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Space Architecture for a Moon Village

Life Support Elements

Interdisciplinary Architecture

Global Impact

Habitat CDF Study
Space Architecture

The study was carried by an interdisciplinary team of experts from across **ESA including SOM and faculty at MIT**.

The primary objectives were:

- Review the boundary conditions of a habitat architecture concept.
- Identify requirements of the habitat module with regards to lunar environment.
- Deliver habitat functional design features.
- Define habitat interior design features.
- Standardise interfaces.

Habitat Features, Functionalities and Design:

- **Accommodate a crew of 4 people**.
- **Provide functions for Crew Habitation as well as support to Science and Surface operations**, including crew access to and from the lunar surface.
- **Sufficient radiation protection** to meet maximum allowable exposure levels during periods of nominal and solar event external radiation levels.
- **A 10-year lifetime** after deployment on the moon surface.
- **Located to provide access to resources**, benign illumination conditions and scientific interest.

Launch, Transfer and Delivery:

- Compatibility with current state-of-the-art launcher capabilities.
- The Habitat and required support components shall be transferred into an appropriate Lunar Orbit, and then from lunar orbit to the lunar surface.
- Transfer to the final destination and deployment at the selected site.


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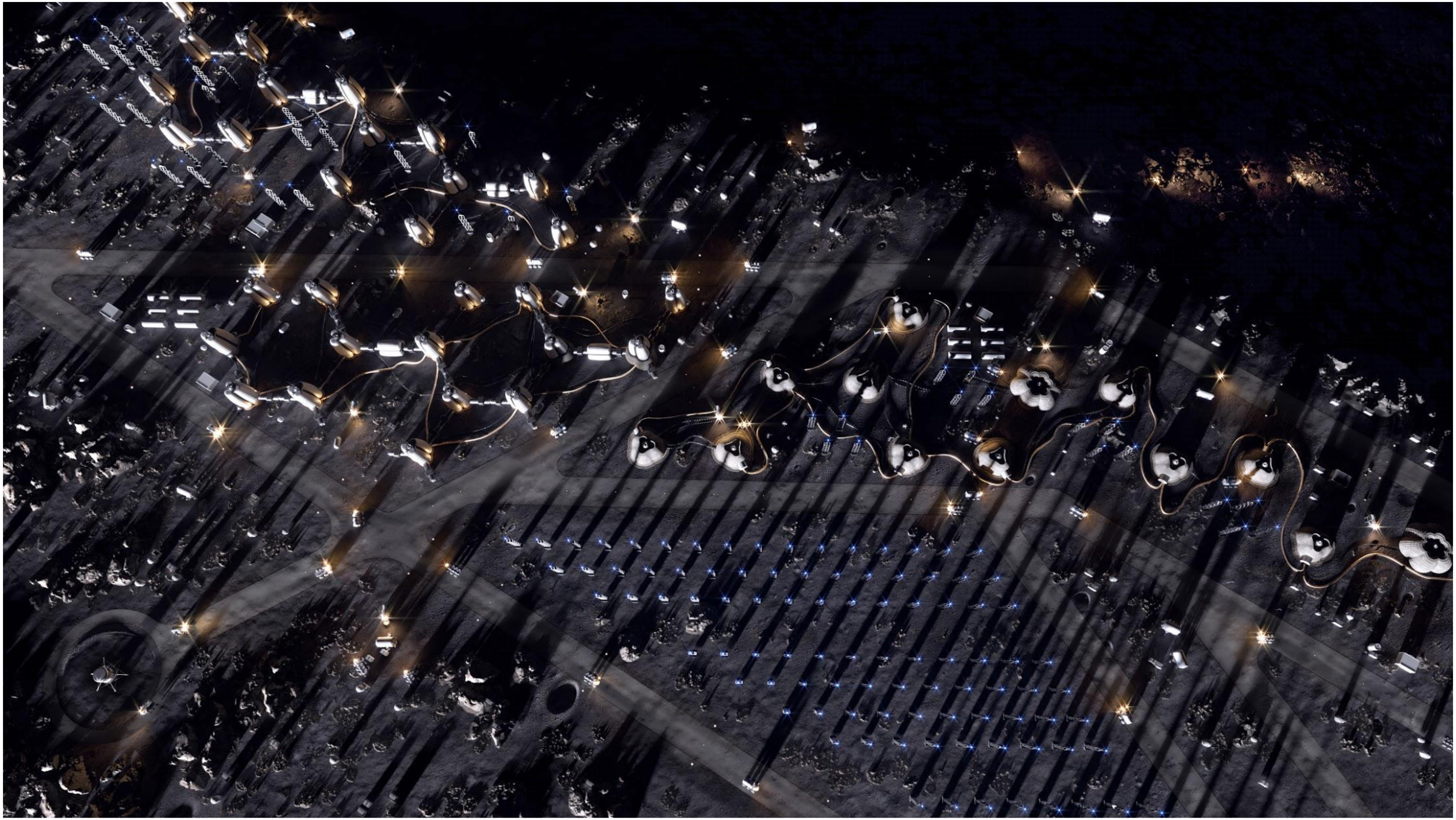


