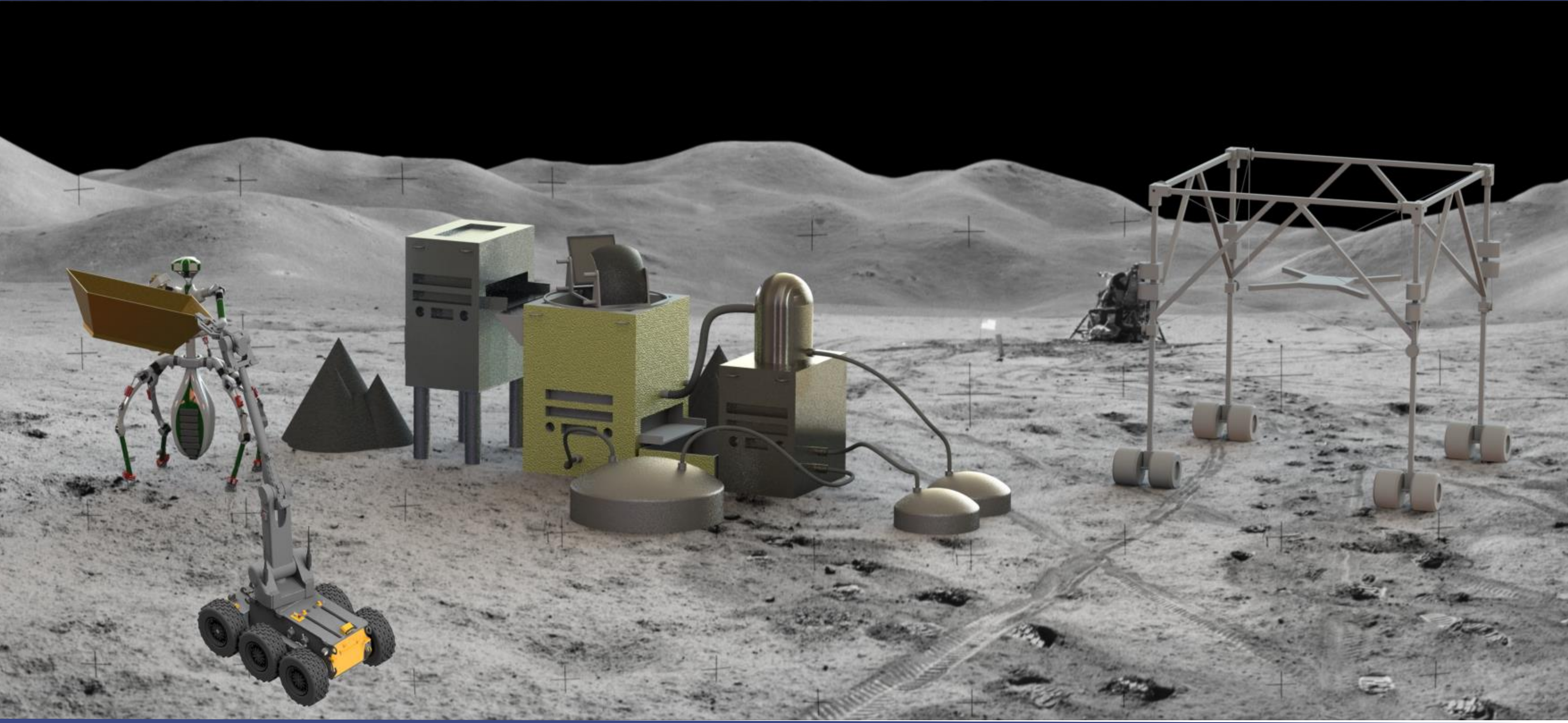
- **Specific Objective 1 (SO1):** Reviewing, extending and integrating ESROCOS, ERGO, InFuse, I3DS and SIROM outcomes as part of a comprehensive multi-robot system
- **Specific Objective 2 (SO2):** CREW (Cooperative Robotics for Enhanced Workforce) consisting of integrated components from ERGO, InFuse, cooperative SLAM and ESROCOS
- **Specific Objective 3 (SO3):** Customizing existing mobile robotic platforms and preparing facilities in relation to (1) ISRU capabilities establishment and (2) preparing dust mitigation surfaces (3) Partially assembling and deploying a gantry/3D printer.

