ACHIEVED ACADEMY MBSE PROJECT: LUNAR HABITAT MODULE ARCHITECTURE MODEL

NB: This is a Report. The complete project can be found here: ACHIEVED MBSE Assignment or as an attachment to the mail.

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PROJECT DESCRIPTION:

We were tasked to design a conceptual model for the architecture of a lunar habitat module using the ARCADIA methodology and the Capella tool. The lunar habitat module would serve as a living research space for astronauts during extended missions on the moon.

INTRODUCTION:

A lunar base is a critical component of modern space exploration programs because the Moon represents the most practical initial destination in space. Its challenging environment will present obstacles across all fields of engineering involved. In the scope of the assignment, we were tasked to learn and apply the ARchitecture Analysis and Design Integration Approach (ARCADIA) methodology to learn field-related concepts and come up with the architectural design of our lunar space habitat module. The Capela tool was to be used to create, design and analyze the system's architecture. Last but not least, we had to identify the key operational activities, functions, interfaces, and components of the habitat.

Operational Analysis

The operational analysis focused on understanding the operations from the perspective of the requirements, functions, and capabilities.

Mission Objectives and Requirements

Objective

To provide a safe, sustainable environment for astronauts to live and conduct research during extended missions.

High-Level Requirements

- Maintain life support systems (oxygen, water, food)
    - Water recycling, management of atmospheric contaminants (e.g. CO_2), temperature and humidity control.
    - Food storage and supply mechanisms.

- Ensure structural integrity to withstand the lunar environment.

- This includes gravity ($1.625 m/s^2$), Internal air pressurization for EVA suits ($34.5\,kPa - 101.4\,kPa$), Radiation/Shielding (solar/cosmic or electromagnetic/ionizing radiations and meteoroid impacts), vacuum, dust, moonquakes and temperature ($100\ to\ -150\ ^{0}C$)

- Support scientific research activities
  - Laboratories equipped with the necessary tools and instruments for conducting scientific experiments.

- Enable communication with Earth
  - High-bandwidth communication with ground stations and low-bandwidth communication for activities outside habitat.

- Power Supply
  - Reliable power generation from solar panels / nuclear power sources
  - Energy storage systems provisions during lunar nights / emergencies.

- Facilitate health and well-being of crew members
  - Adequate living space per crew member, exercising and recreational facilities.

Low-level Requirements

- Navigation and Mobility
  - Transportation modules such as lunar rovers for mid/long distance explorations.

- Manage waste and maintain hygiene
  - Provision of vacuum pumps and airtight bags

- Emergency systems
  - Escape or safe haven provisions within the habitat
  - Life-saving systems and protocols including telemedicine facilities

Operational Context

Actor	Role (Functions)	Interactions	Functions Mapping
Crew (Astronauts)	- Primary users of habitat - Responsible for conducting	• **Daily Operations** - Operate and *monitor*	- Astronauts report daily status and receive

	scientific research - Perform maintenance tasks - Manage daily operations within the habitat	*habitat systems* - Conduct research - Manage resource use - Perform health checks ● **Emergency Response** - Implement emergency protocols - Manage survival systems - Communicate with *mission control*	instructions from **Mission control** - Astronauts monitor and maintain **Support Systems**
Mission Control	- Provide operational support from Earth - Facilitate strategic decision-making and emergency management - Coordinates communication - Perform resupply missions - Scientific data analysis	- Monitor *habitat systems* and *crew health from Earth* - Provide technical support and troubleshooting - Make critical decisions in emergencies	- Mission control analyses the data sent by **Astronauts** and **Support systems**
Support Systems	- Life support systems - Power management - Waste recycling - Habitat integrity monitoring	- Regulate air quality, water recycling and waste management - Perform diagnosis and alert about maintenance needs or	- Support systems detect potential issues and schedules maintenance or alert **Astronauts** & **Mission**

		failures - Collect and process scientific data, manage internal communications and data storage	**Control**

Operational Entities

Using the Capella tool and based on the generalized functions and actors described on the previous table, we were able to create the first iteration of basic operational entities and actors pertaining to our lunar surface habitat module as shown on the figure below.

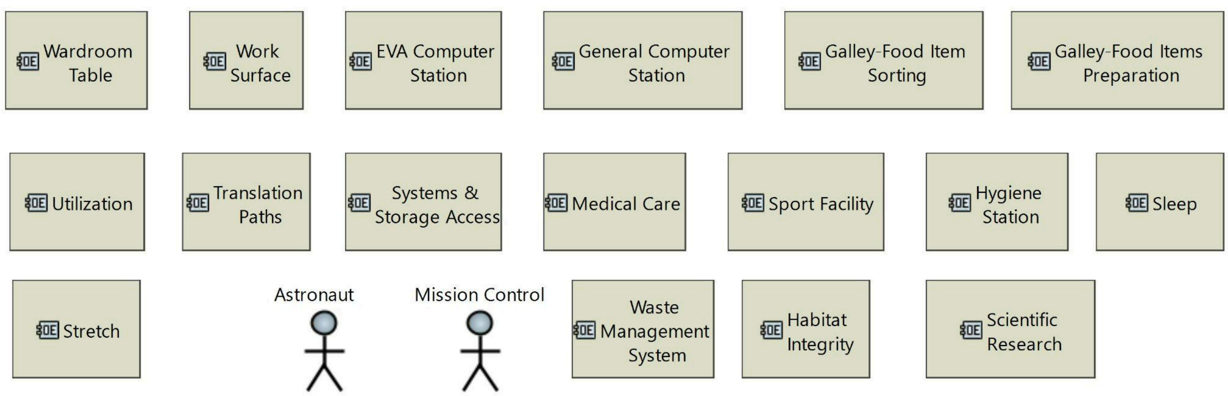


Fig1.1 - Operational Entities from Capella

The Capella tool was then used to illustrate the interactions between the various functions, operational entities and actors. For simplicity and clarity of design in line with the ARCADIA methodology, the operational capabilities were categorized with respect to the operational entities and actors involved as shown in the following figures.