Habitat Design Accomodations

- Private Quarters
- Dining and Communal Spaces Workspaces
- Exercise Area & Equipment EVA Suit Donning & Doffing Medical Care
- Hygiene
- Translation Corridors

- Recommendations for net **habitable volume depend on functions required of the mission, crew size and mission duration**. 25 m³ net habitable volume per person should be considered the absolute minimum for deep space habitats. However, this number is significantly smaller than the minimum net habitable volume of the ISS (85.17 m³), and older stations like Skylab (120.33 m³), Mir (45 m³) and Salyut (33.5 m³) which all have or had shorter mission durations than 500 days.
- **A net habitable area of about 80m³ per person** is recommended for the crew size and long duration of the surface mission.

- The structure and outfitting system of the habitat has to **maximise the usability of the habitable volume** provided to the crew. The module needs to be highly volume-efficient and designed to optimise habitability.
- **Quarters have to provide optimal noise protection and personalised air conditioning and illumination control** to provide comfortable living conditions.

Budget Requirements: (Volume, Power and Mass)

- Galley and Food System
- Waste Collection and Hygiene
- Sleep Accommodation, Health and Clothing
- Operational Supplies and Maintenance

Habitat Design Considerations

Volume

- Volume Allocation for Mission Task
- Volume for Crew Member Accommodation
- Volume for Mission Accommodation
- Volume for Behavioral Health

Configuration

- Functional Arrangement
- Interference
- Spatial Orientation
- Consistent Orientation
- Interface Orientation
- Location Identifiers
- Location Aids
- Visual Distinctions

Translation

- Internal Translation Paths
- Emergency Translation Paths
- Translation Path Interference
- Simultaneous Use
- Hazard Avoidance
- Path Visibility
- Crew Egress Translation Path
- Crew Ingress/Egress Zones

Hatches and Doorways

- Hatch Cover and Door Operation without Tools
- Hatch Size and Shape
- Visibility Across the Hatch
- Hatch Cover and Door Interference
- Hatch Cover Closure and Latching Status Indication
- Hatch Cover Pressure Indication

Restraints & Mobility Aids

- Crew Restraint Provision
- Crew Restraint Design
- Mobility Aid Standardization
- Mobility Aid for Assisted Ingress and Egress
- Ingress, Egress and Escape Mobility Aids
- EVA Operations Mobility Aids

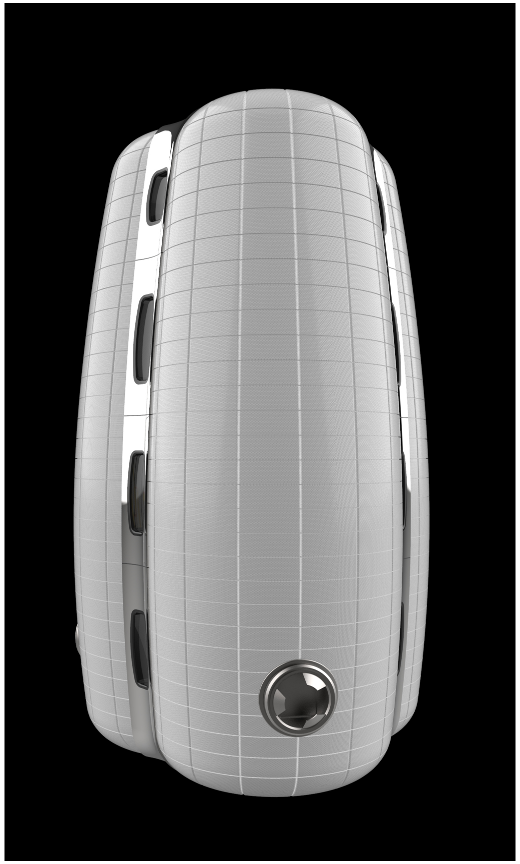
Windows

- Window Visibility
- Window Obstruction
- Window Proximity Finishes
- Window Light Blocking
- Window Protection Removal and Replacement/Operation without Tools