PRO-ACT Objectives





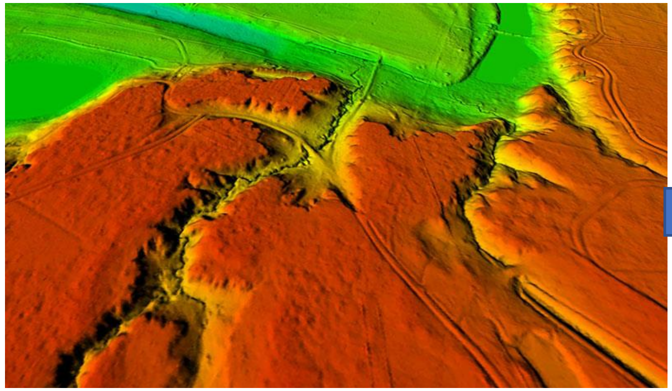
PRO-ACT Scenario



Addressed Sections of a Lunar scenario

1. Fine scale surveying of areas prior to carry out construction work
2. Site clearing by grading and shoveling (from stones and debris)
3. Unloading equipment/construction elements from the lander(s) and transporting them to the assembly sites
4. Assembly of specific modular components of an ISRU plant
5. Assisting partial assembly and mobility of cable driven gantry
6. 3D printing of modular building elements from pseudo-regolith simulant
7. Sample assembly of printed elements (bricks) to construct simple structures, habitation spaces and dust mitigation surfaces.

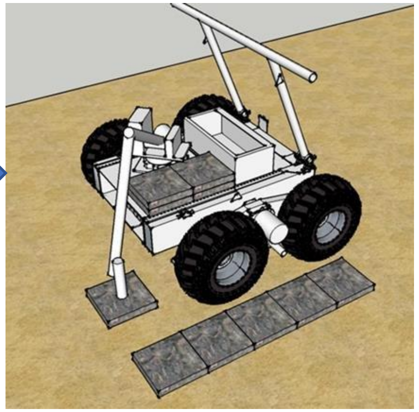
Addressed Sections of a Lunar scenario



Surveying

Grading (credit: PISCES)

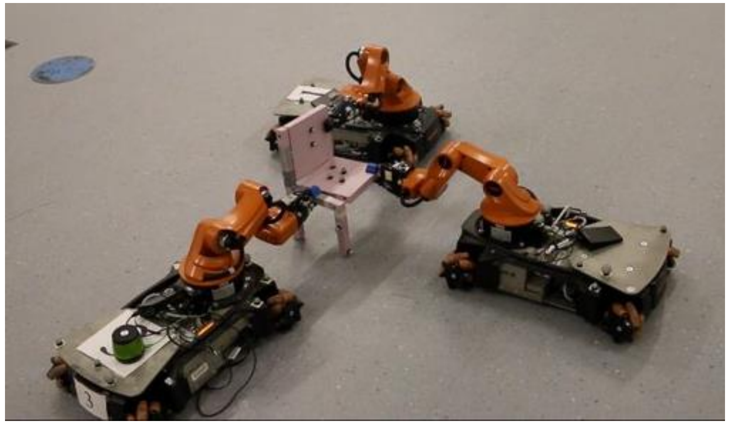
Tile/brick/modular block 3D printing (credit: Cornell)



Tiling/modular block assembly (credit: PISCES)

Unloading

Transportation



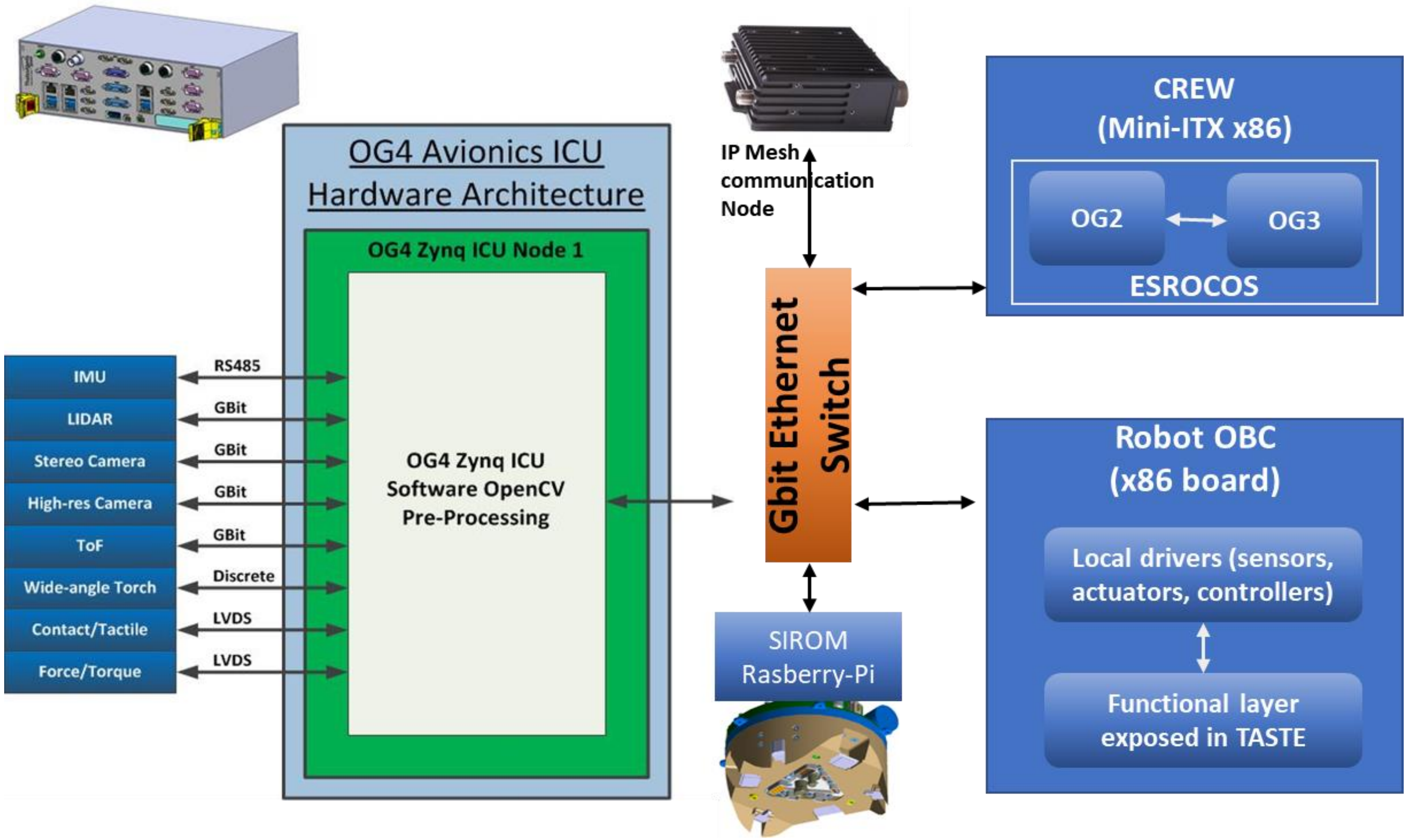
Assembling modular components, deploying hardware (ICRA.2015.7138999)