Operational Capabilities - Wardroom Table

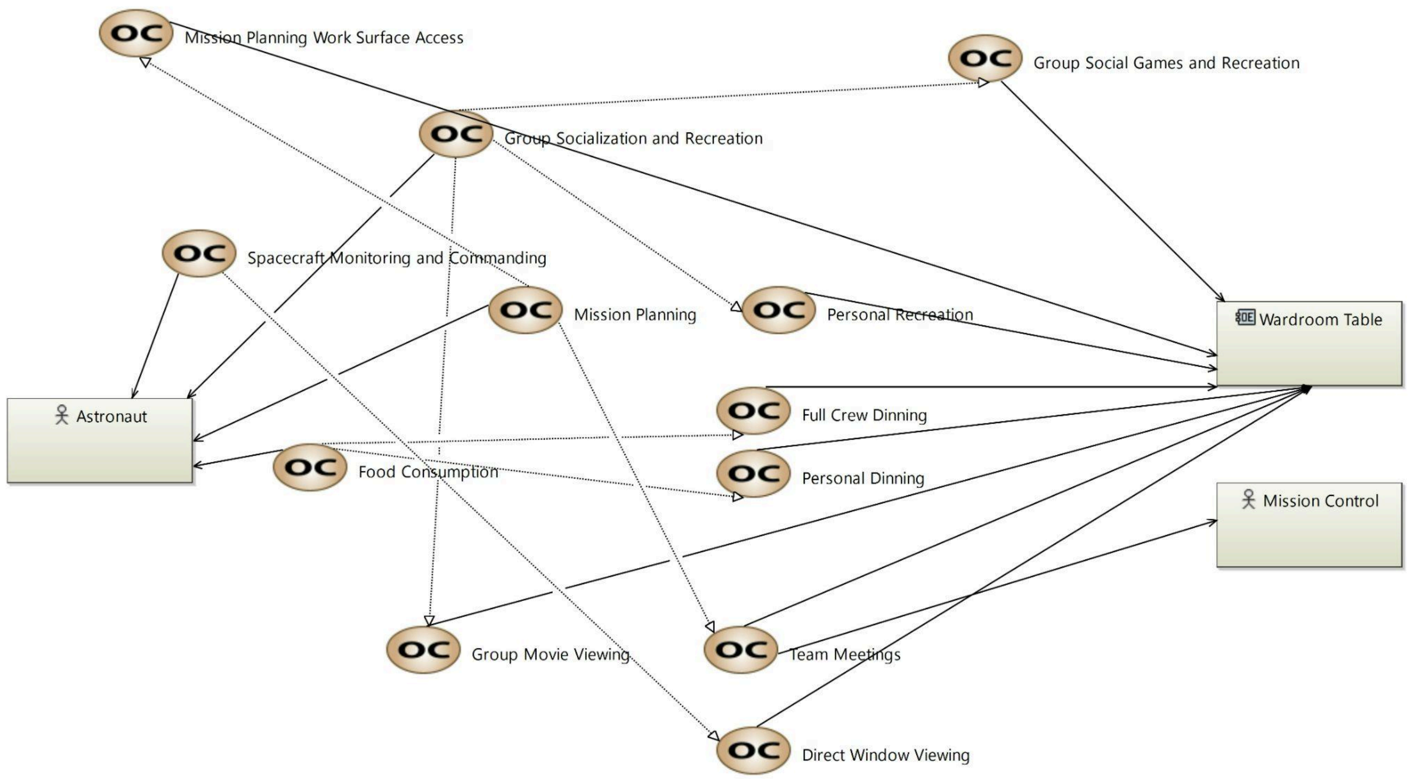


Figure 1.2 - Operational Capabilities - Wardroom table

Operational Capabilities - Work Surface & Extra Vehicular Activities

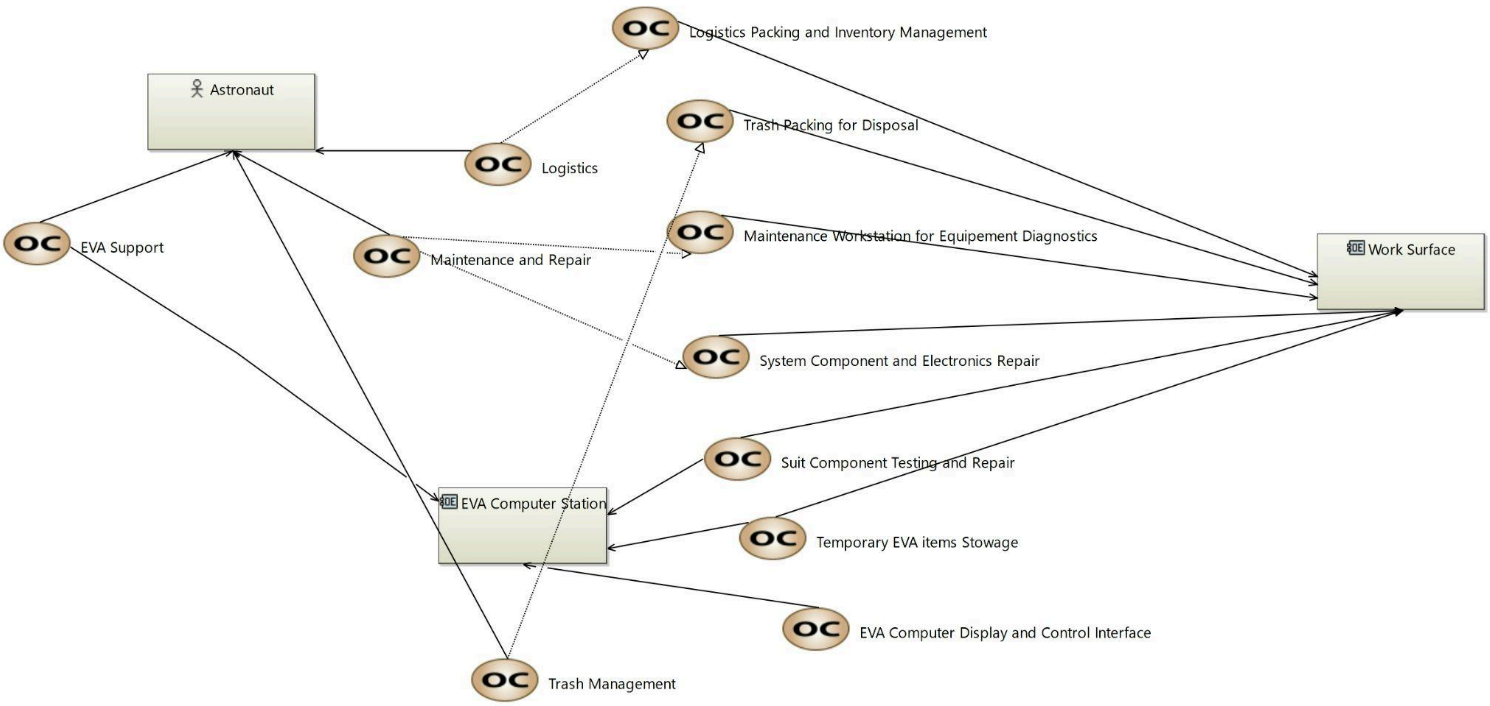


Figure 1.3 - Operational Capabilities - Work Surface & EVA

***EVA** - Extra Vehicular Activities refer to activities that will be performed outside the premises of the lunar surface habitat but still depend on it.

Operational Capabilities - General Computer Station (GCS)