Lighting

- Illumination Levels
- Exterior Lighting
- Emergency Lighting
- Circadian Entrainment
- Lighting Controls
- Lighting Adjustability
- Glare Prevention

Habitat Design
Baseline Concept



Configuration Deployed		
Mass	Dry Mass (w/ margin)	58.227 kg
	Wet Mass	65.433 kg
Dimensions	Stowed	~8 m (diameter) x 15.5m (height)
	Deployed	~10.5 m (diameter) x 15.5 m (height)
Instruments and Crew Accommodation	Galley, Crew Quarters, Waste Collection, Hygiene facilities, Restraints and Mobility Aids, Medical suite and supplies	
Mechanisms	Deployable Hinged floors, Interfacing Hatches (x4), Restraining Clamp Bands (for transfer)	
Power	1 kW Intrinsic Power Generation System with 15 m2 structure mounted solar panels and batteries; 59 kW surface-deployed Fission Reactor	
Environment Control and Life Support	Regenerative closed loop systems for air and water, Food production and Preparation, Waste collection and Handling, Consumable fluids (water, oxygen, nitrogen) and storage	
Radiation Protection	Nominal and Solar Event radiation protection, through use of locally sourced regolith placed on deployable walls (protection across the Habitat) and water storage on first-level floor (for shelter improved shielding)	
Thermal	Multilayer Insulation (MLI) for transfer (external blanket) and usage (integrated in the deployable shell), Heaters	
Structures	Primary Metallic Rigid "3-pillar" structure, Partially Deployable floors, Modular Interior Outfitting, Multi-layer Inflatable Shell	

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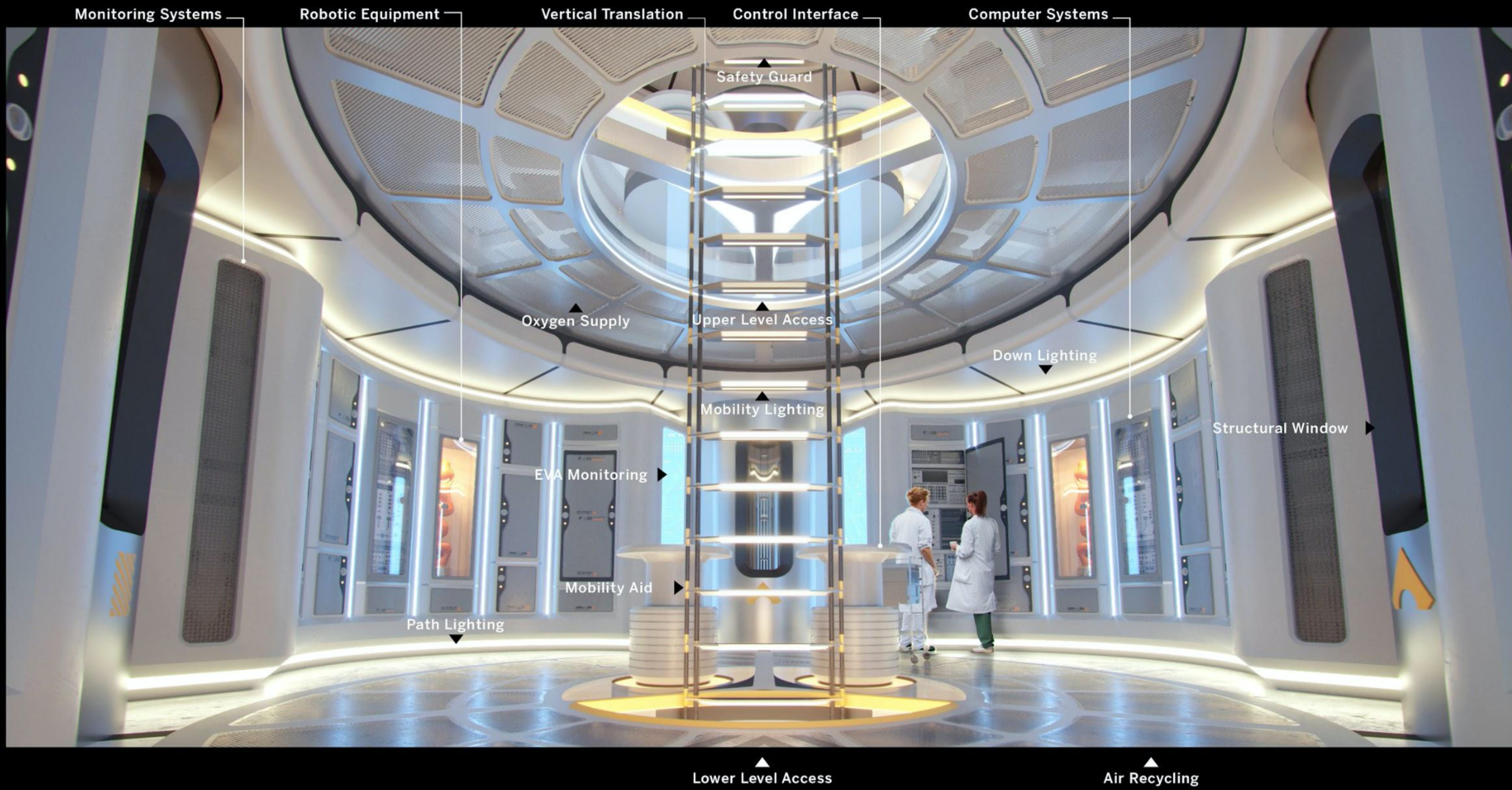
- Control Interfaces
- Controlled Lighting
- Air Supply & Recycling
- Structural Windows
- Safety
- Work Stations
- Mobility Aids
- Vertical Translation