An indicative illustration of the potential tasks (analogues or Earth-based applications)

PRO-ACT Consortium

Partner	Logo	Country	Role
Space Applications Services		BE	Coordinator, Infuse adaptation, SIROM adaptation, system integration, communications, mission control
DFKI		DE	Mantis HW adaptations, Simulation, mission control, mobility and manipulator control SW, Integration of CREW
PIAP		PL	Ibis HW adaptations, locomotion and manipulator control SW, Exploitation, Integration of CREW
GMV		ES	Design and support for ESROCOS functional layer for robots and ERGO adaptation for CREW
University of Cranfield		UK	Cooperative SLAM, integration with CREW , Dissemination
LAAS-CNRS		FR	Cooperative manipulation – planning and control, integration with CREW
THALES		UK	Compact I3DS ICU adaptation, I3DS sensors, HW acceleration
AVS		ES	Modular mobile gantry, Control of 3D printing head, integration of CREW
La Palma Research Center		ES	Requirement analysis, site access and preparation, end user

Single Agent System Architecture



Adapting and integrating previous OGs outcomes

1. ESROCOS: extending the framework to allow for distributed (multi-OBC) configuration, integration with functional layer of robot

2. ERGO: Extending the framework for multi-robot mission, path and task planning – centralized and experimentally distributed configuration