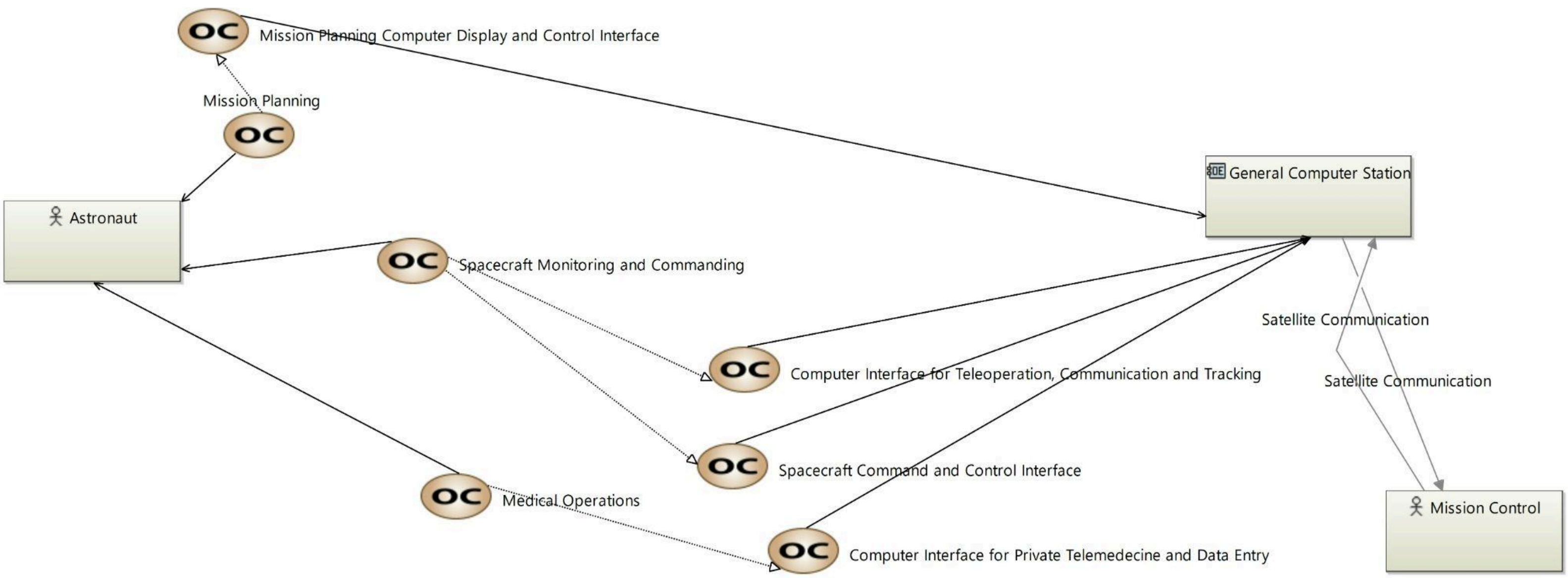


Figure 1.4 - Operational Capabilities - GCS

Operational Capabilities - Others

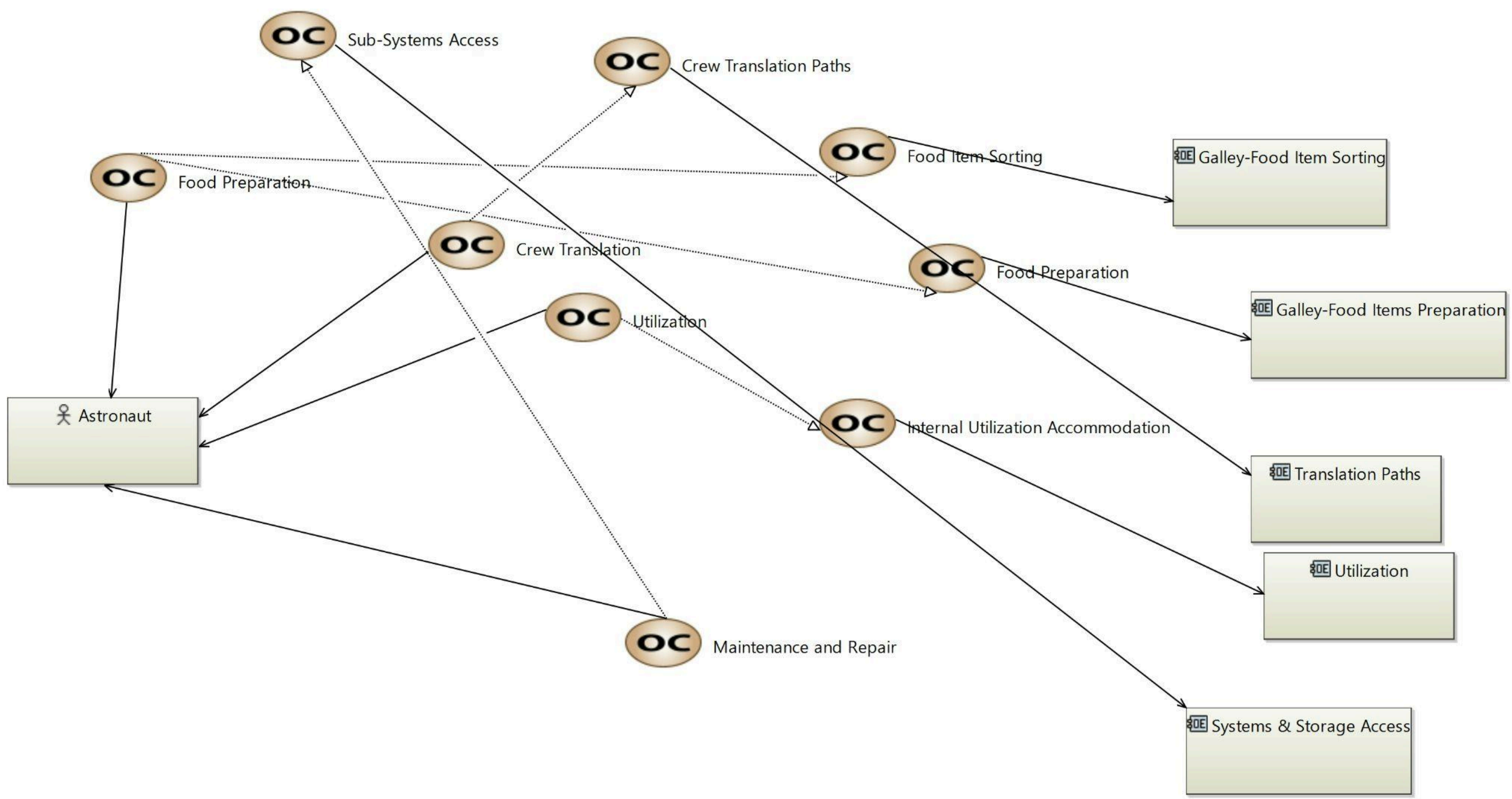


Fig 1.5 - Operational Capabilities - Others

Operational Capabilities - Life Support

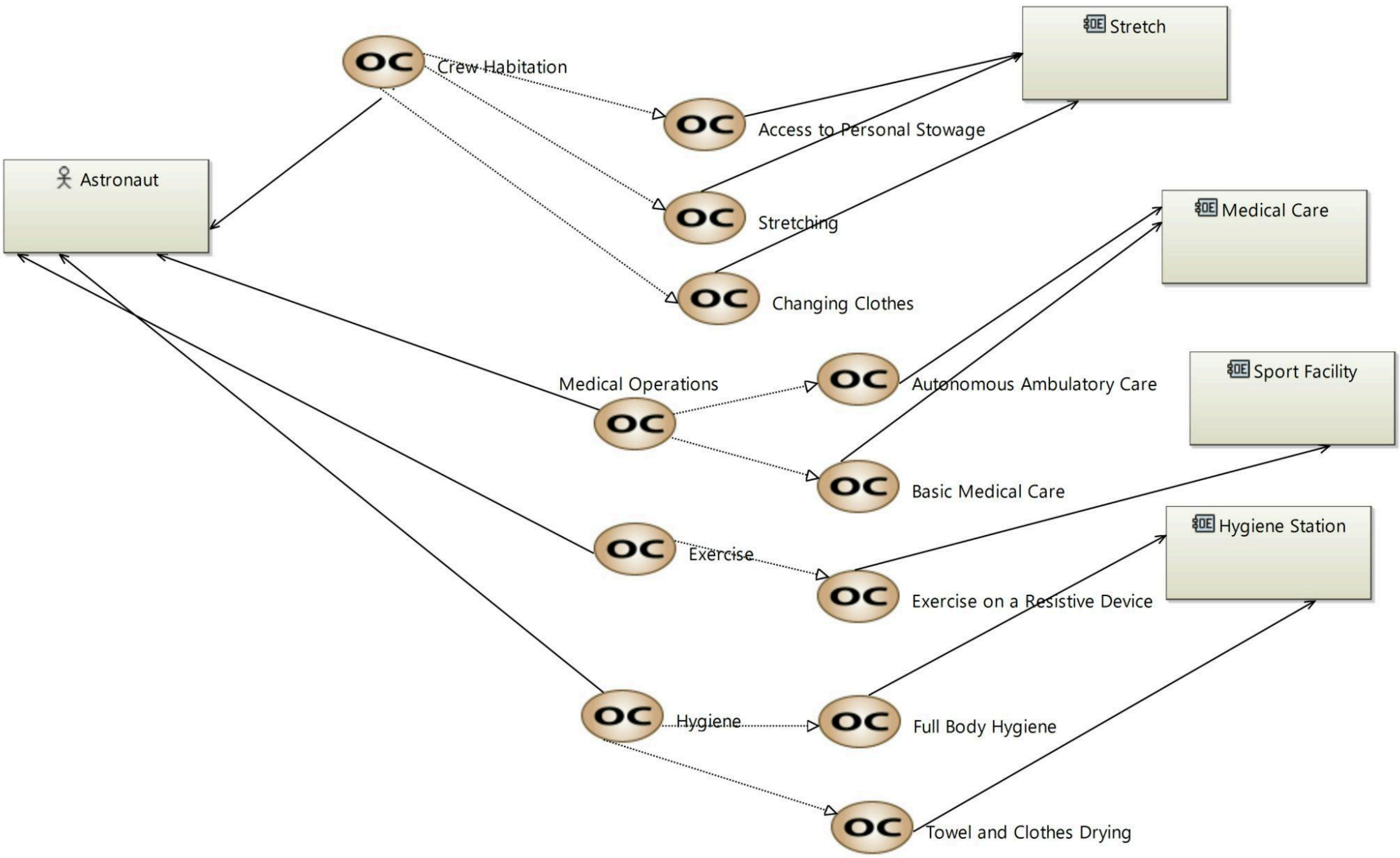