Concurrent Design Facility Study
Moon Village Partnership

- Personal Quarters
- Personal Console
- Storage
- Circadian Lighting
- Safety
- Air & Moisture Control
- Temperature Control
- Visibility

Habitat Design
Environmental Protection

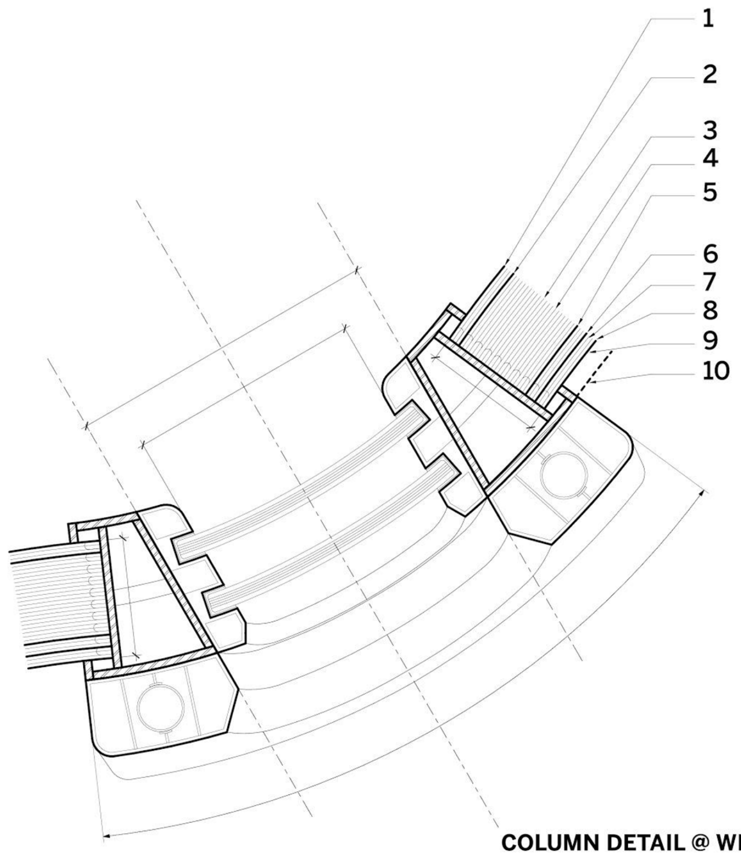
Shielding
Thermal
Structure

↓

Safety
Performance
Comfort
Radiation

- **Layer 1** -External deployable system in the form of straps.
- **Layer 2** -External protective layer for dust and mechanical resilience. (Nextel AF-62)
- **Layer 3** -Multi-Layer Insulation (MLI) for thermal control. Typical multilayer (20 layer) combination of double aluminized mylar/kapton.
- **Layer 4** -MMOD fabric layer
- **Layer 5** -MMOD foam support between MMOD layers made of lightweight polyurethane open foam cell structure.
- **Layer 6** - Kevlar or Vectran restraint layer used for structural support.