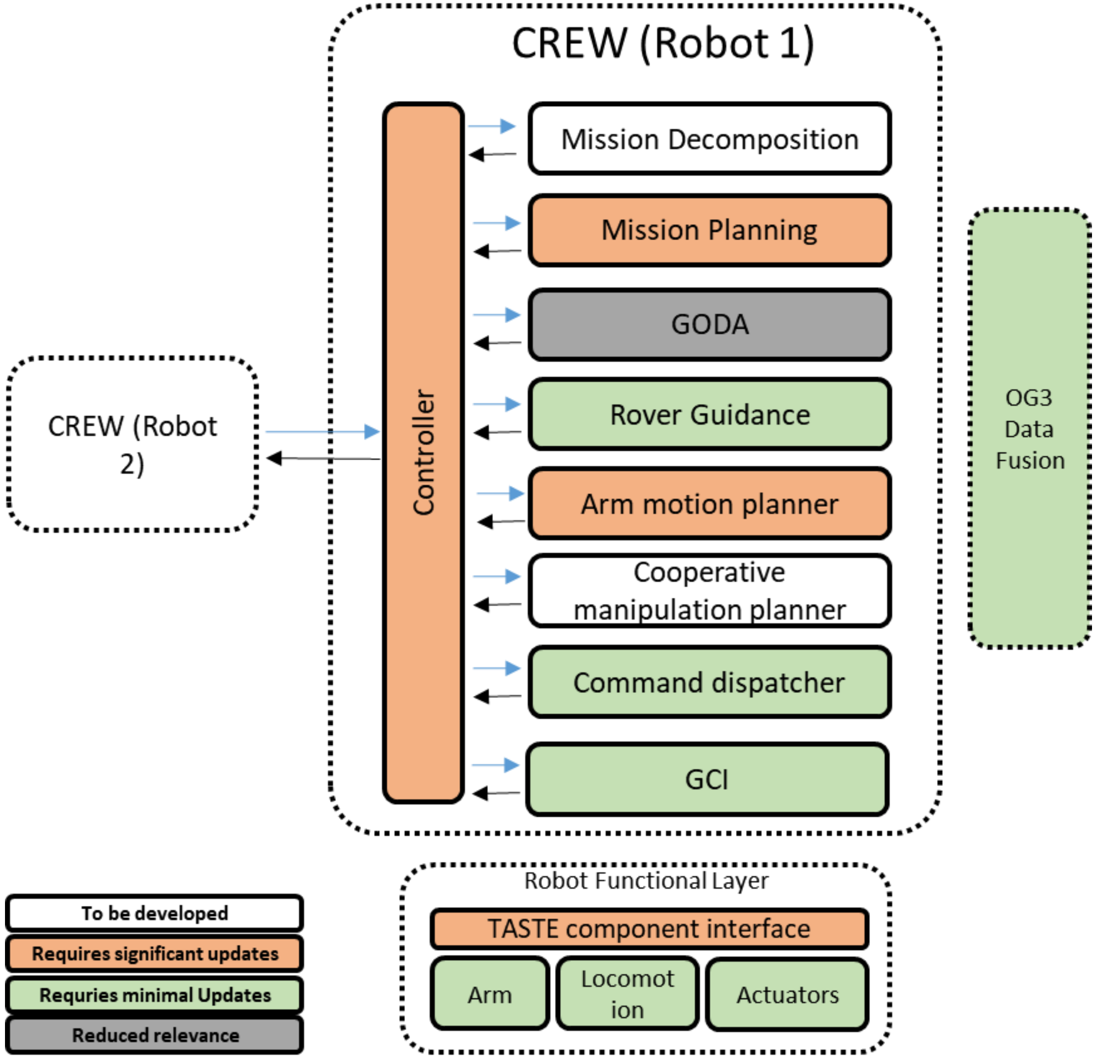
3. InFuse: Deploying relevant data fusion methods, adaptations to existing techniques and introducing cooperative SLAM

4. I3DS: Optimization for a compact ICU, relying more extensively on FPGA for RT low level data fusion

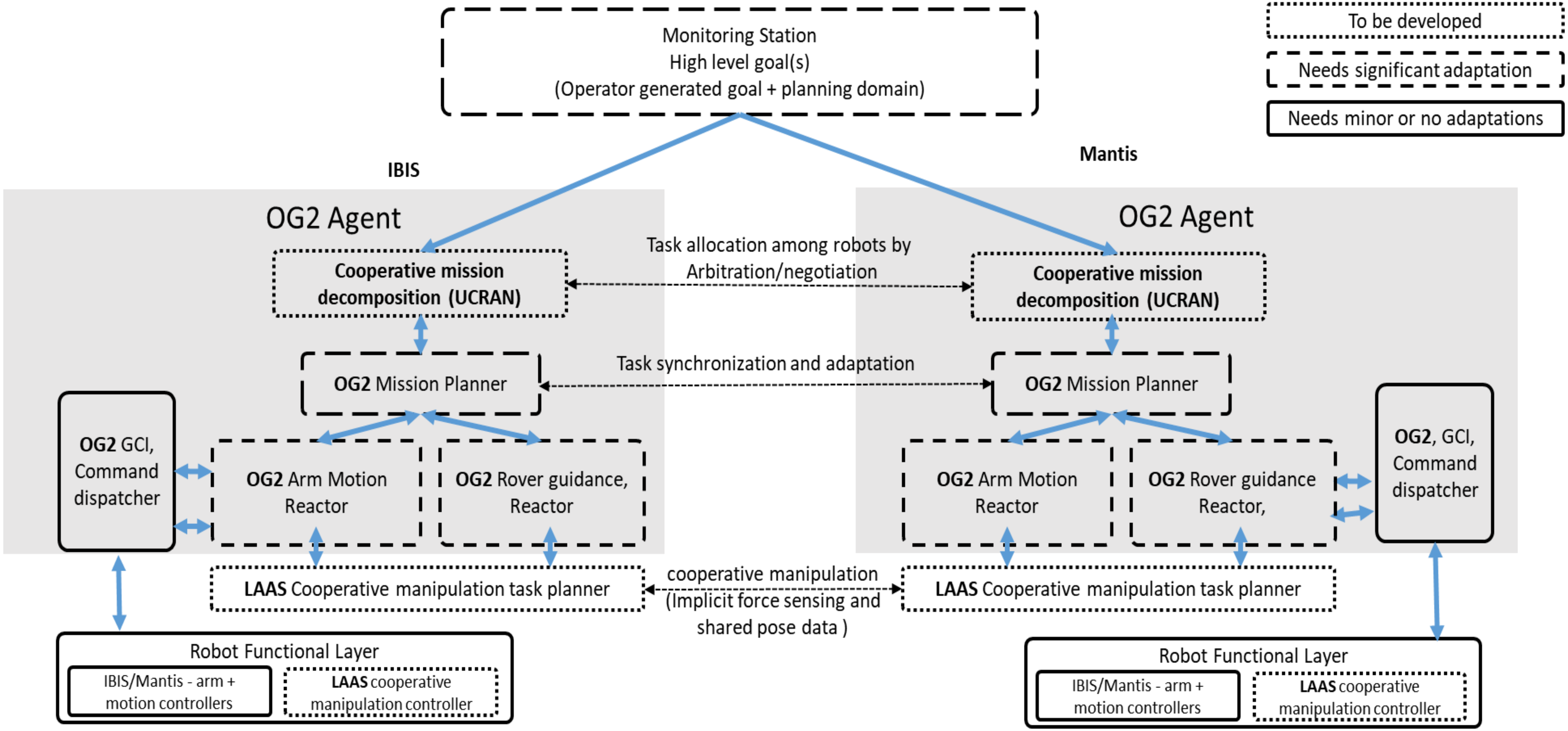
5. SIROM: design adaptation to specific end effector needs => new tools, integration with heterogeneous robots