Fig 1.5 - Operational Capabilities - Life Support

Operational Capabilities - Waste Management, Research & Habitat Integrity

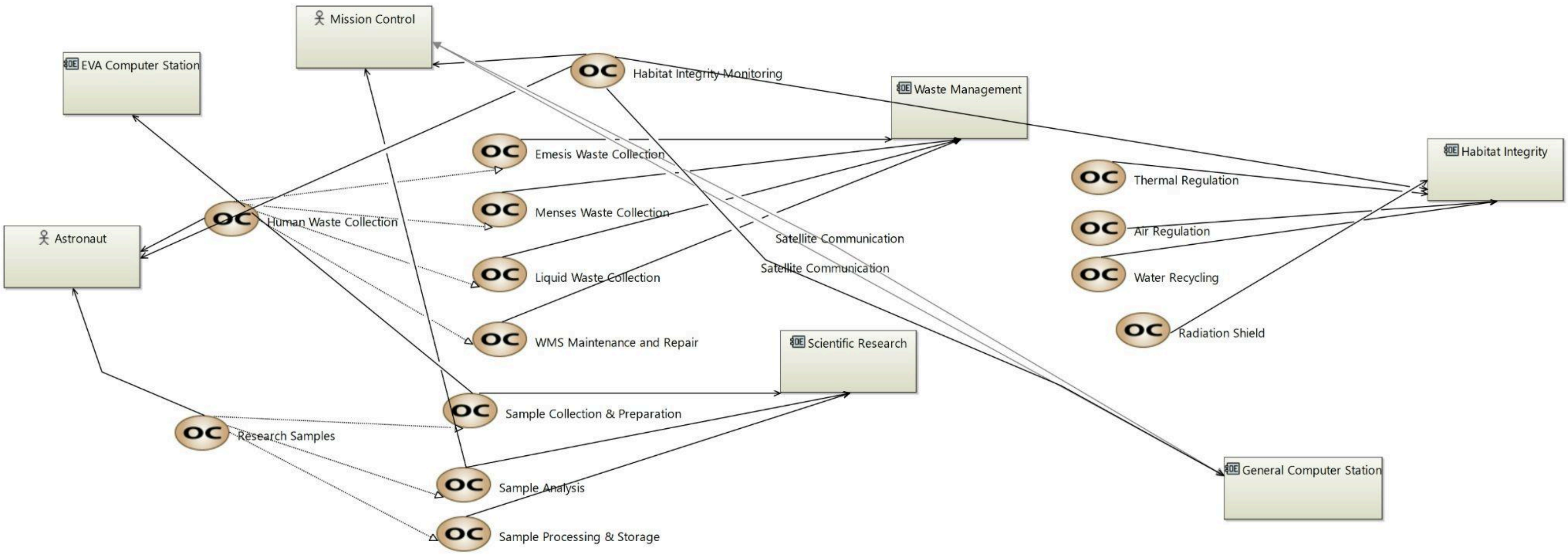
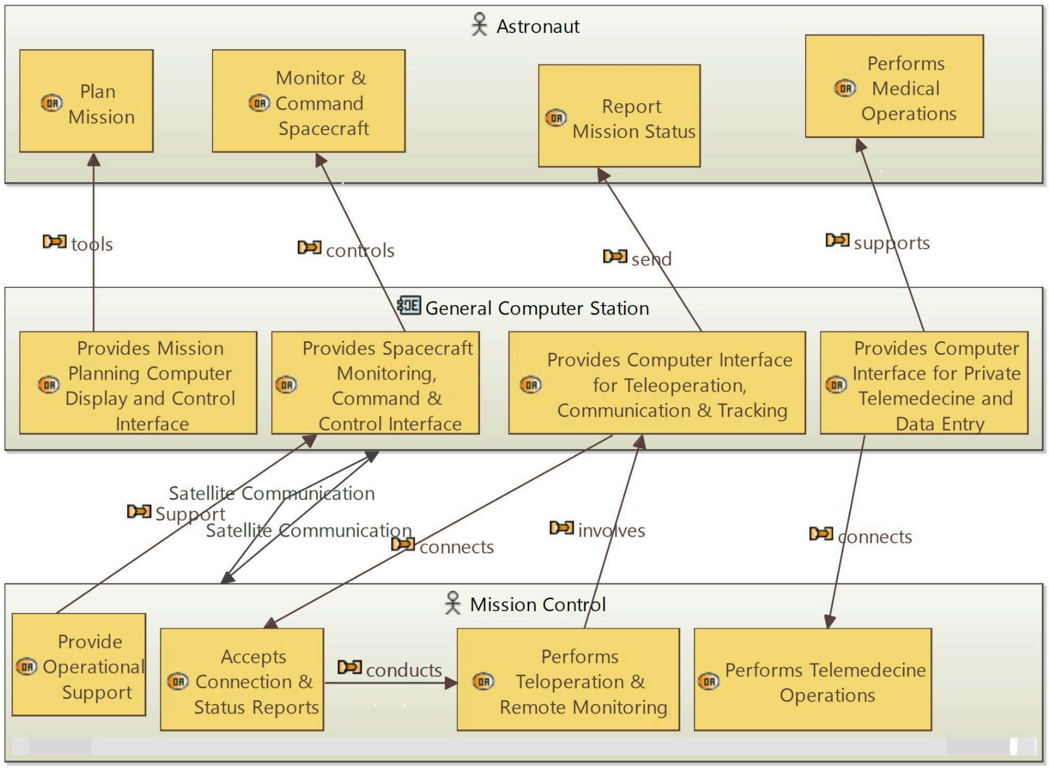
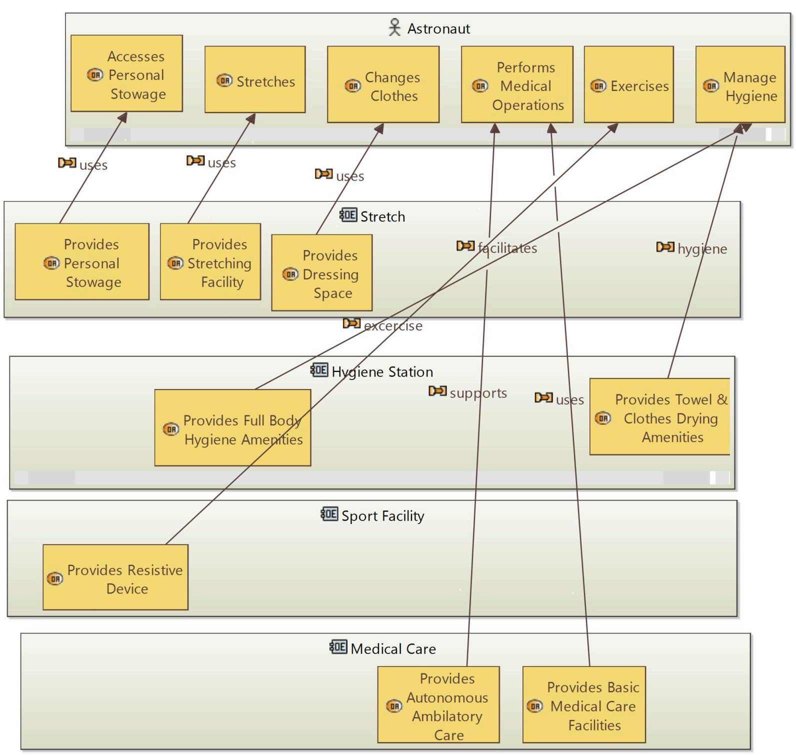
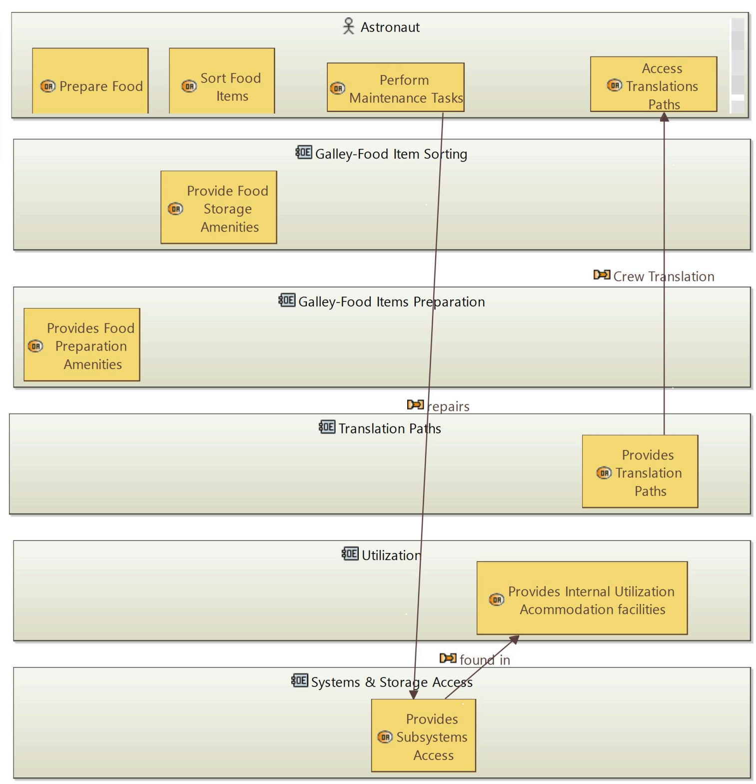