- **Layer 7** - Bladder layer used for air containment within the habitable zone. This can consist of a complex combination of combitherm/silicone/polyurethane from transhab or more recent technology by Bigelow.
- **Layer 8** - Bladder separation layer composed of Aramid Kevlar.
- **Layer 9** - Final inner bladder protection layer made of nomex aramid fabric.
- **Layer 10** - Internal water layer for increased radiation protection.



COLUMN DETAIL @ WINDOW

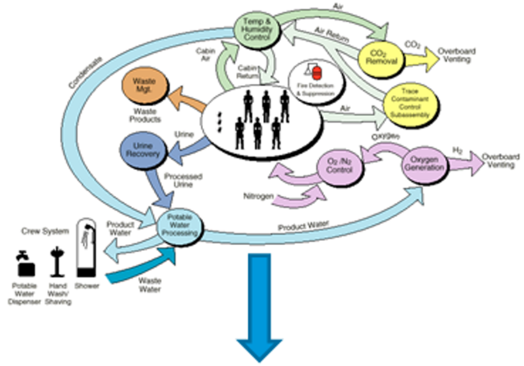
Living Scenario, Concept of Operations, Challenges and Needs
Life Support Systems

- **Stay of a pioneer group of 4 persons, the first step of a Moon settlement, paving the way for larger communities of "Moon citizens"**
  - 500 d mission duration
  - only 1 re-supply from Earth per year
- Habitat volume is high, **architecture is conceptually very different** from current Space Habitat, making difficult a "simple" extrapolation of existing systems, piping and instrumentation layouts, type of racks….
- Building/deployment in a Lunar environment will require an additional in depth analysis to define a **step-wise LS deployment strategy**, while ensuring survival and safety of the crew at any time;
- Requiring full redundancy of Life Support Systems, a significant impact on requirements such as mass, power, etc
- Some technologies considered in this study, or to be considered in the future for a Moon Habitat, **today lack of maturity** (e.g. food preparation, greenhouses, ISRU, ..) to enable their accurate quantification (e.g. sizing, mass, power, crew time,…)

Baseline Solution: Key Drivers

Life Support Systems

- **Regenerative closed loop system for air and water, on-site production of 5% of the food**, on-site storage of wastes, preferably outside of the habitat;
- **Full redundancy** of the systems (i.e. based on different technologies) except for the food production.
- At a later stage, **greenhouses and ISRU should be considered, to reduce re-supply from Earth, and reduce ultimate wastes.**
- Radiation protection, emergency situations, maintenance and troubleshooting need to be taken into consideration for the **final accommodation** of e.g. systems, tanks, per floor, or in the walls, or in the floors.



The MELiSSA loop, courtesy of the MELiSSA Foundation

Baseline Solutions: Main Technologies

Life Support Systems

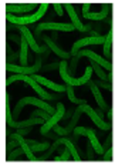
Life Support System Rack (or Advanced Closed Loop System) ©ESA/NASA

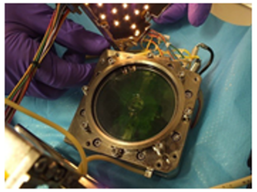
air revitalisation

ACLS
cold redundant with MELiSSA based C4a (photobioreactors).

C4b, MELiSSA Pilot Plant, courtesy of UAB

5% food production

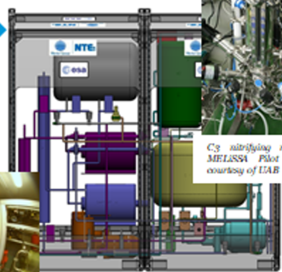




Open view of ArtEMISS flight hardware, courtesy of the MELiSSA Foundation

Water recycling

WRS (ISS)
cold redundant with MELiSSA based urine and grey waters treatment units