CREW - Cooperative Robotics for Enhanced Workforce

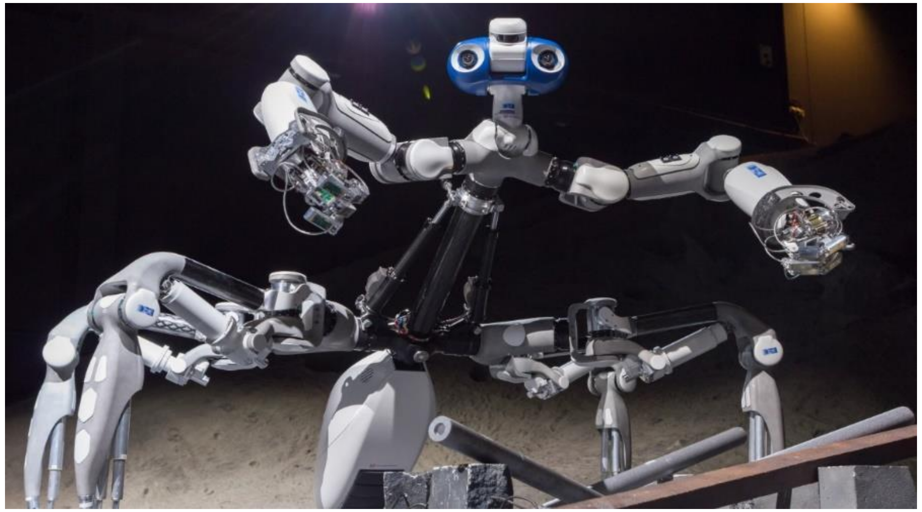
- Centralized and decentralized (experimental) multi-robot mission planning
- Cooperative manipulation planner
- Interface with robot functional layer
- Integration with DFPCs for cooperative localization and mapping