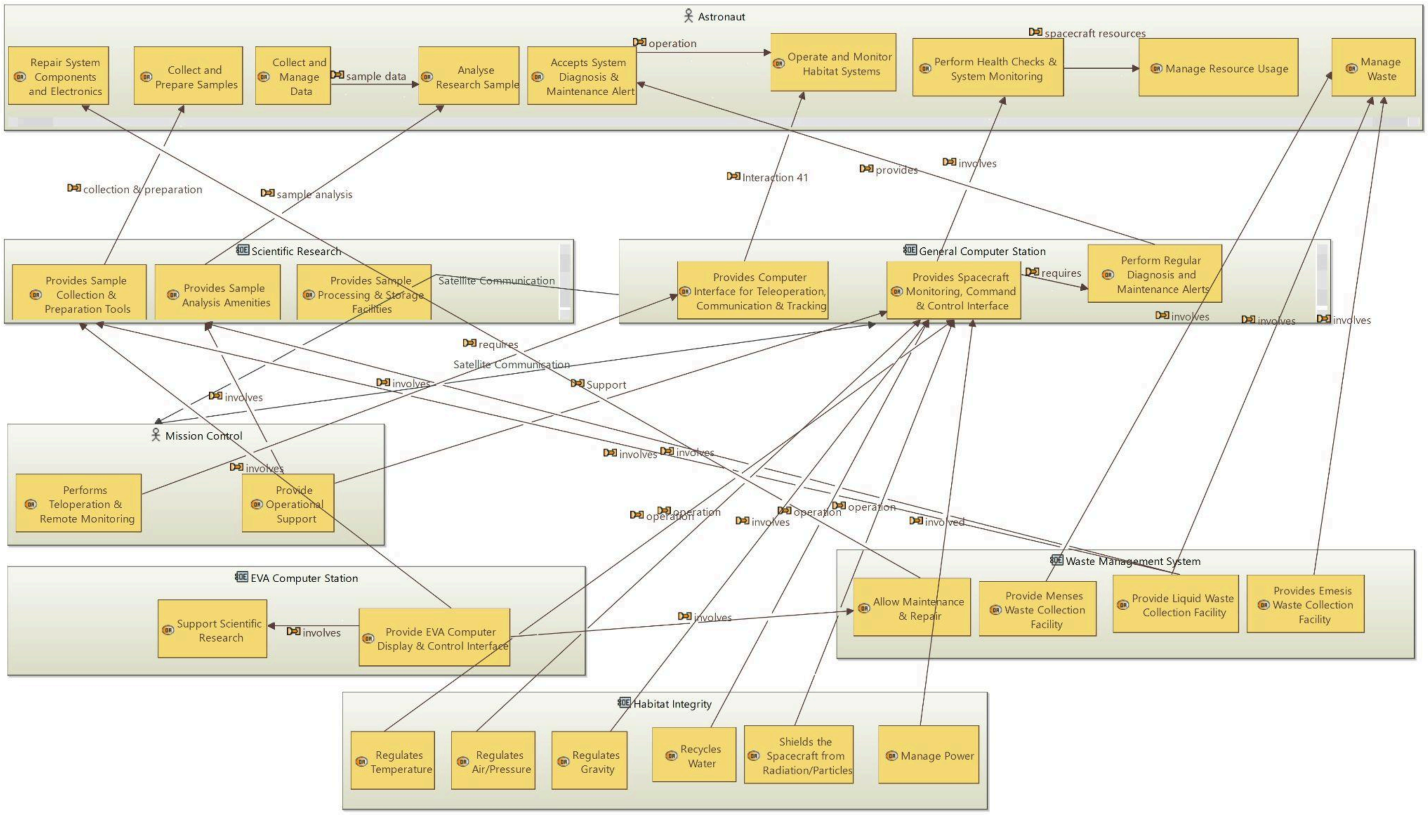
Fig 1.5 - Operational Capabilities - WMS, Scientific Research & Habitat Integrity