MELiSSA Space Adaptation, NTE/ESA

C3 nitrifying reactor, MELiSSA Pilot Plant, courtesy of UAB

Grey Water treatment @Concordia Antarctica Station, courtesy of FIRMUS

Baseline Solution: All Interfaces and Ancillary Equipment
Life Support Systems

Atmosphere monitoring and control:
- Ventilation
- Temperature, humidity and pressure control
- gas trace contaminants monitoring (e.g. ESA ANITA)
- microbial contamination monitoring

Food production :
- Biomass harvesting unit(s)
- Food processing unit(s)

Waste collection and handling:
- Space toilet(s)
- Waste compaction/inertion (e.g. Nasa Heat Melt Compactor)

Storage tanks for water and gases (oxygen, nitrogen)

All piping and instrumentation

Tentative Budgets: Consumables and Assumptions

Life Support Systems

- Tailored to the mission scenario, i.e. higher water demand linked to hygiene- and household- related uses.

Consumables	Description	consumables kg/CrewMember.day
Water	Potable water: drinking water and water for food hydration	3.8
	Hygienic water: urinal flush, personal hygiene, shower, laundry, dish-washing	15
	Medical water	0.5
Oxygen		0.82
Dry food		0.6
Dry food packaging		0.3
Other	cleaning wipes for personal hygiene, household wipes, disinfection wipes...	0.2

Tentative recycling ratios and other assumptions

- **95% recovery for water** (from the collection and recycling of urine, habitat condensates, hygienic and medical waste waters), meaning 5% has to be re- supplied.
- **99% recovery for oxygen** (from the collection and processing of carbon dioxide), meaning 1% has to be re-supplied
- **5% of the food** (in mass) will be produced on the Moon and therefore does not need to be supplied from Earth. The corresponding dry food packaging will be avoided.
- **Atmosphere leak rate**: due to the overall design of the habitat (700m3 habitable volume, hatches, windows, inflatable structure,..), assumption of 1 to 2 kg/d of air will be lost.

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Tentative Mass Budgets: Consumables and Equipment

Life Support Systems

Description	Raw mass (kg)	Mass margin (%)	Total mass (kg)
Initial mass process water	320	10	352
Inoculum for biological processes	20	10	22
Packaged dry food	1,710	5	1,796
Other supplies	400	20	480
Total water to be supplied	1,930	5	2,027
Oxygen	204	20	245
Nitrogen	663	20	795
		TOTAL	5,716

Description	Number of items	Total mass (kg)
Tanks (gas and water), associated instrumentation	37	2644
ACLS for 4 CM	1	935
MELiSSA → C4a → compartment (photobioreactor) for 4 CM	1	1,560
Urine Treatment Unit for 4CM	1	300
Grey Water Treatment Unit for 4 CM	1	720
WRS for 4 CM	1	1,521
Biomass Harvesting	2(1)	240
Food processing unit	2(1)	120
Waste compaction/inertion	2(1)	120
Space toilet	2(1)	110
Gas trace → contaminants monitoring	2(1)	66
Microbial → contamination monitoring	2(1)	72
Atmosphere control	6(2)	1,656
All interfaces	1(3)	520
(1) 2 redundant units (2) 6 subsystems distributed over the habitat (3) bulk estimation TOTAL		10,584

Tentative Power budget

Approx. **40 kW**

Equipment mass

Approx. **11 t**

Consumable Mass

Approx. **5.7 t**

Limitations, Remarks and Options
Life Support Systems

- The strategy proposed for Life Support is going much **beyond what is currently in operation on-board ISS**, resulting in uncertainties on systems mass and on all the interfaces needed.
- **Recycling efficiencies** of processes have a significant impact on the consumable budget: as an example, increasing the recovery of water from 95 to 98%, would result in the reduction of supplied water by more than 1 t.
- The **overall leak rate of the habitat is a key issue**, however rather difficult to estimate, due to the unknowns on the habitat structure and materials;
- **Additional systems** for e.g. EVAs, fire suppression, have not been discussed yet but should be included at a later stage, when operations will be defined in more details;
- **Spare parts strategy** has not been discussed at this stage (neither for Life Support Systems nor for the whole settlement), however impact on the mass budget can be extremely significant.
- **Food production**, including greenhouses should be considered for future permanent settlement.
- **In-Situ Resource Utilisation** should be explored as an option to reduce supply from Earth.

Merits of Study
Life Support Systems

- An attempt to get **orders of magnitude for mission budgets**.
- A great opportunity to **identify challenges**, gaps to cover, questions to answer.
- More widely, **thinking outside the box** about living scenarios in Space.