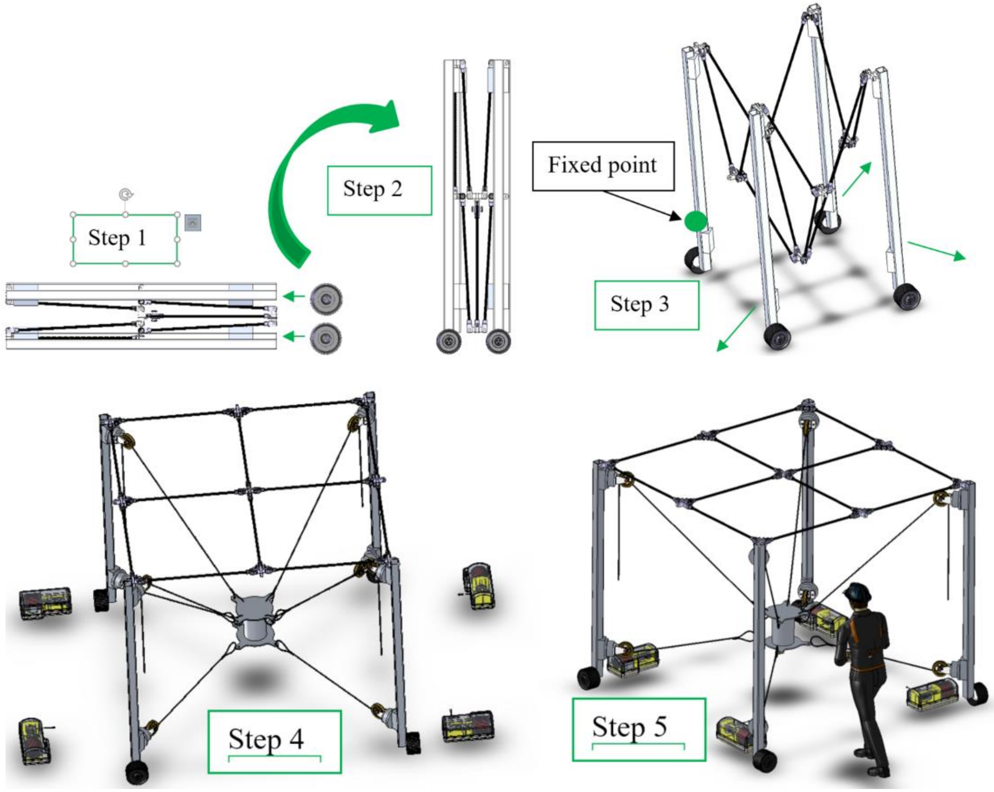


Multi-Agent Planning for Collaboration

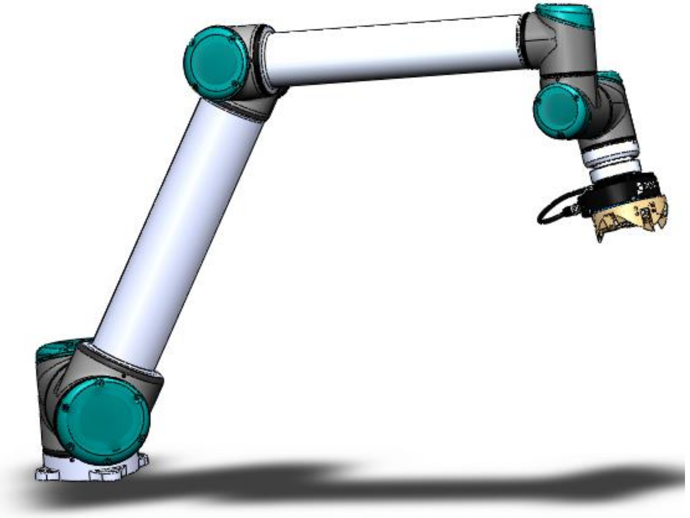


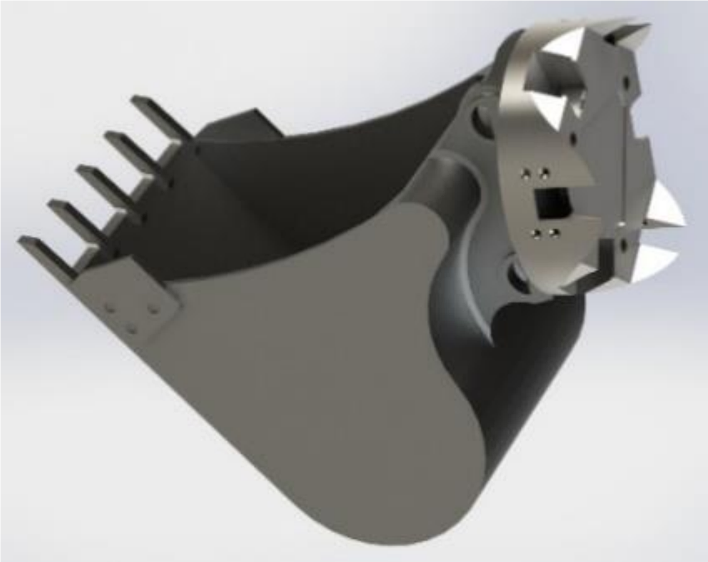
Robot adaptations