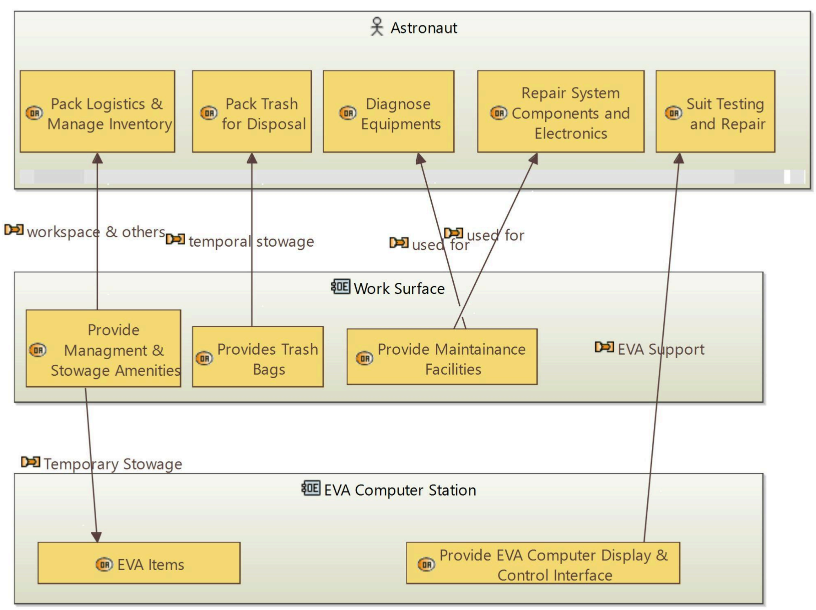
Operational Architectures

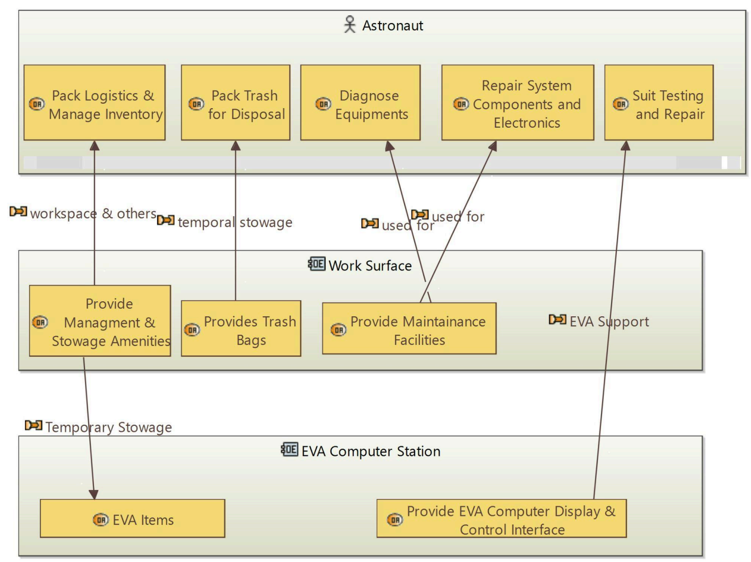







Astronaut
Repair System Components and Electronics
Collect and Prepare Samples
Collect and Manage Data
sample data
Analyse Research Sample
Accepts System Diagnosis & Maintenance Alert
operation
Operate and Monitor Habitat Systems
spacecraft resources
Perform Health Checks & System Monitoring
Manage Resource Usage
Manage Waste
collection & preparation
sample analysis
Interaction 41
provides
involves
Scientific Research
Provides Sample Collection & Preparation Tools
Provides Sample Analysis Amenities
Provides Sample Processing & Storage Facilities
Satellite Communication
General Computer Station
Provides Computer Interface for Teleoperation, Communication & Tracking
Provides Spacecraft Monitoring, Command & Control Interface
requires
Perform Regular Diagnosis and Maintenance Alerts
involves
requires
Satellite Communication
involves
Support
involves
Mission Control
Performs Teleoperation & Remote Monitoring
involves
Provide Operational Support
involves
involves
operation
operation
involves
operation
operation
involved
EVA Computer Station
Support Scientific Research
involves
Provide EVA Computer Display & Control Interface
involves
Waste Management System
Allow Maintenance & Repair
Provide Menses Waste Collection Facility
Provide Liquid Waste Collection Facility
Provides Emesis Waste Collection Facility
Habitat Integrity
Regulates Temperature
Regulates Air/Pressure
Regulates Gravity
Recycles Water
Shields the Spacecraft from Radiation/Particles
Manage Power


Astronaut
Pack Logistics & Manage Inventory
Pack Trash for Disposal
Diagnose Equipments
Repair System Components and Electronics
Suit Testing and Repair
workspace & others
temporal stowage
used for
used for
Work Surface
Provide Managment & Stowage Amenities
Provides Trash Bags
Provide Maintainance Facilities
EVA Support
Temporary Stowage
EVA Computer Station
EVA Items
Provide EVA Computer Display & Control Interface


Astronaut
Pack Logistics & Manage Inventory
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Temporary Stowage
EVA Computer Station
EVA Items
Provide EVA Computer Display & Control Interface

System Analysis

The system analysis describes what the system must achieve for its users and clearly captures the high-level functions from the Operational context.

Function	Description	Actor(s) Associated
Research and Development Support	• **Laboratory Operations** - Manage laboratory spaces and equipments for scientific experiments • **Data acquisition and Analysis** - Collect scientific data and perform initial analysis, ensuring integrity and accessibility for further study.	- Astronauts - Support systems - Mission Control
Life Support Management	• **Air Regeneration**: Scrub carbon dioxide from air, replenish oxygen levels, manage humidity and trace contaminants to maintain breathable air quality. • **Water Recycling:** Filter and purify water from all habitat sources • **Food Production and Storage**	- Support Systems
Environmental Control	• **Thermal Regulation**: Maintain and adjust internal temperature to optimal levels despite external lunar temperatures extremes. • **Radiation Shielding:**	- Support Systems

	Continuously monitor and enhance protection against solar and cosmic radiation ● **Pressure Regulation:** Ensure the habitat's internal pressure is maintained at safe, breathable levels	
Waste Management	● **Solid Waste Processing:** Compact, recycle, or safely store solid waste materials. ● **Chemical and Biological Waste Treatment:** Treat and dispose of or recycle chemical and biological wastes safely	- Support Systems
Habitat Integrity	● **Structural Health Monitoring:** Continuously assess the structural integrity of the habitat to predict and prevent potential failures. ● **Leak Detection and Management:** Quickly detect and address any breaches or leaks in the habitat's structure.	- Astronauts - Support systems
Communication Systems	● **External Communication:** Maintain communication links with Earth for data transmission, operational commands, and	- Support systems - Astronauts - Mission Control

	emergency support. ● **Internal Communication Systems:** Facilitate communication within the habitat and with external modules or activities.	

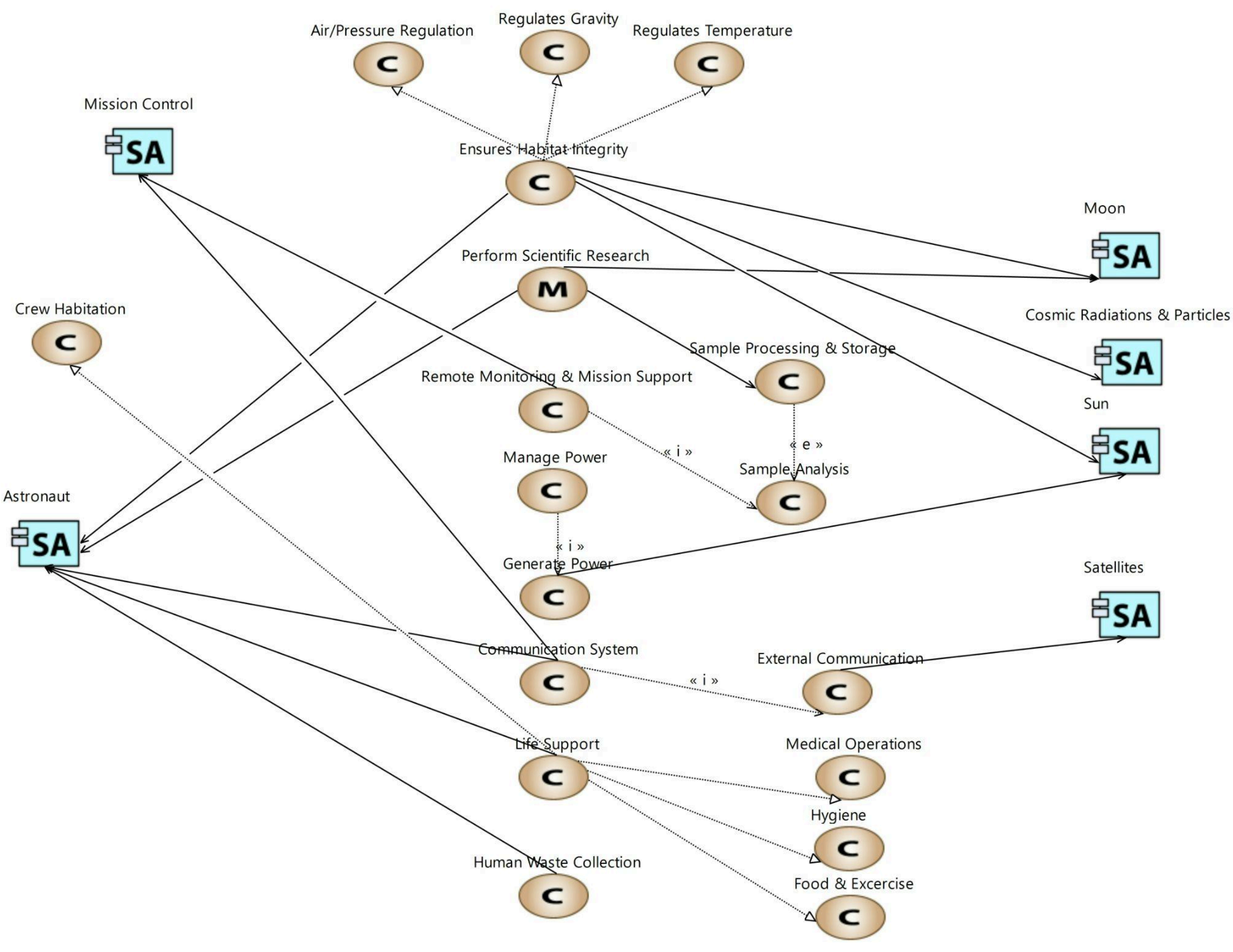

Fig 1.7 - High level Mission Capabilities

Functional Flow

Function	Sub-Function	Depends On	Supports	Interactions
Life Support Management	• Air Regeneration • Water Recycling • Food Production and Storage	• Environmental Control	• Waste Management • Research and Development Support	- Relies on *Environmental Control* for adjusting internal conditions to optimal levels. - Supplies resources essential for research activities and outputs waste managed by *Waste Management*
Environmental Control	• Thermal Regulation • Radiation Shielding • Pressure Regulation	• Habitat Integrity	• Life Support Management • Habitat Integrity	- Adjusts internal habitat conditions based on structural feedback from *Habitat Integrity* - Modifies the environment to suit *Life Support* needs.
Waste Management	• Solid Waste Processing • Chemical and Biological Waste Treatment	• Life Support Management	• Habitat Integrity	- Processes waste products originating from *Life Support* activities, crucial for maintaining operational cleanliness and safety - Operational cleanliness and safety is overseen by *Habitat Integrity*
Habitat Integrity	• Structural Health Monitoring • Leak Detection and Management	• Environmental Control	• Life Support Management • Environmental Control • Waste Management • Research and Development • Communication Systems	- Monitors habitat's structural health, providing essential data to *Environmental Control* for dynamic adjustments - Is foundational for the safety of *all* habitat operations.
Research and Development Support	• Laboratory Operations • Data Acquisition and Analysis	• Life Support Management • Communicatio n Systems	• Communication Systems	- Uses resources managed by *Life Support* for experiments - Relies on *Communication Systems* for data sharing with Earth, influencing further research directions

Communication Systems	• External Communication • Internal Communication Systems	• Research and Development Support	• Life Support Management • Environmental Control • Waste Management • Research and Development • Habitat Integrity	- Facilitates data and command flows essential for operational coordination and scientific data exchange - dependent on data generated by *Research and Development* for transmission

Using the Capella tool, a high level-model of the functional analysis described in the table above was designed to illustrate the general functioning and interactions of the Lunar Surface Habitat Module. The design below depicts the functional interaction between various parts of the system with functional chains (colored lines).

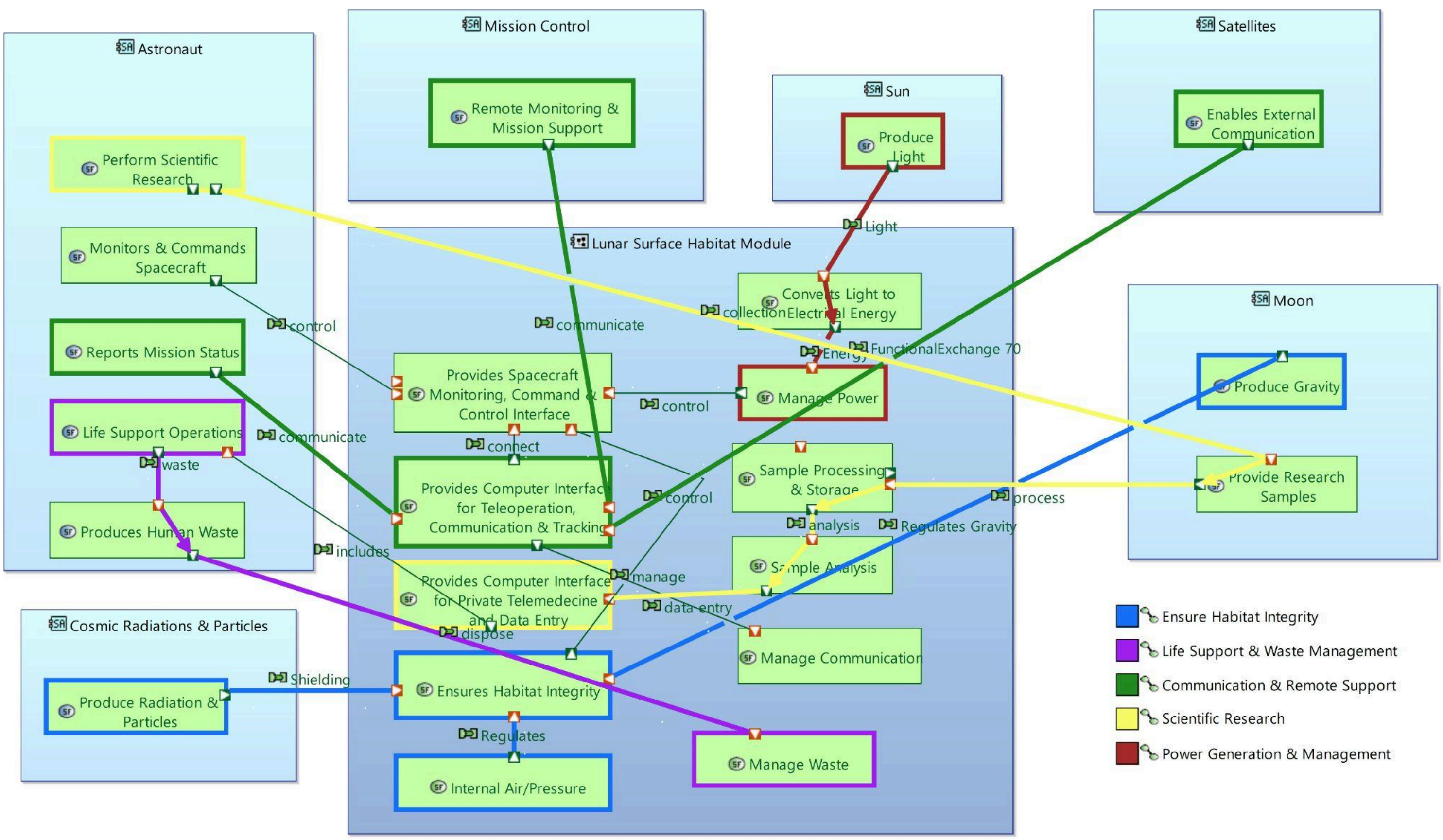

Fig 1.7 - High Level System Architecture with Functional Chains

Logical Architecture

We can structure the logical architecture of the lunar habitat module around several core systems, each responsible for vital aspects of the habitat operations.