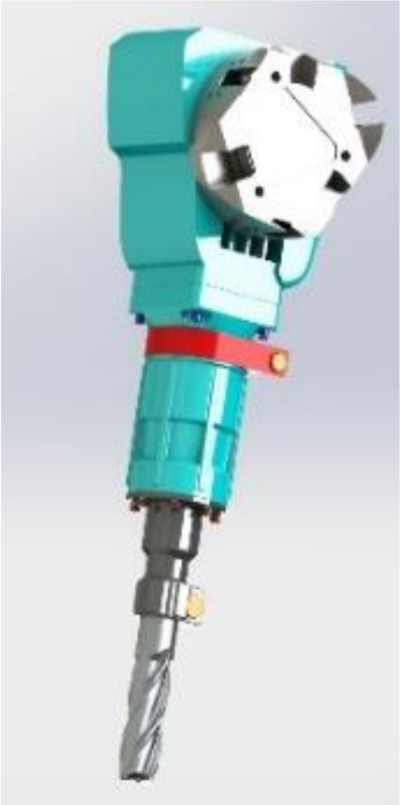




SIROM based end effector tools



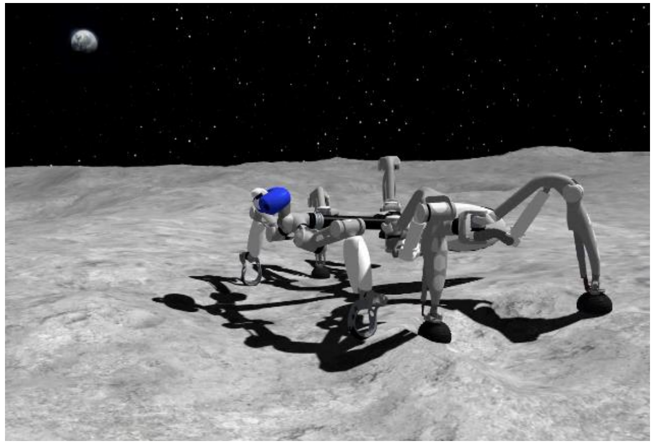
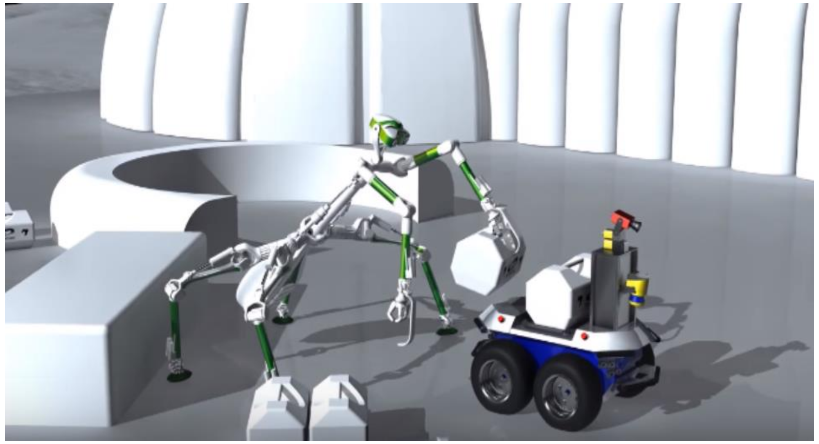
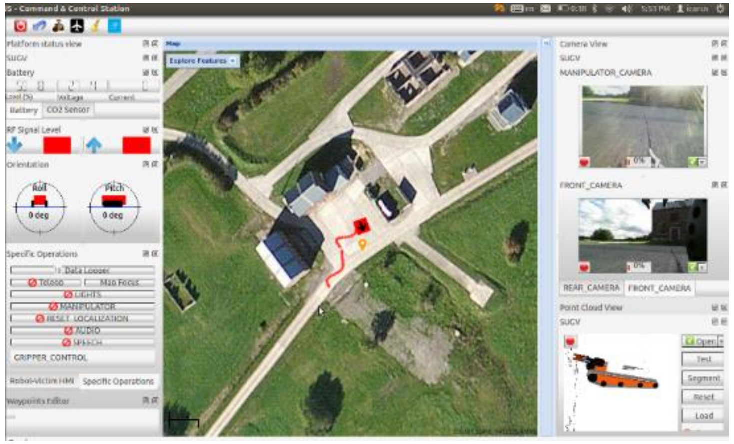