1. Life Support System (LSS)

- Subsystems:
  - **Air Management:** Responsible for air purification, oxygen generation, and carbon dioxide removal.
  - **Water Recovery and Management:** Includes technologies for water filtration, recycling, and purification.
  - **Waste Management:** Comprises systems for processing and recycling solid and liquid waste.

2. Waste Management

- Subsystems:
  - **Human Waste Disposal**
  - **Organic Waste Disposal**
  - **Inorganic Waste Disposal**

3. Habitat Integrity

- Subsystems:
  - **Structural Monitoring:** Includes sensors and algorithms for assessing the structural health of the habitat.
  - **Leak Detection and Mitigation:** Identifies breaches in the habitat's integrity and executes immediate countermeasures.
  - **Maintenance and Repair:** Involves tools and protocols for upkeep and addressing damages.
  - **Thermal Control:** Manages habitat temperature through heating, cooling, and insulation.

- **Pressure Control:** Ensures the maintenance of a stable and safe atmospheric pressure inside the habitat.
- **Radiation Protection:** Provides shielding against cosmic and solar radiation and monitors radiation levels.

4. Power Unit

- Subsystems:
  - **Energy Production:** Composed of solar panels and potential nuclear reactors.
  - **Energy Storage:** Involves battery systems and other technologies for storing electrical power.
  - **Power Distribution**: Manages and allocates power to various systems and subsystems efficiently.

5. Research Unit

- Subsystems:
  - **Laboratories:** Specifically equipped areas for conducting scientific research.
  - **Experiment Support:** Tools and systems that facilitate the execution of experiments.
  - **Data Management:** Systems for handling the collection, storage, and analysis of scientific data.

6. Communication Unit

- Subsystems:
  - **External Communication:** Equipment and protocols for maintaining communication links with Earth.

- **Internal Communication:** Systems that support communication within the habitat and with external modules.

7. Crew Support Unit

- Subsystems:
  - **Living Quarters:** Individualized spaces designed for privacy and rest.
  - **Recreational Facilities:** Equipment and areas designated for physical activities and relaxation.
  - **Social and Community Spaces:** Designed to facilitate social interactions and community building among the crew.

8. Control Unit

- **Manages ALL Systems Combined**

Subsystems Interactions

- **LSU** and **HIU** interact closely to ensure that air and temperature are regulated according to the needs dictated by environmental conditions and crew activities.

- **HIU** adjusts environmental controls based on structural status and integrity.

- **PU** supports all systems by providing necessary power, with prioritization managed based on operational criticality.

- **RU** relies on **LSU** and **CSU** for maintaining experimental conditions and communicating results to Earth.

- **CSU** is supported by all systems to ensure a habitable, comfortable environment conducive to long-term human occupancy.

- **CU** manages everything together.

A logical component break down and system architecture was performed with the Capella tool as shown in the diagram below:

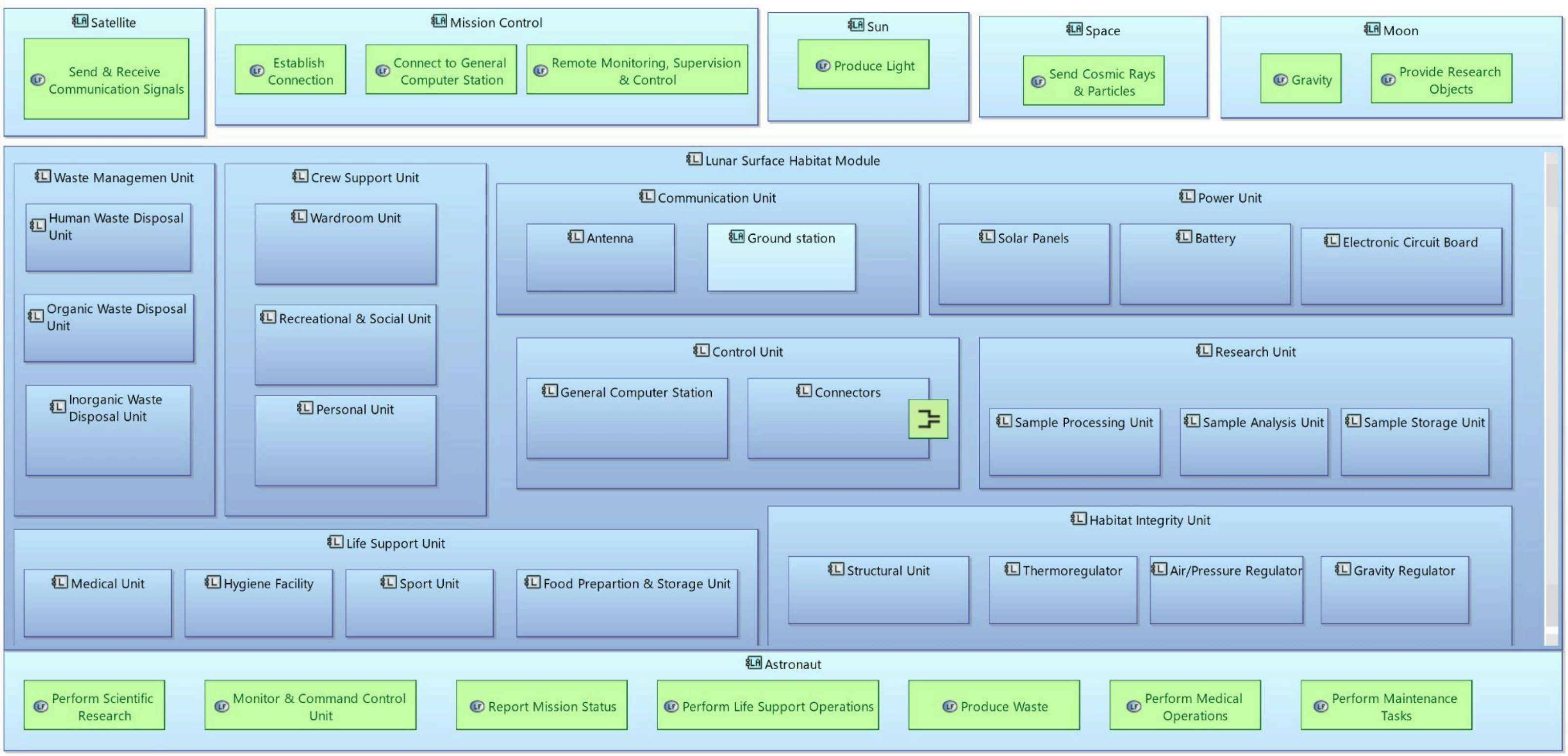

Fig 1.7 - High Level Logical Component Breakdown