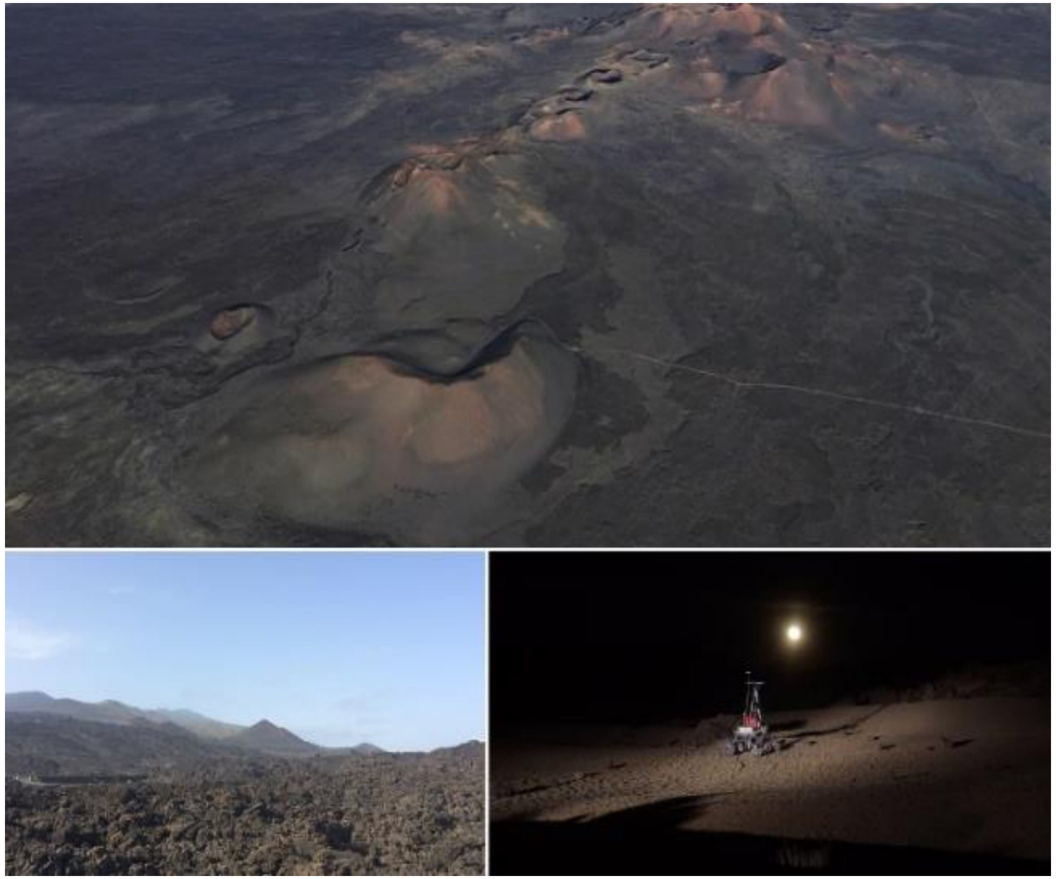
Simulation environment, Communications & Control Center

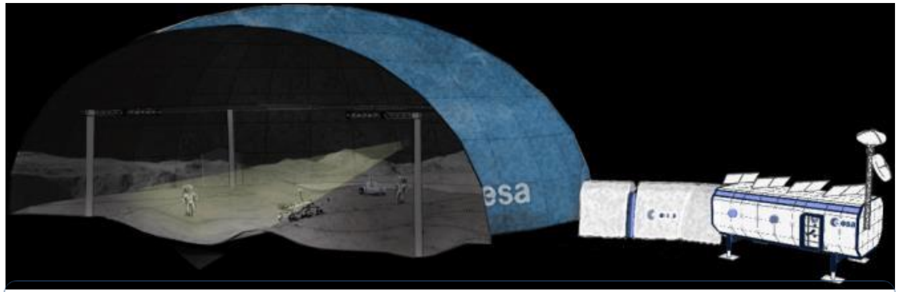
- Environment Simulation with improved physics and robot dynamics for cooperative manipulation
- Communications –IP Mesh radio based high bw, ad-hoc, reliable network
- Extension of multi-robot control center for specific scenario

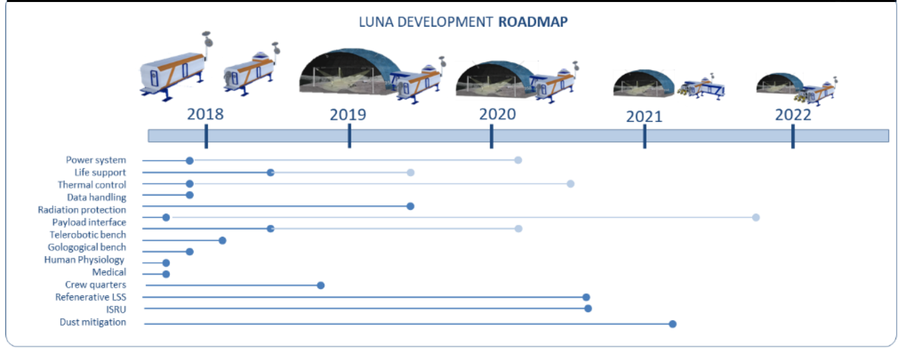


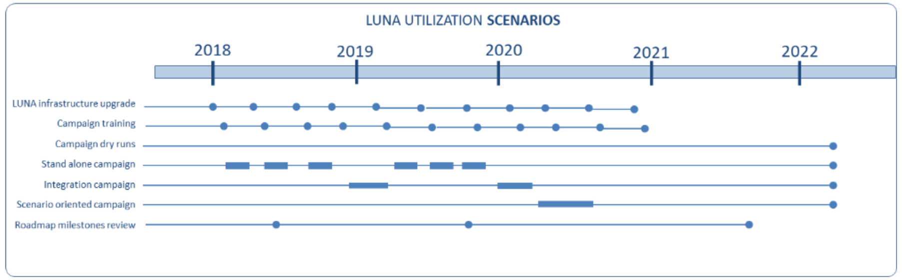





Testing and Validation









Thank you

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